TUTORIAL PROBLEM SET

SESSI 2008/09

SEMESTER II

PAST YEAR TESTS, QUIZZES AND EXAM QUESTIONS

(2003/04 – 2007/08)

ZCT 104/3E Modern Physics
Semester Test I, Sessi 2003/04
Duration: 1 hour

Answer all questions

1. A radar antenna is rotating at an angular speed of 0.25 rad/s, as measured on Earth. To an observer moving past the antenna at a speed of 0.8*c*, what is its angular speed in rad/s?

   A. 0.42 **B.** 0.09 **C.**1.92 **D.** 0.15
   E. Non of the above
   ANS: D, Cutnell, Q1, pg. 877

2. Suppose that you are travelling on board a spacecraft that is moving with respect to the Earth at a speed of 0.975*c*. You are breathing at a rate of 8.0 breaths per minute. As monitored on Earth, what is your breathing rate?
   A. 13.3 **B.** 2.88 **C.**22.2 **D.** 1.77
   E. Non of the above
   ANS: D, Cutnell, Q4, pg. 877

3. At what speed is the magnitude of the relativistic momentum of a particle three times the magnitude of the non-relativistic momentum?
   A. 0.999*c* **B.** 0.900*c* **C.**0.911*c* **D.** 0.94 3*c*
   E. Non of the above
   ANS: D, Cutnell, Q17, pg. 878

4. An electron and a positron collide and undergo pair-annihilation. If each particle is moving at a speed of 0.8*c* relative to the laboratory before the collision, determine the energy of each of the resultant photon.

   A. 0.85MeV **B.** 1.67 MeV **C.** 0.51 MeV **D.** 0.72MeV
   E. Non of the above
   ANS: A, Cutnell, Q17, pg. 878, modified

5. Ultraviolet light with a frequency of 3.0×10^{15} Hz strikes a metal surface and ejects electrons that have a maximum kinetic energy of 6.1 eV. What is the work function of the metal?

   A. 13.6 eV **B.** 1.67 eV **C.** 0.51 eV **D.** 6.3 eV
   E. Non of the above
   ANS: D, Cutnell, Q5, pg. 900, modified

6. X-ray of wavelength 1.2 Å strikes a crystal of *d*-spacing 4.4 Å. Where does the diffraction angle of the second order occur?

   A.16^o **B.** 33^o **C.** 55^o **D.** 90^o
   E. Non of the above
   ANS: B, Schaum's 3000 solved problems, Q38.46, pg. 715

7. A honeybee (mass 1.3×10^{-4} kg) is crawling at a speed of 0.020 m/s. What is the de Broglie wavelength of the bee?
   A. 1.6×10^{-28} m **B.** 4.6×10^{-28} m **C.** 2.6×10^{-28} m
   D. 3.06×10^{-28} m **E.** Non of the above
   ANS: C, Cutnell, Q21, pg. 901, modified

8. An electron is trapped within a sphere whose diameter is 6×10^{-15} m. Estimate the minimum uncertainty in the electron's momentum in MeV/*c*.

   A. 16 **B.** 1 **C.** 50 **D.** 2 **E.** 10
   ANS:A , Cutnell, Q32, pg. 901, modified

9. Incident x-rays have a wavelength of 0.3120 nm and are scattered by the "free electron" in a graphite target. The angle of the scattered x-ray photon is 135 degree. What is the magnitude of the momentum of the incident photon?

   A. 0.01300 MeV/*c* **B.** 0.00391 MeV/*c* **C.** 0.03450 MeV/*c*
   D. 0.01315 MeV/*c* **E.** 0.00397 MeV/*c*
   ANS:E , Cutnell, Q15, pg. 900

10. What is the magnitude of the momentum of the scattered photon in Question 9?
    A. 0.01300 MeV/*c* **B.** 0.00391 MeV/*c* **C.** 0.03450 MeV/*c*
    D. 0.01315 MeV/*c* **E.** 0.00397 MeV/*c*
    ANS:B , Cutnell, Q15, pg. 900

11. Which of the following statement(s) is (are) true?
    I(T) When two observer who are moving relative to each other measure the same physical quantity, they may obtain different values
    II(T) The laws of physics are the same for observers in all inertial frames
    III (T) The speed of light in free space has the same value in all direction and in all inertial frames
    IV(F) Maxwell theory of electromagnetic radiation is inconsistent with special theory of relativity

    A. II,III **B. I, II,III** **C. II, III, IV**
    D. I only **E. I,II,III,IV**

    ANS:B, Christman's pocket companion, pg. 291.292

12. Which of the following statement(s) is (are) true?
    I(T) Relativity theory requires a revision of the definition of momentum if it were to be consistent with conservation of momentum
    II(F) The kinetic energy of a relativistic particle with rest mass m_0 moving with speed *v* is given by $m_0c^2(1-\gamma)$, where γ is the Lorentz factor
    III (F) The total energy of a relativistic particle is given by m_0c^2 (m_0 is the rest mass)
    IV(F) The classical expression of kinetic energy $K=\dfrac{p^2}{2m_0^2}$, where *p* is the linear momentum of the particle, is a special case of the relativistic energy $E=\sqrt{(pc)^2+(m_0c^2)^2}$

    A. II,III **B. I, II,III** **C. II, III, IV**
    D. I, IV **E. I,II, III,IV**

    ANS:**I only** (free mark will be given for this question since the correct answer is not in the option)
    Christman's pocket companion, pg. 299.300

13. Which of the following statement(s) is (are) true?

I(T) Photon carries momentum
II(F) The Compton shift $\Delta\lambda$ is greater for higher-energy photons
III(F) The Compton shift $\Delta\lambda$ is smaller for lower-energy photons

A. I only **B. I, II** **C. II, III**
D. I,III **E. I,II, III**

ANS:A, Machlup, pg. 497

14. Which of the following statements correctly describe the following experiments?
I(T) Photoelectricity exhibits particle nature of light
II(F) Electron diffraction exhibits wave nature of light
III (T) Compton effect exhibits particle nature of electron
IV(T) Compton effect exhibits particle nature of light
A. II,III **B. I, II,III** **C. II, III, IV**
D. I,III, IV **E. I,II, III,IV**

ANS:D, My own questions

15. Which of the following statements correctly describe light?
I(T) According to Einstein, the energy in an electromagnetic beam is concentrated in discrete bundles called photon
II(T) According to the classical Maxwell theory of radiation, light is described as electromagnetic wave
III (F) The energy of the photon is proportional to the root-mean-square of the amplitude of the electromagnetic fields
IV (*) The intensity of a beam of light is proportional to the root-mean-square of the amplitude of the electromagnetic fields
A. II,III **B. I, II,IV** **C. II, III, IV**
D. I,III, IV **E. I,II, III,IV**

ANS:**C** (Free mark will be given for this question because statement IV may appear confusing and ill-stated).

(*) Rigorously speaking, statement IV is correct because the "root-mean-square of the amplitude" is equal to the square of the amplitude. The amplitude is a constant independent of time and space, hence whether you average its square over a complete period or simply squaring it without taking its "average" the answer is still the same. Mathematically this is stated as $\langle E_0^2 \rangle = \frac{1}{T}\int_0^T E_0^2\, dt = E_0^2$.

My own questions

16. Which of the following statements correctly describe photoelectricity?
I(T) If the frequency is unchanged the number of electrons ejected depends on the incident intensity
II(F) If the frequency is unchanged the kinetic energies of electrons ejected depends on the incident intensity
III (T) In photoeletricity the fundamental event is the interaction of a single quantum of light with a single particle of matter
IV(T) Electrons are ejected immediately when photoelectricity occurs
A. II,III **B. I, II,III** **C. II, III, IV**
D. I,III, IV **E. I,II, III,IV**

ANS:D, Christman's pocket companion, pg. 302-303

17. Which of the following statements correctly describe Compton scattering?
I(T) The Compton effect has to be treated relativistically
II(T) The Compton effect is significant only when the incident wavelength of the light used is comparable to the Compton wavelength of the electron
III(T) The maximum change in wavelength is given by $\Delta\lambda_{\max} = 2\lambda_C$, where λ_C is the Compton wavelength of electron
IV (F) The Compton effect is much larger for electrons bounded to atoms than for free electrons

A. II,III **B. I, II,III** **C. II, III, IV**
D. I,III, IV **E. I,II, III,IV**

ANS:B, partly Christman's pocket companion, pg. 305, partly own question

18. Which of the following statement(s) is (are) true?
I(F) The Davisson-Gremer experiment verifies the particle nature of electromagnetic wave
II(T) In the Davisson-Gremer experiment the wavelength of the electron is comparable to the interatomic spacing in the crystal
III(T) At the quantum scale particles behave like waves
IV (T) At the quantum scale waves behave like particles

A. II,III **B. I, II,III** **C. II, III, IV**
D. I,III, IV **E. I,II, III,IV**

ANS:C, My own question

19. An increase in the voltage applied to an x-ray tube causes an increase in the x-rays'
I(F) wavelength
II(F) speed
III(T) energy
IV (T) frequency

A. III,IV **B. I, II,III** **C. II, III, IV**
D. I,III, IV **E. I,II, III,IV**

ANS:A, Arthur Beiser, Modern technical physics, Q 7, pg. 801

20. The description of a particle in terms of matter waves is legitimate because
I(F) It is based on common sense
II(F) The analogy with electromagnetic waves is plausible
III(T) theory and experiment agree

A. III only **B. I, II** **C. II, III**
D. I,III **E. I,II, III**

ANS:A, Arthur Beiser, Modern technical physics, Q 9, pg. 801

Data
speed of light in free space, $c = 3.00 \times 10^{8}$ m s^{-1}

elementary charge, $e = 1.60 \times 10^{-19}$ C

the Planck constant, $h = 6.63 \times 10^{-34}$ J s

unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg

rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg rest mass of proton, m_p = 1.67 x 10^{-27} kg

ZCT 104/3E Modern Physics
Semester Test II, Sessi 2003/04
Duration: 1 hour

Data

speed of light in free space, c = 3.00 x 10^8 m s^{-1}
elementary charge, e = 1.60 x 10^{-19} C
the Planck constant, h = 6.63 x 10^{-34} J s
unified atomic mass constant, u = 1.66 x 10^{-27} kg
rest mass of electron, m_e = 9.11 x 10^{-31} kg
rest mass of proton, m_p = 1.67 x 10^{-27} kg

Answer all questions

1. A particle of mass m is confined to a one-dimensional box of length L. The particle's momentum is given by

   A. $h/2L$ **B.** $nh/2L$ **C.** $\hbar/2L$ **D.** $n\hbar/2L$
   E. Non of the above
   ANS: B, Ronald and William, Q10.20, pg. 92

2. The energy of the particle in Q1 is given by

   A. $n^2 \frac{\hbar^2}{8m\pi L^2}$ **B.** $n^2 \frac{h^2}{8mL^2}$ **C.** $n^2 \frac{\pi^2 h^2}{2mL^2}$ **D.** $n^2 \frac{\hbar^2}{2mL^2}$
   E. Non of the above
   ANS: B, Ronald and William, Q10.20, pg. 92

3. What is the ionisation energy of the hydrogen atom?

   A. infinity **B.** 0 **C. -**13.6 eV **D.** 13.6 eV
   E. Non of the above
   ANS: D, Modern Technical Physics, Beiser, pg. 786

4. What is the ground state energy of the hydrogen atom?

   A. infinity **B.** 0 **C. -**13.6 eV **D.** 13.6 eV
   E. Non of the above
   ANS: C, Modern Technical Physics, Beiser, pg. 786

5. An electron collides with a hydrogen atom in its ground state and excites it to a state of n =3. How much energy was given to the hydrogen atom in this collision?

   A. -12.1 eV **B.** 12.1 eV **C.** -13.6 eV **D.** 13.6 eV
   E. Non of the above
   ANS: B, Modern Technical Physics, Beiser, Example 25.6, pg. 786

6. Which of the following transitions in a hydrogen atom emits the photon of lowest frequency?

   A. n = 3 to n = 4 **B.** n = 2 to n = 1 **C.** n = 8 to n = 2 **D.** n = 6 to n = 2
   E. Non of the above
   ANS: D, Modern Technical Physics, Beiser, Q40, pg. 802, modified

7. In Bohr's model for hydrogen-like atoms, an electron (mass *m*) revolves in a circle around a nucleus with positive charges *Ze*. How is the electron's velocity related to the radius *r* of its orbit?

A. $v = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{mr}$ **B.** $v = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{mr^2}$ **C.** $v = \frac{1}{4\pi\varepsilon_0}\frac{Ze}{mr^2}$ **D.** $v^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{mr}$
E. Non of the above
ANS: D, Schaum's series 3000 solved problems, Q39.13, pg 722 modified

8. How is the total energy of the electron in Question 7 related the radius of its orbit?

A. $E = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r}$ **B.** $E = \frac{1}{4\pi\varepsilon_0}\frac{Ze}{2r}$ **C.** $E = -\frac{1}{4\pi\varepsilon_0}\frac{Ze}{2r}$
D. $E = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r}$
E. Non of the above
ANS: D, Schaum's 3000 solved problems, Q39.14, pg. 722

9. The quantum number *n* of the lowest energy state of a hydrogen atom

A. is 0 **B.** is 1 **C.** depends on the orbit size
D. depends on the electron speed **E.** Non of the above
ANS: B, Modern Technical Physics, Beiser, Q23, pg. 802

10. The electron of a ground state hydrogen atom

A. has left the atom **B.** is at rest **C.** is in its orbit of lowest energy **D.** is in its orbit of highest energy **E.** Non of the above
ANS: C, Modern Technical Physics, Beiser, Q16, pg. 801

11. A proton and an electron, far apart and at rest initially, combine to form a hydrogen atom in the ground state, A single photon is emitted in this process. What is its wavelength?

A. 13.6 nm **B.** 20 nm **C.** 91 nm **D.** infinity **E.** Non of the above
ANS: C, Modern Technical Physics, Beiser, Q30, pg. 804

12. The wave function of a particle trapped in an infinite quantum well of width *L* is given by $\psi_n = A_n \sin\frac{n\pi x}{L}$. Determine the normalisation constant A_n.

A. $\sqrt{\frac{L}{2}}$ **B.** $\frac{2}{L}$ **C.** $\sqrt{\frac{2n}{L}}$ **D.** $\sqrt{\frac{2}{L}}$ **E.** Non of the above
ANS: D, my own question

13. Where does the particle in Question 12 spend most of its time while in the ground state?
A. around $x = 0$ **B.** around $x = L$ **C.** around $x = L/2$ **D.** around $x = L/4$
E. Non of the above
ANS:C, My own question

14. How many different photons can be emitted by hydrogen atoms that undergoes transitions to the ground states from the $n = 5$ states?
A. 3 **B.** 6 **C.** 10 **D.** 15
E. Non of the above
ANS: C, Ronald and William, Q11.8, pg. 109

15. Which of the following statements are true about an electron trapped on the *x*-axis by infinite potential energy barriers at $x = 0$ and $x = L$?
I(T) Inside the trap the coordinate-dependent part of the wave function ψ satisfy the Schrodinger equation
II(T) ψ obeys the boundary conditions $\psi(0) = 0$ and $\psi(L) = 0$
III (F) The probability to locate the electron is everywhere the same inside the well
IV(T) Outside the trap, $\psi = 0$
A. II,III **B. I, II,III** **C. II, III, IV**
D. I, II, IV only **E. Non of the above**
ANS:D, Christman's pocket companion, Item 40.3, pg. 312

16. Which of the following statements are true?
I(T) The energy of a particle trapped inside an finite quantum well is quantised
II(T) The energy of a particle trapped inside an infinite quantum well is quantised
III (F) The lowest energy of a particle trapped in an infinite quantum well is zero
A. II,III **B. I, II,III** **C. II, III**
D. I, II **E. Non of the above**
ANS:D my own question

17. Which of the following statement(s) is (are) true?
I(T) The plum pudding model cannot explains the backscattering of alpha particles from thin gold foils
II(T) Rutherford model assumes that an atom consists of a tiny but positively charged nucleus surrounded by electrons at a relatively large distance
III(T) In the Bohr model, an electron in a stationary state emits no radiation
IV(T) In the Bohr model, electrons bound in an atom can only occupy orbits for which the angular momentum is quantised

A. III,IV **B. I, II.III** **C. I, II, III.IV** **D. I,II**
E. Non of the above
ANS:C,Giancoli, Summery on pg 972

18. Which of the following statement(s) is (are) true?
I(F) Bohr's theory worked well for one electron ions as well as for multi-electron atoms
II(F) Bohr's model is plagued by the infrared catastrophe
III(F) In the Bohr model, $n = 1$ corresponds to the first excited state
IV(T) Rutherford model cannot explain the stability of atomic orbit

A. III,IV **B. I, II.III** **C. I, II, III.IV** **D. I,II**
E. Non of the above
ANS:E, My own question

19. Which of the following statements are correct?
I(F) Balmer series corresponds to the spectral lines emitted when the electron in a hydrogen atom makes transitions from higher states to the $n = 1$ state

II(F) Lyman series corresponds to the spectral lines emitted when the electron in a hydrogen atom makes transitions from higher states to the $n = 2$ state

II(T) Paschen series corresponds to the spectral lines emitted when the electron in a hydrogen atom makes transitions from higher states to the $n = 3$ state

A. II,III **B. I, II,III** **C. II, III**
D. III only **E. Non of the above**
ANS:D, My own questions

20. Which of the following statements are correct?

I(T) Frank-Hertz experiment shows that atoms are excited to discrete energy levels
II(T) Frank-Hertz experimental result is consistent with the results suggested by the line spectra
III (T) The predictions of the quantum theory for the behaviour of any physical system must correspond to the prediction of classical physics in the limit in which the quantum number specifying the state of the system becomes very large
IV(T) The structure of atoms can be probed by using electromagnetic radiation
A. II,III **B. I, II,IV** **C. II, III, IV**
D. I,II, III, IV **E. Non of the above**

ANS:D, My own questions

UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2003/2004

February/March 2004

ZCT 104E/3 - Physics IV (Modern Physics)
[Fizik IV (Fizik Moden)]

Duration: 3 hours
[Masa: 3 jam]

Please check that the examination paper consists of **SIXTEEN** pages of printed material before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **ENAM BELAS** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]*

Instruction: Answer any **FOUR (4)** questions. Students are allowed to answer all questions in Bahasa Malaysia or in English.

*[**Arahan**: Jawab mana-mana **EMPAT** soalan. Pelajar dibenarkan menjawab semua soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]*

…2/-

Data

speed of light in free space, c = 3.00 x 10^{8} m s^{-1}

permeability of free space, μ_0 = 4π x 10^{-7} H m^{-1}

permittivity of free space, ε_0 = 8.85 x 10^{-12} F m^{-1}

elementary charge, e = 1.60 x 10^{-19} C

the Planck constant, h = 6.63 x 10^{-34} J s

unified atomic mass constant, u = 1.66 x 10^{-27} kg

rest mass of electron, m_e = 9.11 x 10^{-31} kg

rest mass of proton, m_p = 1.67 x 10^{-27} kg

molar gas constant, = 8.31 J K^{-1} mol^{-1}

the Avogadro constant, N_A = 6.02 x 10^{23} mol^{-1}

gravitational constant, G = 6.67 x 10-11 N m^{2} kg^{-2}

acceleration of free fall, g = 9.81 m s^{-2}

…3/-

Question 1. (25 marks)

1.1 A spaceship of proper length L_p takes t seconds to pass an Earth observer. What is its speed as measured by the Earth observer according to classical physics?
[Sebuah kapal angkasa yang panjang proper-nya L_p mengambil masa t untuk bergerak melalui seorang pemerhati di Bumi. Mengikut fizik klasik, apakah kelajuannya yang terukur oleh pemerhati di Bumi itu?]

A. L_P / t **B.** $\frac{cL_P / t}{\sqrt{c^2 + (L_P / t)^2}}$ **C.** c **D.** L_P

E. Non of the above
[Tiada dalam pilihan di atas]

ANS: A, Serway solution manual 2, Q9A, pg. 336

1.2 In Question 1, what is its speed as measured by the Earth observer according to special relativity?
[Dalam soalan 1, apakah kelajuan yang terukur oleh pemerhati di Bumi mengikut teori kerelatifan khas?]

A. L_P / t **B.** $\frac{cL_P / t}{\sqrt{c^2 + (L_P / t)^2}}$ **C.** c **D.** L_P

E. Non of the above
[Tiada dalam pilihan di atas]

ANS: B, Serway solution manual 2, Q9A, pg. 336

1.3 What is the momentum of a proton if its total energy is twice its rest energy?
[Apakah momentum bagi suatu proton jika jumlah tenaganya adalah dua kali tenaga rehatnya?]

A. 1620 Ns **B.** 1 MeV/c **C.** 938 MeV/c **D.** 2 MeV/c

E. 1620 MeV/c

ANS: E, Serway solution manual 2, Q21, pg. 339

1.4 The power output of the Sun is 3.8×10^{26} W. How much rest mass is converted to kinetic energy in the Sun each second?
[Output kuasa Matahari ialah 3.8×10^{26} W. Berapakah jisim rehat yang ditukarkan kepada tenaga kinetik setiap saat di dalam Matahari?]

A. 4.2×10^{9} kg **B.** 1.3×10^{17} kg **C.** 3.6×10^{8} kg

D. 6.6×10^{10} kg **E.** 4.2×10^{8} kg

ANS: A, Serway solution manual 2, Q37, pg. 340

1.5 What is the value of *hc*/*e* in unit of $\text{nm}\cdot\text{eV}$
[Apakah nilai hc/e dalam unit $\text{nm}\cdot\text{eV}$ *?]*

A. 1.240 **B.** 1240×10^{-6} **C.** 1240 **D.** 1240×10^{-9}

E. 1240×10^{-3}

ANS: C, my own question [note: typo: the quantity should read *hc* instead of *hc*/*e*]

1.6 By what factor is the mass of an electron accelerated to the speed of 0.999*c* larger than its rest mass?
[Berapa besarnya factor jisim satu elektron yang dipecutkan kepada kelajuan 0.999c *berbanding dengan jisim rehatnya?]*

A. 31.6 **B.** 0.03 **C.** 0.04 **D.** 22.3 **E.** 1.0

ANS: D, my own question

1.7 The rest mass of a photon
[Jisim rehat foton]

A. is zero
[ialah sifar]
B. is the same as that of an electron
[sama dengan jisim elektron]
C. depends on its frequency
[bergantung kepada frekuensinya]
D. depends on its energy
[bergantung kepada tenaganya]
E. Non of the above
[Tiada dalam pilihan di atas]

ANS: A, Modern physical technique, Beiser, MCP 6, pg. 801

1.8 Determine the vacuum wavelength corresponding to a γ-ray energy of 10^{19} eV
[Tentukan jarak gelombang vakum bagi sinar γ yang bersepadanan dengan tenaga 10^{19} eV]

A. 1.24×10^{-9} pm
B. 1.24×10^{-16} pm
C. 1.24×10^{-25} nm
D. 1.24×10^{-16} nm
E. 1.24×10^{-25} nm

ANS: D, Schaum's 3000 solved problems, Q38.3, pg. 708

1.9 To produce an x-ray quantum energy of 10^{-15} J electrons must be accelerated through a potential difference of about
[Untuk menghasilkan sinar-x dengan tenaga kuantum 10^{-15} J suatu elektron mesti dipecutkan melalui satu beza keupayaan yang nilainya lebih kurang]

A. 4 kV
B. 6 kV
C. 8 kV
D. 9 kV
E. 10 kV

ANS: B, OCR ADVANCED SUBSIDIARY GCE PHYSICS B (PDF), Q10, pg. 36

Question 1.10– 1.12
[Soalan 1.10-1.12]

A. 10^{-4} m
B. 10^{-7} m
C. 10^{-10} m
D. 10^{-12} m
E. 10^{-15} m

1.10 Which of the values in the list above is the best estimate of the radius of an atom?
[Nilai yang manakah dalam senarai di atas memberikan anggaran yang paling baik untuk radius satu atom?]

ANS: C, OCR ADVANCED PHYSICS B (PDF), Q1, pg. 74

1.11 Which of the values in the list above is the best estimate of the wavelength of visible light?
[Nilai yang manakan dalam senarai di atas memberikan anggaran yang paling baik untuk jarak gelombang cahaya ternampak?]

ANS: B, OCR ADVANCED PHYSICS B (PDF), Q1, pg. 74

1.12 Which of the values in the list above is the best estimate of the wavelength of a 1.5 MeV electron?

[Nilai yang manakan dalam senarai di atas memberikan anggaran yang paling baik untuk jarak gelombang bagi elektron 1.5 MeV*?]*

ANS: D, OCR ADVANCED PHYSICS B (PDF), Q1, pg. 74

1.13 What is the momentum of a single photon of red light ($\nu = 400 \times 10^{12}$ Hz) moving through free space?
[Apakah momentum foton cahaya merah ($\nu = 400 \times 10^{12}$ Hz*) yang bergerak melalui ruang bebas?]*

A. 8.8×10^{-27} kg m/s
B. 6 keV
C. 1240 eV/*c*
D. 1.65 eV/*c*
E. 2.4 eV/*c*

ANS: D, Schaum's 3000 solved problems, Q8.12, pg. 709

1.14 What potential difference must be applied to stop the fastest photoelectrons emitted by a nickel surface under the action of ultraviolet light of wavelength 2000 Å? The work function of nickel is 5.00 eV.
[Apakah beza keupayaan yang mesti dikenakan untuk menghentikan fotoelektron paling pantas yang dipancarkan dari permukaan nikel di bawah tindakan cahaya ultraungu yang jarak gelombangnya 2000 Å*? Fungsi kerja nikel ialah* 5.00 eV*.]*

A. 1.0 kV
B. 1.2 kV
C. 2.0 V
D. 1.0 V
E. 1.2 V
ANS: E, Schaum's 3000 solved problems, Q38.18, pg. 710

1.15 Which of the following statement(s) is (are) true?
[Manakah kenyataan yang berikut adalah benar?]

I. The assumption of the Ether frame is inconsistent with the experimental observation
[Tanggapan rangka Ether adalah tidak konsisten dengan pemerhatian eksperimen]

II. The speed of light is constant
[Kelajuan cahaya adalah malar]

III. Maxwell theory of electromagnetic radiation is inconsistent with the notion of the Ether frame
[Teori sinaran keelektromagnetan Maxwell adalah tidak konsisten dengan tanggapan rangka Ether]

SESSI 03/04/FINAL

IV Special relativity is inconsistent with the notion of the Ether frame
[Kerelatifan Khas adalah tidak konsistent dengan tanggapan rangka Ether]

A. III,IV **B.** I, II, III **C.** I, II, III,IV

D. I, II **E.** I, II,IV

ANS: E, my own question

1.16 Which of the following statements are true about light?
[Yang manakah kenyataan berikut adalah benar berkenaan dengan cahaya?]

I. It propagates at the speed of $c = 3 \times 10^8$ m/s in all medium
[Cahaya tersebar pada kelajuan c = 3 x 10^8 m/s *dalam semua jenis medium]*

II. It's an electromagnetic wave according to the Maxwell theory
[Cahaya ialah gelombang elektromagnetik mengikut teori Maxwell]

III. It's a photon according to Einstein
[Cahaya ialah foton menurut Einstein]

IV. It always manifests both characteristics of wave and particle simultaneously in a given experiment
[Cahaya sentiasa memperlihatkan kedua-dua ciri gelombang dan kezarahan secara serentak dalam sesuatu eksperimen]

A. I,IV **B.** II, III,IV **C.** I, II, III,IV

D. I, II **E.** II,III

ANS: E, my own question

1.17 Which of the following statements are true about Lorentz transformation?
[Yang manakah kenyataan berikut adalah benar berkenaan dengan transformasi Lorentz?]

I. It relates the space-time coordinates of one inertial frame to the other
[Ia menghubung-kaitkan koordinat-koordinat ruang-masa suatu rangka inersia dengan koordinat-koordinat ruang-masa rangka inersia lain]

II. It is the generalisation of Galilean transformation
[Ia merupakan generalisasi transformasi Galilean]

III. It constitutes one of the Einstein's special relativity postulates

[Ia merupakan salah satu postulat teori kerelatifan khas Einstein]

IV. Its derivation is based on the constancy of the speed of light postulate
[Ia diterbitkan berdasarkan postulat kemalaran kelajuan cahaya]

A. I,IV **B.** I,II, IV **C.** I, II, III,IV

D. I, II **E.** II,III

ANS: B, my own question

1.18 The expression of linear momentum has to be modified in the relativistic limit in order to
[Ekspresi momentum linear kena dimodifikasikan pada limit relativistik supaya]

I. preserve the consistency between the Lorentz transformation and conservation of linear momentum
[konsistensi antara transformasi Lorentz dengan keabadian momentum linear terpelihara]

II. preserve the consistency between the Galilean transformation and conservation of linear momentum
[konsistensi antara transformasi Galilean dengan keabadian momentum linear terpelihara]

III. preserve the consistency between special relativity with Newtonian mechanics
[konsistensi antara kerelatifan khas dengan mekanik Newton terpelihara]

IV. preserve the consistency between the Lorentz transformation and Galilean transformation
[konsistensi antara transformasi Lorentz dengan transformasi Galilean terpelihara]

A. I only **B.** I,II, IV **C.** I, III,IV **D.** III,IV **E.** IV only

ANS: A, my own question

Question 2. (25 marks)
[Soalan 2 (25 markah)]

2.1 What is the kinetic energy of the fastest photoelectrons emitted by a copper surface, of work function 4.4 eV when illuminated by visible light 0f 700 nm?
[Apakah tenaga kinetik fotoelektron paling pantas yang dipancarkan oleh permukaan kuprum, yang fungsi kerjanya 4.4 eV*, semasa disinari cahaya*

ternampak 700 nm*?]*

A. 1.17 eV
B. 6.17 eV
C. 1.17 eV
D. 1.0 eV
E. non of the above
[Tiada dalam pilihan di atas]

ANS: E, Schaum's 3000 solved problems, Q38.21, pg. 710

2.2 Suppose that a beam of 0.2-MeV photon is scattered by the electrons in a carbon target. What is the wavelength of those photon scattered through an angle of 90^{o}?
[Katakan satu bim foton 0.2 MeV *diserakkan oleh elektron di dalam sasaran karbon. Apakah jarak gelombang bagi foton yang diserakkan melalui satu sudut* 90^{o}*?]*

A. 0.00620 nm
B. 0.00863 nm
C. 0.01106 nm
D. 0.00243 nm
E. non of the above
[Tiada dalam pilihan di atas]
ANS: B, Schaum's 3000 solved problems, Q38.31, pg. 712

2.3 Determine the cut-off wavelength of x-rays produced by 50-keV electrons in a x-ray vacuum tube?
[Tentukan jarak gelombang penggal bagi sinar-x yang dihasilkan oleh elektron 50 keV *dalam satu tiub sinar-x vakum.]*

A. 0.000248 $\mathring{A}$
B. 2.48 $\mathring{A}$
C. 248 $\mathring{A}$
D. 0.248 $\mathring{A}$

E. non of the above
[Tiada dalam pilihan di atas]
ANS: D, Schaum's 3000 solved problems, Q38.39, pg. 714

2.4 A lamp emits light of frequency 5.0×10^{15} Hz at a power of 25 W. The number of photons given off per seconds is
[Suatu lampu memancarkan cahaya berfrekuensi 5.0×10^{15} Hz *pada kuasa* 25 W. *Bilangan foton yang dihasilkan per saat ialah]*

A. 1.3×10^{-19} **B.** 8.3×10^{-17} **C.** 7.5×10^{18} **D.** 1.9×10^{50}

E. 2.9×10^{13}
ANS:C , Modern physical technique, Beiser, MCP 34, pg. 802, modified

2.5 Which of the following transitions in a hydrogen atom emits the photon of lowest frequency?
[Dalam senarai di bawah, peralihan yang manakah memancarkan foton frekuensi terendah di dalam atom hidrogen?]

A. $n = 1$ to $n = 2$ **B.** $n = 2$ to $n = 1$ **C.** $n = 2$ to $n = 6$

D. $n = 6$ to $n = 2$ **E.** n = infinitely large to $n = 1$
[n = sebesar tak terhingga ke n = 1]

ANS:D, Modern physical technique, Beiser, MCP 40, pg. 802

2.6 The speed of an electron whose de Broglie wavelength is 1.0×10^{-10} m is
[Kelajuan satu elektron yang jarak gelombang de Broglie-nya 1.0×10^{-10} m *ialah]*

A. 6.6×10^{-24} m/s **B.** 3.8×10^{3} m/s **C.** 7.3×10^{6} m/s

D. 1.0×10^{10} m/s **E.** 6.6×10^{2} m/s
ANS:C, Modern physical technique, Beiser, MCP 36, pg. 802

2.7 A large value of the probability density of an atomic electron at a certain place and time signifies that the electron
[Nilai yang besar bagi ketumpatan kebarangkalian suatu elektron atom pada sesuatu tempat dan masa menunjukkan elektron itu]

A. is likely to be found there
[agak mungkin dijumpai di sana]

B. is certain to be found there
[pasti dijumpai di sana]

C. has a great deal of energy there
[mempunyai banyak tenaga di sana]

D. has a great deal of charge
[mempunyai banyak cas]

E. is unlikely to be found there

SESSI 03/04/FINAL

[tidak berapa mungkin dijumpai di sana]

ANS:A, Modern physical technique, Beiser, MCP 25, pg. 802

2.8 Ionisation energy of hydrogen is 13.5 eV. What is the shortest wavelength in the Lyman series of hydrogen atom?
[Tenaga pengionan hidrogen ialah 13.5 eV. *Apakah jarak gelombang terpendek dalam siri Lyman hidrogen?]*

A. 364 nm **B.** 121 nm **C.** 91 nm **D.** 819 nm

E. 103 nm
ANS:C, my own question

2.9 If the momentum of a particle is doubled, its wavelength is multiplied _______ times
[Jika momentum suatu zarah digandakan dua, jarak gelombangnya digandakan _________ kali]

A. 1 **B.** 2 **C.** 1/2 **D.** 8 **E.** 0

ANS: C, Machlup, Review question 7, pg. 522, modified

2.10 A standing wave cannot have less than ___ antinode. In quantum mechanics, that fundamental mode would be called the _________.
[Suatu gelombang pegun tidak boleh mempuyai kurang daripada _____antinod. Dalam mekanik kuantum, mod asas ini dinamakan _______.]

A. 1, first excited state
[keadaan teruja pertama]
B. 1, ground state
[keadaan dasar]

C. 2, first excited state
[keadaan teruja pertama]
D. 2, ground state
[keadaan dasar]

E. 0, ground state
[keadaan dasar]
ANS: B, Machlup, Review question 9, pg. 522, modified

2.11 Assume that the uncertainty in the position of a particle is equal to its de Broglie wavelength. What is the minimal uncertainty in its velocity, v_x?
[Anggapkan bahawa ketidakpastian dalam kedudukan suatu zarah adalah sama dengan jarak gelombang de Broglie-nya. Apakah ketidakpastian minimum dalam halajunya v_x*?]*

A. $v_x/4\pi$ **B.** $v_x/2\pi$ **C.** $v_x/8\pi$ **D.** v_x

E. v_x/π

ANS: A, Schaum's 3000 solved problems, Q38.66, pg. 718

2.12 If the ionisation energy for a hydrogen atom is 13.6 eV, what is the energy of the level with quantum number $n = 3$?
[Jika tenaga pengionan satu atom hidrogen ialah 13.6 eV*, apakah tenaga untuk paras yang bernombor kuantum n = 3?]*

A. 1.51 eV **B.** 3.4 eV **C.** 12.1 eV

D. -1.51 eV **E.** -3.4 eV

ANS: D, Schaum's 3000 solved problems, Q39.6, pg. 720

2.13 What is the zero-point energy of an electron trapped in an infinite potential well of size $L = 0.5\ \mathring{A}$
[Apakah tenaga titik-sifar bagi elektron yang terperangkap di dalam suatu telaga keupayaan infinit yang saiznya $L = 0.5\ \mathring{A}$]

A. 7.5×10^{-9} eV **B.** 11.7×10^{-6} eV **C.** 0.30×10^{-6} eV

D. 13.6 eV **E.** 65×10^{-6} eV

ANS: 150 eV. Free marks will be given for this question since there is no correct answer in the options.

2.14 A moving body is described by the wave function ψ at a certain time and place; ψ^2 is proportional to the body's
[Suatu jasad bergerak diperihalkan oleh fungsi gelombang ψ pada suatu masa dan tempat tertentu; ψ^2 adalah berkadar dengan]

A. electric field
[medan elektrik]
B. speed
[kelajuan]
C. energy
[tenaga]
D. probability of being found
[kebarangkalian untuk dijumpai]
E. mass
[jisim]

ANS:D , Modern physical technique, Beiser, MCP 11, pg. 801

SESSI 03/04/FINAL

2.15 The continuous x-ray spectrum produced in an x-ray tube can be explained by
[Keselanjaran spektrum sinar-x yang dihasilkan dalam suatu tiub sinar-x dapat diterangkan oleh]

I. Classical Electromagnetic wave theory
[Teori klasik gelombang keelektromagnetan]
II. Pair production
[Penghalisan pasangan]
III. Bremsstrahlung
[Bremsstrahlung]
IV. Diffraction
[Belauan]

A. I,IV **B.** I,II, IV **C.** I, III,IV **D.** I, III

E. II,III
ANS: D, My own questions

2.16 Planck constant
[Pemalar Planck]

I. is a universal constant
[ialah satu pemalar universal]
II. is the same for all metals
[adalah sama bagi semua jenis logam]
III. is different for different metals
[adalah tidak sama bagi logam yang berlainan]
IV. characterises the quantum scale
[mencirikan skala kuantum]

A. I,IV **B.** I,II, IV **C.** I, III,IV **D.** I, III

E. II,III

ANS: B, Machlup, Review question 8, pg. 496, modified

2.17 A neon sign produces
[Suatu lampu neon menghasilkan]

I. a line spectrum
[suatu spektrum garis]
II. an emission spectrum
[suatu spektrum pancaran]
III. an absorption spectrum
[suatu spektrum penyerapan]
IV. photons
[foton]

A. I,IV **B.** I,II, IV **C.** I, III,IV **D.** I, III

E. II,III

ANS:B , Modern physical technique, Beiser, MCP 20, pg. 801, modified

2.18 Which of the following statements are true?
[Kenyataan berikut yang manakah benar?]

I.. the ground states are states with lowest energy
[keadaan asas adalah keadaan dengan tenaga yang paling rendah]

II. ionisation energy is the energy required to raise an electron from ground state to free state
[tenaga pengionan adalah tenaga yang diperlukan untuk menaikan suatu elektron dari keadaan asas ke keadaan bebas]

III. Balmer series is the lines in the spectrum of atomic hydrogen that corresponds to the transitions to the $n = 1$ state from higher energy states
[Balmer siri adalah garis-garis spectrum atom hidrogen yang bersepadanan dengan peralihan dari paras-paras tenaga yang lebih tinggi ke paras $n = 1$]

A. I,IV **B.** I,II, IV **C.** I, III,IV **D.** I, II

E. II,III

ANS: D, My own question
(note: this is an obvious typo error with the statement IV missing. In any case, only statement I, II are true.)

Question 3. (25 marks)
[Soalan 3. (25 markah)]

(a) Lithium, beryllium and mercury have work functions of 2.3 eV, 3.9 eV and 4.5 eV, respectively. If a 400-nm light is incident on each of these metals, determine
[Fungsi kerja Lithium, beryllium dan raksa adalah 2.3 eV, 3.9 eV dan 4.5 eV masing-masing. Jika cahaya 400 nm ditujukan ke atas setiap satu logam itu, tentukan]

(i) which metals exhibit the photoelectric effect, and
[logam yang manakah memperlihatkan kesan fotoelectrik, dan]

(ii) the maximum kinetic energy for the photoelectron in each case (in eV)
[tenaga kinetik maksimum untuk fotoelektron dalam setiap kes itu (dalam unit eV)]

Serway solution manual 2, Q21, pg. 357

(b) Molybdenum has a work function of 4.2 eV.
[Fungsi kerja Molybdenum ialah 4.2 eV.]

(i) Find the cut-off wavelength (in nm) and threshold frequency for the photoelectric effect.
[Carikan jarak gelombang penggal (dalam unit nm*) dan frekuensi ambang untuk kesan fotoelektrik]*

(ii) Calculate the stopping potential if the incident radiation has a wavelength of 180 nm.
[Hitungkan keupayaan penghenti jika sinaran tuju mempunyai jarak gelombang 180 nm.*]*

Serway solution manual 2, Q16, pg. 356

(c) A 0.0016-nm photon scatters from a free electron. For what scattering angle of the photon do the recoiling electron and the scattered photon have the same kinetic energy?
[Suatu foton 0.0016 nm diserakkan oleh elektron bebas. Apakah sudut serakan foton supaya elektron yang tersentak dan foton yand terserak itu mempunyai tenaga kinetik yang sama?]

Serway solution manual 2, Q35, pg. 358

Solution:
Q3a(i)
The energy of a 400 nm photon is $E = hc/\lambda$ = **3.11 eV**
[2 mark]

The effect will occur only in **lithium***
[2 marks, with or without explanation]

Q3a(ii)
For lithium, $K_{max} = h\nu - W_0$ = 3.11 eV – 2.30 eV = **0.81 eV***
[3 marks]

[Note*: for Q3a(i,ii), the full 2+2+3 marks only for the unique answer set {lithium, K_{max} = 0.81 eV}. Minus 2 marks for any extra answer set involving other metals]

Q3b(i)
Cut-off frequency = $\lambda_{cutoff} = hc/W_0$ = 1240 nm eV / 4.2 eV = **295 nm**
Cut-off frequency (or threshold frequency)= $\nu_{cutoff} = c/\lambda$ = **1.01 x 10^{15} Hz**
[3 + 3 marks]

Q3b(ii)
Stopping potential $V_{stop} = (hc/\lambda - W_0) / e$= (1240 nm.eV/180 nm – 4.2 eV)/e = **2. 7 V**

[3 marks]

Q3c
The energy of the incoming photon is $E_i = hc/\lambda$ = **0.775 MeV**
[3 mark]

Since the outgoing photon and the electron each have half of this energy in kinetic form,
$E_o = hc/\lambda'$ = 0.775 MeV / 2 = 0.388 MeV and
$\lambda' = hc/E_o$ = 1240 eV. nm / 0.388 MeV = 0.0032 nm
The Compton shift is $\Delta\lambda = \lambda' - \lambda$ = (0.0032 – 0.0016) nm = 0.0016 nm
[3 marks]

By $\Delta\lambda = \lambda_c (1 - \cos\theta) = h/m_e c\ (1 - \cos\theta)$
0.0016 nm = 0.00243 nm $(1 - \cos\theta)$
$\Rightarrow \theta = 70^\circ$
[3 marks]

Question 4. (25 marks)
[Soalan 4. (25 markah]

(a) An electron is contained in a one-dimensional box of width 0.100 nm. Using the particle-in-a-box model,
[Suatu elektron terkandung di dalam satu kotak satu dimensi yang lebarnya 0.100 nm. Dengan menggunakan model zarah-dalam-satu-kotak]

(i) Calculate the $n = 1$ energy level and $n = 4$ energy level for the electron in eV.
[Hitungkan paras tenaga n = 1 dan n = 4 untuk elektron itu dalam unit eV.]

(ii) Find the wavelength of the photon (in nm) in making transitions that will eventually get it from the the $n = 4$ to $n = 1$ state
[Hitungkan jarak gelombang foton (dalam unit nm) semasa ia membuat peralihan yang membawanya dari keadaan n = 4 ke keadaan n = 1]

Serway solution manual 2, Q33, pg. 380, modified

(b) Consider a 20-GeV electron.
[Pertimbangkan suatu elektron 20 GeV.]

(i) What is its Lorentz factor γ?
[Apakah faktor Lorentznya?]

(ii) What is its de Broglie wavelength?
[Apakah jarak gelombang de Broglie-nya?]

Serway solution manual 2, Q12, pg. 376, modified

SESSI 03/04/FINAL

(c) A photon is emitted as a hydrogen atom undergoes a transition from the $n = 6$ state to the $n = 2$ state. Calculate
[Suatu foton dipancarkan ketika suatu atom hidrogen melakukan satu peralihan dari keadaan n = 6 ke n = 2. Hitungkan]

(i) the energy
[tenaga]

(ii) the wavelength
[jarak gelombang]

(iii) the frequency
[frekuensi]

of the emitted photon
[foton yang dipancarkan]

Serway solution manual 2, Q47, pg. 360, modified

Solution:
Q4a(i)
In the particle-in-a-box model, standing wave is formed in the box of dimension L:

$$\lambda_n = \frac{2L}{n}$$

[1 marks]

The energy of the particle in the box is given by

$$K_n = E_n = \frac{p_n^2}{2m_e} = \frac{(h/\lambda_n)^2}{2m_e} = \frac{n^2 h^2}{8m_e L^2} = \frac{n^2\pi^2\hbar^2}{2m_e L^2}$$

[2 marks]

$$E_1 = \frac{\pi^2\hbar^2}{2m_e L^2} = 37.7 \text{ eV}$$

[2 mark]

$$E_4 = 4^2 E_1 = 603 \text{ eV}$$

[2 mark]

Q4a(ii)
The wavelength of the photon going from n = 4 to n = 1 is $\lambda = hc/(E_6 - E_1)$
= 1240 eV nm/ (603 – 37.7) eV = **2.2 nm**
[2 marks]

Q4b(i)
From $E = \gamma m_e c^2$, $\gamma = E/m_e c^2$ = 20 GeV/0.51 MeV = **39216**
[4 marks]

Q4b(ii)

Momentum $p = E/c$ = 20 GeV/c (rest mass of electron ignored, $m_e c^2 << E$)
$\lambda = hc/E = hc/pc$ = 1240 eV nm / 20 GeV = **6.2 x 10^{-17} m**
[3 marks]

Q4c

For hydrogen, $E_n = -\frac{13.6}{n^2}$ eV

Q4c(i)

$$\Delta E_{6\to2} = E_6 - E_2 = -13.6\left(\frac{1}{6^2} - \frac{1}{2^2}\right)\text{eV} = 3.02\text{eV}$$

[3 marks]

Q4c(ii)

$\lambda_{6\to2} = hc / \Delta E_{6\to2} = 1240\text{nm}\cdot\text{eV} / 3.02\text{eV} =$ **410 nm**
[3 marks]

Q4c(iii)

$\nu = c/\lambda$ = **7.32 x 10^{14} Hz**
[3 marks]

UNIVERSITI SAINS MALAYSIA

KSCP
Academic Session 2003/2004

April 2004

ZCT 104E/3 - Physics IV (Modern Physics)
[Fizik IV (Fizik Moden)]

Duration: 3 hours
[Masa: 3 jam]

Please check that the examination paper consists of **ELEVEN** pages of printed material before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **SEBLELAS** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]*

Instruction: Answer all **FOUR (4)** questions.

Students are allowed to answer all questions in Bahasa Malaysia or in English.

Please answer Question 1 in the objective answer form provided. Submit the objective answer form and the answers to the structured questions (i.e. Q2 – Q4) separately.

*[**Arahan**: Jawab kesemua **EMPAT** soalan. Pelajar dibenarkan menjawab semua soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris. Sila jawab Soalan 1 dalam kertas jawapan objecktif yang dibekalkan. Hantar kertas jawapan objecktif dan jawapan kepada soalan struktur (iaitu Soalan 2 – Soalan 4) berasingan.]*

Data
speed of light in free space, c = 3.00 x 10^{8} m s^{-1}
permeability of free space, μ_0 = 4π x 10^{-7} H m^{-1}
permittivity of free space, ε_0 = 8.85 x 10^{-12} F m^{-1}
elementary charge, e = 1.60 x 10^{-19} C
the Planck constant, h = 6.63 x 10^{-34} J s
unified atomic mass constant, u = 1.66 x 10^{-27} kg
rest mass of electron, m_e = 9.11 x 10^{-31} kg
rest mass of proton, m_p = 1.67 x 10^{-27} kg
molar gas constant, = 8.31 J K^{-1} mol^{-1}
the Avogadro constant, N_A = 6.02 x 10^{23} mol^{-1}
gravitational constant, G = 6.67 x 10-11 N m^{2} kg^{-2}
acceleration of free fall, g = 9.81 m s^{-2}

Q1. [25 marks]

1.1 What were the consequences of the negative result of the Michelson-Morley experiment?
[Antara berikut yang manakah akibat keputusan negatif eksperimen Michelson-Morley?]

I. It render untenable the hypothesis of the ether
[Ia menjadikan hipotesis ether tidak dapat dipertahankan]

II. It suggests the speed of light in the free space is the same everywhere, regardless of any motion of source or observer
[Ia mencadangkan bahawa laju cahaya dalam ruang bebas adalah sama di mana-mana sahaja, tidak kira sama ada punca cahaya atau pemerhati mempunyai sebarang pergerkan]

III. It implies the existence of a unique frame of reference in which the speed of light in this frame is equal to *c*
[Ia mengimplikasikan kewujudan suatu rangka rujukan yang laju cahaya dalam rangka tersebut adalah bersamaan dengan c]

A. III only **B. I,II** **C. I, III** **D. I, II, III**
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: B
Murugeshan, S. Chand & Company, New Delhi, pg. 25, Q1.

1.2 Which of the following statement(s) is (are) true?
[Manakah kenyataan yang berikut adalah benar?]

I. The expression for kinetic energy of a relativistic particle is given by $\frac{1}{2}mv^2$
[Ekspresi tenaga kinetic suata zarah kerelatifan ialah $\frac{1}{2}mv^2$*]*

II. Special theory of relativity is applicable to accelerating system
[Teori kerelatifan khas boleh dipergunakan ke atas sistem yang mengalami pecutan]

III. The maximal velocity ever attainable is that of light in free space
[Laju maksimum yang mungkin tercapai ialah laju cahaya dalam ruang bebas]

IV. The mass of a particle becomes infinite at the speed equal to *c*
[Jisim suatu zarah menjadi infinit pada kelajuan bersamaan dengan c]

SESSI 03/04/KSCP

A. II,III **B. I,II,III,IV** **C. I, II, III** **D. III, IV**

E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: D
Murugeshan, S. Chand & Company, New Delhi, pg. 18, Q23.(for I), pg. 26, Q5.(for II), pg. 27, Q12.(for III), pg. 27, Q14.(for IV),

1.3 Which of the following statement(s) is (are) true?
[Manakah kenyataan yang berikut adalah benar?]

I The concept of Bohr orbit violates the uncertainty principle
[Konsep orbit Bohr melanggar prinsip ketidakpastian]

II A hydrogen atom has only a single electron
[Atom hidrogen mempunyai satu elektron tunggal sahaja]

III The spectrum of hydrogen consists of many lines even though a hydrogen atom has only a single electron
[Spektrum hidrogen terdiri daripada banyak pinggir (garisan) walaupun atom hidrogen hanya mempunyai satu elektron sahaja]

IV Most of an atom consists of empty space
[Kebanyakan daripada isipadu suatu atom terdiri daripada ruang kosong]

A. I,II **B. I,II,III,IV** **C. I, II, III** **D. III, IV**
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: D
Murugeshan, S. Chand & Company, New Delhi, pg. 86, Q13.(for I), pg. 88, Q19.(for II,III), pg. 87, Q11.(for IV)

1.4 Which of the following statement(s) is (are) true?
[Manakah kenyataan yang berikut adalah benar?]

I In the Bohr theory of the hydrogen atom, the potential energy of the orbiting electron is positive
[Dalam teori atom hidrogen Bohr, tenaga keupayaan elektron yang mengorbit ialah positif]

II In the Bohr theory of the hydrogen atom, the kinetic energy of the orbiting electron is positive
[Dalam teori atom hidrogen Bohr, tenaga kinetik elektron yang mengorbit ialah positif]

III In the Bohr theory of the hydrogen atom, the potential energy of the orbiting electron is negative

[Dalam teori atom hidrogen Bohr, tenaga keupayaan elektron yang mengorbit ialah negatif]

IV. In the Bohr theory of the hydrogen atom, the kinetic energy of the orbiting electron is negative
[Dalam teori atom hidrogen Bohr, tenaga kinetik elektron yang mengorbit ialah negatif]

A. I,II **B. III,IV** **C. I, IV** **D. II, III**
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: D
Murugeshan, S. Chand & Company, New Delhi, pg. 91, Q36

Q1.5 – Q1.7 refers to the energy diagrams shown in Figure 1.
[Soalan 1.5 - Soalan 1.7 merujuk kepada gambarajah yang terpapar di Gambarajah 1.]

Some of the energy levels of the hydrogen atom are shown (not to proportion)
[Beberapa paras tenaga atom hidrogen dipaparkan seperti berikut (tidak mematuhi nisbah)]

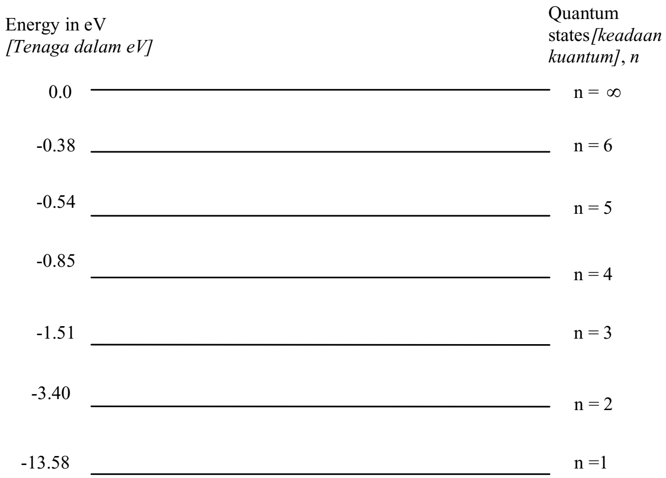


Figure 1 ***[Gambarajah 1]***

1.5 How much energy in eV is required to raise an electron from the ground state to the $n = 5$ state? (ignore selection rules)
[Apakah tenaga (dalam unit eV) yang diperlukan untuk menaikkan suatu elektron dari keadaan bumi ke keadaan n = 5? (abaikan petua pilihan)]

SESSI 03/04/KSCP

A. 13.58 **B.** 10.18 **C.** 12.73 **D.** 13.04
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: D
Murugeshan, S. Chand & Company, New Delhi, pg. 92, Q44, modified;
Diagram adopted from Gautreau and Savin, Schaum's series, pg. 105.

1.6 What is the approximate wavelength of photon (in nm) emitted when the electron makes a transition from state $n = 6$ to $n = 2$? (ignore selection rules)
[Apakah anggaran jarak gelombang (dalam unit nm) untuk foton yang terpancar semasa elektron beralih dari keadaan n = 6 ke n = 2? (abaikan petua pilihan)]

A. 91 **B.** 122 **C.** 94 **D.** 410
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: D
My own question

1.7 How many different photons can be emitted by the hydrogen atom that undergoes transitions to the $n = 4$ state from the $n = 6$ state? (ignore selection rules)
[Terdapat berapa foton berbeza yang terpancar oleh atom hidrogen yang mengalami peralihan ke keadaan n = 6 dari keadaan n = 4? (abaikan petua pilihan)]

A.3 **B.** 4 **C.** 1 **D.** 6
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: A
Murugeshan, S. Chand & Company, New Delhi, pg. 90, Q30, modified

1.8 In relativity, which of the following observable(s) is (are) not absolute but depend on the reference frame of observer?
[Dalam teori kerelatifan, pembolehcerap yang mana adalah tidak mutlak tetapi bersandar kepada rangka rujukan pemerhati?]

I. Space
II. Time
III. Mass
IV. Energy

A. I,II **B. I,II,III,IV** **C. I, II, III** **D. III,IV**
E. Non of the above *[Tiada dalam pilihan di atas]*
Ans: B
Murugeshan, S. Chand & Company, New Delhi, pg. 28, Q23.

1.9 Which of the following statement(s) is (are) true?
[Manakah kenyataan yang berikut adalah benar?]

I. γ-rays have much shorter wavelength than x-rays
[Jarak gelombang sinar γ adalah jauh lebih pendek daripada jarak gelombang sinar x]

II. The wavelength of x-rays in a x-ray tube can be controlled by varying the accelerating potential
[Jarak gelombang sinar x dalam suatu tiub sinar x dapat dikawal dengan menyelaraskan beza upaya pecutan]

III. x-rays are electromagnetic waves
[Sinar x ialah gelombang elektromagnetik]

IV. x-rays show diffraction pattern when passing through crystals
[Sinar x memperlihatkan corak belauan semasa ia melalui hablur]

A. I,II **B. I,II,III,IV** **C. I, II, III** **D. III.IV**
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: B
Murugeshan, S. Chand & Company, New Delhi, pg. 132, Q1.(for I),
pg. 132, Q3 (for II), pg. 132, Q4 (for III,IV)

1.10 Which of the following statement(s) is (are) true?
[Manakah kenyataan yang berikut adalah benar?]

I. Photoelectric effect arises due to the absorption of electrons by photons
[Kesan fotoelektrik muncul kerana penyerapan elektron oleh foton]

II. Compton effect arises due to the scattering of photons by free electrons
[Kesan Compton muncul kerana penyerakan foton oleh elektron bebas]

III. In the photoelectric effect, only part of the energy of the incident photon is lost in the process
[Dalam kesan fotoelektrik, hanya sebahagian daripada tenaga foton tuju terlesap dalam proses tersebut]

IV. In the Compton effect, the photon completely disappears and all of its energy is given to the Compton electron
[Dalam kesan Compton, foton hilang langsung dan kesemua tenaganya diberikan kepada elektron Compton]

A. I,II **B. II,III,IV** **C. I, II, III** **D. III,IV**

Ans: E [I = false; II = true; III = false; IV = false]
Murugeshan, S. Chand & Company, New Delhi, pg. 134, Q13,

1.11 Which of the following statement(s) is (are) true?
[Manakah kenyataan yang berikut adalah benar?]

I. Compton effect is experimentally observed for visible light rays
[Kesan Compton boleh dicerap secara eksperimen bagi cahaya ternampak]

II. The presence of the unmodified line in Compton scattering can be explained in terms of Rayleigh scatterings
[Kehadiran pinggir (garisan) yang tidak terubah dalam penyerakan Compton dapat diterangkan dengan penyerakan Rayleigh]

III. In Compton scattering, one neglects the effect of the nucleus on the x-rays
[Dalam penyerakan Compton, kita mengabaikan kesan ke atas sinar x oleh nucleus]

A. II, III **B. I, III** **C. I, II, III** **D. II only**
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: A
Murugeshan, S. Chand & Company, New Delhi, pg. 134, Q14 (for I), Q15 (for II), Q16 (for III),

1.12 Which of the following statement(s) is (are) true?
[Manakah kenyataan yang berikut adalah benar?]

I The energy of the quantum of light is proportional to the frequency of the wave model of light
[Tenaga kuantum cahaya adalah berkadar dengan frekuensi model gelombang cahaya]

II In photoelectricity, the photoelectrons has as much energy as the quantum of light which causes it to be ejected
[Dalam kesan fotoelektrik, fotoelektron mempunyai tenaga sebanyak tenaga kuantum cahaya yang menyebabkan fotoelektron terlenting]

III In photoelectricity, no time delay in the emission of photoelectrons would be expected in the quantum theory
[Dalam teori kuantum, tiada tunda masa dalam pemancaran fotoelektron dijangkakan untuk kesan fotoelektrik]

A. II, III **B. I, III** **C. I, II, III** **D. I ONLY**
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: B

Murugeshan, S. Chand & Company, New Delhi, pg. 136, Q28 (for I), Q29, Q30 (for II,III)

1.13 An electron, proton and an alpha-particle have the same de Broglie wavelength. Which one moves faster?
[Elektron, proton dan zarah alpha ketiga-tiganya mempunyai jarak gelombang de Broglie yang sama. Yang manakah bergerak dengan lebih pantas?]

A. Electron **B.** Proton **C.** Alpha-particle
D. All particles move at the same speed *[kesemua zarah bergerak dengan kelajuan yang sama]*
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: A
Murugeshan, S. Chand & Company, New Delhi, pg. 163, Q3

1.14 Which of the following statement(s) is (are) true?
[Manakah kenyataan yang berikut adalah benar?]

I. The de Broglie wavelengths of macroscopic bodies are generally too tiny to be experimentally detected
[Jarak gelombang de Broglie jasad makroskopik secara amnya adalah terlalu kecil untuk dikesan secara eksperimen]

II. If Planck's constant were smaller than it is, quantum phenomena would be more conspicuous than they are now
[Jika nilai pemalar Planck adalah lebih kecil daripada nilainya yang sedia ada, fenomena kuantum akan menjadi lebih sedia tercerap berbanding dengan ketercerapannya yang sedia ada]

III In quantum theory, the physical variables (e.g. energy, momentum) used to describe a confined electron are discrete
[Dalam teori kuantum, pembolehubah fizikal (misalnya tenaga dan momentum) yang memerihalkan sesuatu elektron yang terkurung adalah diskrit

A. II, III **B. I ONLY** **C. I, II, III** **D. I, III**
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: D
Murugeshan, S. Chand & Company, New Delhi, pg. 163, Q1 (for I), Q12 (for II), Q21 (for III)

1.15 Which of the following statement(s) is (are) true?
[Manakah kenyataan yang berikut adalah benar?]

SESSI 03/04/KSCP

I. The **e**xperimental proof for which electron posses a wavelength $\lambda = \frac{h}{p}$ was first verified by Davisson and Germer
[Pembuktian scara eksperimen bahawa elektron mempunyai jarak gelombang $\lambda = \frac{h}{p}$ pada mula-mulanya ditentukan oleh Davisson and Germer]

II. The experimental proof of the existence of discrete energy levels in atoms involving their excitation by collision with low-energy electron was confirmed in the Frank-Hertz experiment
[Pembuktian secara eksperimen kewujudan paras tenaga diskrit dalam atom yang melibatkan pengujaan mereka oleh perlanggaran dengan elektron bertenaga rendah telah dipastikan dalam eksperimen Frank-Hertz]

III. Compton scattering experiment establishes that light behave like particles
[Penyerakan Compton menetapkan bahawa cahaya berlagak seperti zarah]

IV. Photoelectric experiment establishes that electrons behave like wave
[Kesan fotoelektrik menetapkan bahawa elektron berlagak seperti gelombang]

A. I,II **B. I,II,III,IV** **C. I, II, III** **D. III,IV**
E. Non of the above *[Tiada dalam pilihan di atas]*

Ans: C
Serway and Moses, pg. 127 (for I), pg. 133 (for II), own options (for III,IV)

Q2. [25 marks]

(a) A man in a spaceship moving at a velocity of 0.9c with respect to the Earth shines a light beam in the same direction in which the spaceship is travelling.
[Seorang yang berada di dalam satu kapal angkasa yang bergerak pada halaju 0.9c relatif kepada Bumi menyinarkan satu bim cahaya ke arah yang mana kapal angkasa itu sedang bergerak.]

Compute the velocity of the light beam relative to Earth using
[Hitungkan halaju bim cahaya itu relatif kepada Bumi dengan menggunakan]

(i) Galilean approach *[pendekatan Galileo]*

[3 marks]

(ii) Special relativity approach *[pendekatan teori kerelatifan khas]*

[6 marks]

Please define clearly all the symbols used in your working.
[Sila nyatakan dengan jelas definasi simbol-simbol yang digunakan dalam kerja anda.]
Ans

(a) O' is the moving frame travelling at v = 0.9c with respect to the Earth. Speed of the light beam as seen in the frame O' is $u' = c$. O is the Earth frame. We wish to find the speed of the light beam as seen from frame O, u.

(i) According to Galilean transformation, $u = u' + v = c + 0.9c = 1.9c$.

(ii) Use

$$u = \frac{u'+v}{1+\left(\frac{v}{c^2}\right)u'} = \frac{c+0.9c}{1+\left(\frac{0.9c}{c^2}\right)c} = c \Rightarrow v = c$$

Acosta, Q4-7, pg. 53, modified

(b) How fast does a rocket have to go for its length to be contracted to 99% of its rest length?
[Berapa cepatkah suatu roket harus bergerak supaya panjangnya menyusut kepada 99% daripada panjang rehatnya?]

[5 marks]

Ans:

SESSI 03/04/KSCP

$$\frac{L}{L_0} = 0.99 = \sqrt{1-\left(\frac{v}{c}\right)^2}$$

$\Rightarrow v = 0.141c$

Gautreau and Savin, Schaum's series modern physics, pg.21, Q. 4.1

(c) The average lifetime of μ-meson with a speed of 0.95c is measured to be 6×10^{-6} s. Compute the average lifetime of μ-meson in a frame in which they are at rest.
[Hayat purata meson-μ yang bergerak dengan kelajuan 0.95c adalah diukur sebagai 6×10^{-6} s. Hitungkan hayat purata meson-μ dalam rangka di mana mereka adalah rehat]

[5 marks]

Ans:

Lorentz factor is $\gamma = \dfrac{1}{\sqrt{1-\left(\frac{v}{c}\right)}} = \dfrac{1}{\sqrt{1-(0.95)}} = 3.20$

The time measured in a frame in which the μ-mesons are at rest is the proper time, Δt_0:

$\Delta t_0 = \Delta t / \gamma = = 6\times10^{-6}$ s/3.2 = 1.87×10^{-6} s

Gautreau and Savin, Schaum's series modern physics, pg.24, Q 5.1

(d) (i) What is the rest mass of a proton in terms of MeV?
[Apakah jisim rehat satu proton dalam unit MeV?]

[2 marks]

(ii) What is the relativistic mass of a proton (in terms of MeV) whose kinetic energy is 1 GeV?
[Apakah jisim kerelatifan satu proton (dalam unit MeV) yang bertenaga kerelatifan 1 GeV?]

[4 marks]

Ans:

(i) $m_p c^2$ = 1.67 x 10^{-27}kg x $(3\times10^8 \text{ m/s})^2$ = 1.503 $\times10^{-10}$ J =
1.503 $\times10^{-10}/(1.6\times10^{-19})$ eV = 939.4 MeV

(ii) $K = (\gamma-1)m_p c^2 = 1$ GeV
$(\gamma-1) = 1\,\text{GeV}/m_p c^2 = 1\,\text{GeV}/939.4\,\text{MeV} = 1.06$
$\gamma = 1.06 + 1 = 2.06$
$mc^2 = \gamma m_p c^2 = 2.06\times 939.4$ MeV = 1939.4 MeV

Note: Due to the inconsistency between the English and Malay version of question I would also give full mark to those who used total relativisic energy $E = \gamma m_p c^2 = 1$ GeV in the calculation (instead of using $K = (\gamma - 1)m_p c^2 = 1$ GeV).

Gautreau and Savin, Schaum's series modern physics, pg.55, Q 8.34, slightly modified.

Q3. [25 marks]

(a) A proton is accelerated from rest through a potential of 1 kV. Find its de Broglie wavelength.
[Suatu proton dipecutkan dari keadaan rehat melalui satu beza keupayaan 1 keV. Hitungkan jarak gelombang de Broglienya.]
[6 marks]

Ans.

$K = \dfrac{p^2}{2m_p}$ = kinetic energy of the proton = 1 keV.

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m_p K}} = \frac{h}{\sqrt{2m_p K}} = \frac{6.63\times10^{-34}\,\text{J}\cdot\text{s}}{\sqrt{2\times1.67\times10^{-27}\,\text{kg}\cdot1000\times1.6\times10^{-19}\,\text{J}}} =$$

9.1×10^{-3} Å

Gautreau and Savin, Schaum's series modern physics, pg.97, Q. 10.38

(b) Determine the cutoff wavelength in Å of x-rays produced by a 50-keV electrons in a x-ray tube.
[Tentukan jarak gelombang penggal (dalam unit Å) sinar x yang dihasilkan oleh elektron 50 keV dalam suatu tiub sinar x.]
[5 marks]

Ans.

$$\lambda_{cutoff} = \frac{hc}{eV} = \frac{1240\text{eV}\cdot\text{nm}}{50\text{keV}} = 0.0248\text{nm} = 0.24\,\text{Å}$$

Schaum's series 3000 solved problem, pg.714, Q. 38.39

(c) Determine the photon flux (in unit of number of photons per unit time per unit area) associated with a beam of monochromatic light of wavelength 3000 Å and intensity 3×10^{-14} W/m^2.

SESSI 03/04/KSCP

[Tentukan fluks foton (dalam unit bilangan foton per unit masa per unit luas) yang bersepadanan dengan suatu bim cahaya monokromatik berjarak gelombang 3000 Å dan berkeamatan 3×10^{-14} W/m^2.]
[8 marks]

Ans:

$$N = I/\varepsilon = I\cdot\left(\frac{\lambda}{hc}\right)$$
$$= 3\times10^{-14}\,\text{W/m}^2\times\frac{300\,\text{nm}}{1240\text{eV}\cdot\text{nm}}$$
$$= 7.26\times10^{-15}\left(\frac{\text{W}}{\text{eV}}\right)/\text{m}^2 = 7.26\times10^{-15}\left(6.25\times10^{18}\,/\,\text{s}\right)/\text{m}^2 = 45375\text{photon}/\text{m}^2\cdot\text{s}$$
$$= 4.5\text{photon}/\text{cm}^2\cdot\text{s}$$

Gautreau and Savin, Schaum's series modern physics, pg.98, Q. 10.53

(d) Suppose that the x-component of the velocity of a 2×10^{-4} kg mass is measured to an accuracy of $\pm10^{-6}$ m/s. What is the limit of the accuracy with which we can locate the particle along the x-axis?
[Andaikan bahawa komponen x halaju suatu jasad berjisim 2×10^{-4} kg diukur tepat kepada kejituan $\pm10^{-6}$ m/s. Apakah limit kejituan kedudukannya yang boleh kita pastikan sepanjang paksi-x?]
[6 marks]

Ans.

$$\Delta p\Delta x \ge \frac{\hbar}{2};\ p = mv;$$
$$\Delta(mv)\Delta x = m\Delta v\Delta x \ge \frac{\hbar}{2}$$
$$\Delta x \ge \frac{\hbar}{2m\Delta v} = \frac{h}{4\pi m\Delta v} = 2.63\times10^{-25}\,\text{m}$$

Gautreau and Savin, Schaum's series modern physics, pg.98, Q. 10.53

Q4. [25 makrs]

(a) Given the ground state energy of hydrogen atom -13.6 eV, estimate the ionisation energy for He^+.
[Diberi bahawa tenaga keadaan bumi atom hidrogen ialah -13.6 eV, anggarkan tenaga pengionan untuk He^+.]
[5 marks]

Ans: Generally, the energy state of an hydrogen-like atom with Z charge in its nucleus is given by $E_n = \frac{Z^2}{n^2} E_0$, E_0 = ground state energy of hydrogen atom.

Hence ionisation energy of He^+ (with Z = 2) =

$$E_\infty(\mathrm{He}^+) - E_0(\mathrm{He}^+) = 0 - \frac{2^2}{1^2} E_0 = -4(-13.6)\,\mathrm{eV} = 54.4\ \mathrm{eV}$$

Serway solution manual 2, Q43, pg. 360, modified

(b) What are the n values in the transition that produces the third longest wavelength in the Balmer series in the hydrogen atom? (ignore selection rules)
[Apakah nilai-nilai n yang peralihannya menghasilkan jarak gelombang yang ketiga paling panjang dalam siri Balmer atom hidrogen? (abaikan petua pilihan)]

[4 marks]

Ans: **n = 5 → n = 2**
Giancoli, pg. 856, Q. 50, modified.

(c) Given the Bohr radius of the hydrogen atom r_0 = 0.5 Å, estimate the speed (in m/s) of the electron in the ground state orbit of the hydrogen atom.

[Diberi bahawa radius Bohr atom hidrogen ialah r_0 = 0.5 Å, anggarkan laju (dalam m/s) elektron dalam orbit keadaan bumi atom hidrogen.]

[8 marks]

Ans: Equating the centrepetal force required by the electron to the electrostatic force,

$$\frac{mv^2}{r} = \frac{e^2}{4\pi\varepsilon_0 r^2} \Rightarrow v_0^2 = \frac{e^2}{4\pi\varepsilon_0 m r_0} \Rightarrow v_0 = \sqrt{\frac{e^2}{4\pi\varepsilon_0 m r_0}} = 2.25\times10^6\ \mathrm{m/s}$$

My own question

(d) Given the Rydberg constant R = 1.0967758 x 10^{-3} Å^{-1}, determine, in Å,

(i) the shortest, and
(ii) the longest

wavelengths of the Lyman series of hydrogen.

SESSI 03/04/KSCP

[Diberi bahawa pemalar Rydberg ialah R = 1.0967758 x 10^{-3} Å^{-1}. Tentukan, dalam unit Å, jarak gelombang yang

(i) paling pendek, dan
(ii) paling panjang

dalam siri Lyman hidrogen]

[4 + 4 marks]

Ans:

(i) Wavelengths in the Lyman series are given by n_l = 1

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right),\ n = 2,3,4...$$

(ii) The longest wavelength corresponds to n = 2:

$$\frac{1}{\lambda_{\max}} = \left(1.097\times10^{-3}\ \text{Å}^{-1}\right)\left(\frac{1}{1^2} - \frac{1}{2^2}\right),\ \text{or}\ \lambda_{\max} = 1215\,\text{Å}$$

The longest wavelength corresponds to $n \to \infty$

$$\frac{1}{\lambda_{\min}} = \left(1.097\times10^{-3}\ \text{Å}^{-1}\right)\left(\frac{1}{1^2} - \frac{1}{\infty^2}\right),\ \text{or}\ \lambda_{\max} = 912\,\text{Å}$$

Gautreau and Savin, Schaum's series modern physics, pg.107, Q. 11.1

ZCT 104/3E Modern Physics
Semester II, Sessi 2004/05
Test I (17 Dec 2004)

Data
Speed of light in free space, $c = 3.00 \times 10^{8}$ ms^{-1}
Elementary charge, $e = 1.60 \times 10^{-19}$ C
The Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg

1. What are the major flaws in the classical model of blackbody radiation given by Rayleigh-Jeans laws?
I (F) Molecular energy is quantized
II (F) Molecules emit or absorb energy in discrete irreducible packets
III(T) The intensity of short wavelength radiation emitted by a blackbody approaches infinity as the wavelength decreases.
IV (T) Energy is continuously divisible

A. III, IV **B. I, II,III** **C. II, III, IV** **D. I, II**
E. Non of the above

ANS:A, Serway, questions 1, 2, page 1313

2. What are the assumptions did Planck make in dealing with the problem of radiation?
I (T) Molecular energy is quantized
II (T) Molecules emit or absorb energy in discrete irreducible packets
III(F) The intensity of short wavelength radiation emitted by a blackbody approaches infinity as the wavelength decreases.
IV (F) Energy is continuously divisible

A. III, IV **B. I, II,III** **C. II, III, IV** **D. I, II**
E. Non of the above

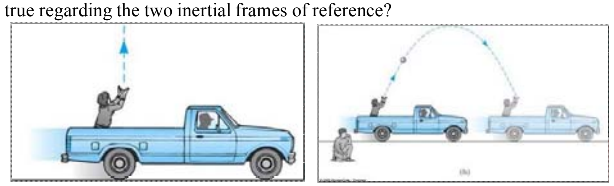
ANS:D, Serway, questions 1, 2, page 1313

3. An unstable high-energy particle enters a detector and leaves a track of length d before it decays. Its speed relative to the detector was $v = c/2$. What is its proper lifetime? That is how long would the particle have lasted before decay had it been at rest with respect to the detector?

A. $\dfrac{d}{c}$ **B.** $\dfrac{4d}{\sqrt{3}c}$ **C.** $\dfrac{2d}{\sqrt{3}c}$ **D.** $\dfrac{\sqrt{3}d}{c}$ **E. Non of the above**

RHW 7th ed. P5, pg. 1050
Solution: D

4. A ball was thrown upward by an observer in a van moving with constant speed $u << c$. He is observed by an observer in a rest frame attached to the ground, see figure below. Which of the following statement(s) is (are) true regarding the two inertial frames of reference?



I The ball thrown follows different path

II The kinematical laws of classical mechanics are valid only the moving frame (the van) but not to the rest frame attached to ground.
III Classically Galilean transformation relates the trajectory of the ball in the rest frame with that in the moving frame.
IV Since $u<<c$, Lorentz transformation will fail to relate the trajectory of the ball in the rest frame with that in the moving frame.

A. II,III **B. I, II,III** **C. II, III, IV** **D. I Only** **E. Non of the above**
My own question
Solution: E (I, III are true)

5. What measurement(s) do two observers in relative motion always agree on?
I The relativistic mass of an object
II The relativistic momentum of an object
III The relativistic energy of an object
IV $E^2 - p^2$, where p is the magnitude of relativistic momentum and E the relativistic energy the object

A. II,III **B. I, II,III** **C. II, III, IV** **D. IV Only**
E. Non of the above

My own question
Solution: D
Free marks will be given for this question due to the typo in IV. It should actually reads: "$E^2 - c^2p^2$, where p is the ".

Actually, the original statement is dimensionally correct in the natural unit system in which the c is taken to have a value of 1. However since we are adopting S.I. unit throughout the course we will take the original statement to be 'dimensionally wrong' as far as the ZCT 104 courses is concerned.

6. Which of the following statement(s) is (are) true?
I The upper limit of the speed of an electron is the speed of light c.
II As more energy E is fed into an object its momentum approaches $\frac{E}{c}$.
III There is no upper limit to the relativistic momentum of an electron.
IV There is an upper limit to the relativistic momentum of an electron.

A. III **B. I, II,III** **C II, IV** **D. IV Only** **E. Non of the above**
Serway Q12, pg. 1276
Solution: B

7. The rest energy and total energy respectively, of three particles, expressed in terms of a basic amount A are (1) A, $2A$; (2) A, $3A$; (3) $3A$, $4A$. Without written calculation, rank the particles according to their kinetic energy, greatest first.

A. 2 > 1 = 3 **B.** 1 > 2 = 3 **C.** 2 > 1 > 3 **D.** 2 = 1 = 3
E. 3 > 1 = 2

RHW 7th ed. Q1, pg. 1050
Solution: A

8. The length of a spaceship is measured to be exactly half its rest length. By what factor do the spaceship's clocks run slow relative to clocks in the observer's frame?

A. 0.866 **B.** 0.745 **C.** 2.000 **D.** 0.366 **E.** 0.134

Solution: C

9. The length of a spaceship is measured to be exactly half its rest length. What is the speed parameter $\beta = v/c$ of the spaceship relative to the observer's frame?

A. 0.87 **B.** 2.00 **C.** 0.75 **D.** 2.73 **E.** 4.00

ANS: A

We solve $L = L_0\sqrt{1-\left(\frac{v}{c}\right)^2} = L_0\sqrt{1-\beta} = \frac{L_0}{\gamma}$ **for** v **and then plug in:**

$$\beta = \sqrt{1-\left(\frac{L}{L_0}\right)^2} = \sqrt{1-\left(\frac{1}{2}\right)^2} = 0.866.$$

Resnick and Halliday, 7th edition, Problem 12, Pg. 1051

10. Consider a light pulse emitted from the origin, O, of a stationary frame S. The origin of a moving frame S', O', which overlaps with O at $t = t' = 0$ is moving with a constant speed u with respect to O. Which statement(s) correctly describe(s) the position of the wavefront of the light sphere as measured from the origins? r (r') is the distance of the wavefront from the origin O (O') at time t (t').

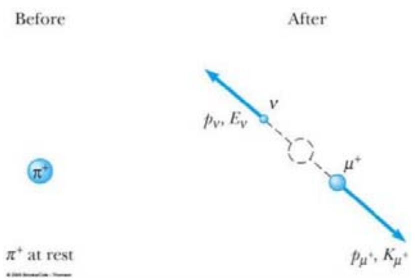
I $r = ct$ **II** $r' = ct'$ **III** $r' = r$ **IV** $r' = ut'$

A. I,II **B. I, II,III** **C. II, III, IV** **D. IV Only** **E. Non of the above**
My own question
Solution: A

11. Which of the following statement(s) is (are) true regarding Lorentz transformation (LT)?
I Time dilation can be recovered from LT
II Length contraction can be recovered from LT
III Absolute simultaneity is not guaranteed by LT
IV Galilean transformation is a generalisation of LT

A. II,III **B. I, II,III** **C. II, III, IV** **D. I, II** **E. Non of the above**
My own question
Solution: B

Question 12-13 are based on the decay of a π meson into a muon and a massless neutrino shown in figure below. The mass of the muon is known to be m_μ = 106 MeV/c^2, and the kinetic energy of the muon is measured to be K_μ = 4.6 MeV. p_μ denotes the momentum of the muon.



12. What is the momentum of the neutrino?

A. $\sqrt{\left(K_\mu + m_\mu c^2\right)^2 - m_\mu^2 c^4}$ **B.** $\left(K_\mu + m_\mu c^2\right)$
C. $\sqrt{2m_\mu K_\mu}$ **D.** p_μ **E. Non of the above**

Serway and Mosses. pg. 53
Solution: D

13. What is the total relativistic energy of the neutrino?

A. $\sqrt{\left(K_\mu + m_\mu c^2\right)^2 - m_\mu^2 c^4}$ **B.** $\left(K_\mu + m_\mu c^2\right) + \sqrt{\left(K_\mu^2 + 2K_\mu m_\mu c^2\right)}$
C. K_μ **D.** $m_\mu c^2$ **E. Non of the above**

Serway and Mosses. pg. 52
Ans: A

Solution: $E_\nu = \sqrt{(p_\nu^2 c^2 + m_\nu^2 c^4)} = p_\nu c$ ($m_\nu c^2$ =0). The momentum of neutrino, $p_\nu^2 = p_\mu^2$ (from Question 12 above) is related to the kinetic energy of the muon via $E_\mu = \sqrt{(p_\mu^2 c^2 + m_\mu^2 c^4)} = m_\mu c^2 + K_\mu$. Therefore the momentum of the neutrino is related to the kinetic energy of the muon via $p_\nu^2 c^2 = (m_\mu c^2 + K_\mu)^2 - m_\mu^2 c^4$. Taking the square root, we then have $E_\nu = p_\nu c = \sqrt{\left(K_\mu + m_\mu c^2\right)^2 - m_\mu^2 c^4}$.

14. Serway and Moses, Questions 12, page 37
What happens to the density of an object as its speed increases, as measured by an Earth observer?

A. Remain the same as it is when at rest
B. Increase by a factor of γ
C. Increase by a factor of γ^2
D. Increase by a factor of $1/\gamma$
E. Non of the above

ANS: **C**, my own question

15. What is the upper limit of the momentum of an electron?

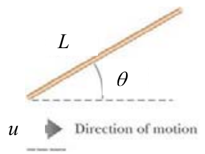
A. $m_e c$ **B.** c **C.** 0 **D.** Infinity **E. Non of the above**

Serway, Q12, pg. 1276
Solution: D

16. Which of the following statement(s) is (are) true?
I Only massless particle can travel at the speed of c.
II Not all massless particle can travel at the speed of c.
III It is not necessary that a massless particle must travel at the speed of c.
IV All particles which are not massless must travel at the speed lower than c.

A. II,III **B. I, II,III** **C. I, III, IV** **D. I, IV** **E. Non of the above**
My own question
Solution: D

17. A moving rod is observed to have a length of L and to be orientated at an angle of θ = 45° with respect to the direction of motion, as shown in the figure below. The rod has a speed of $u = \frac{c}{\sqrt{2}}$.



What is the proper length of the rod?

A. $\frac{3}{2}L$ **B.** L **C.** $\sqrt{\frac{3}{2}}L$ **D.** $\frac{\sqrt{3}L}{2}$ **E. Non of the above**

Serway, P23, page 1279
Solution: C

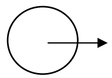
$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}} = \frac{1}{\sqrt{1 - \left(\frac{1}{\sqrt{2}}\right)^2}} = \sqrt{2}$$

We are also given L and θ (both measured in a reference frame moving relative to the rod).

Thus, $L_x = L\cos\theta = \frac{L}{\sqrt{2}}; L_y = L\sin\theta = \frac{L}{\sqrt{2}}$. L'_x is a proper length, related to L_x by $L_x = \frac{L'_x}{\gamma}$.

Therefore, $L'_x = \gamma L_x = \sqrt{2}\frac{L}{\sqrt{2}} = L$, and $L'_y = L_y = \frac{L}{\sqrt{2}}$. (Lengths perpendicular to the motion are unchanged). $\Rightarrow (L')^2 = (L'_y)^2 + (L'_x)^2 = \frac{L^2}{2} + L^2 = \frac{3L^2}{2} \Rightarrow L' = \sqrt{\frac{3}{2}}L$

18. A spaceship in the shape of a sphere moves past and observer on Earth with a speed of $v = 0.5c$ in the direction as indicated by the arrow. What shape will the observer see as the spaceship move past?



A B C D

E. Non of the above
Solution: A

19. What is the speed of an object having relativistic momentum of magnitude p and rest mass m?

A. $\frac{p}{m}$ **B.** $\frac{c}{\sqrt{1+(mc/p)^2}}$ **C.** $\frac{mc^2}{u}$ **D.** $\frac{mu^2}{c}$ **E. Non of the above**

Serway, P32, page 1280
Solution: B

20. An electron with rest mass m_e moves with a speed of $\frac{\sqrt{3}}{2}c$. What is the work required to increase its speed to $\frac{2\sqrt{2}}{3}c$?

A. m_ec^2 **B.** $0.511m_ec^2$ **C.** $\frac{5}{36}m_ec^2$ **D.** $\frac{\sqrt{5}}{6}m_ec^2$ **E. Non of the above**

Serway, P35, page 1280
Solution: A

ZCT 104/3E Modern Physics
Semester II, Sessi 2004/05
Test II (18 Feb 200b)

1. Which statements is (are) TRUE about photoelectricity according to classical physics? (ANS: D)

I) Light beam of higher intensity is expected to eject electrons with higher kinetic energy from the metal surface (T)
II) In photoelectric experiment the energy carried by a beam of light is considered to be continuous (T)
III) Light is wave and not comprised of quantum of energy (T)
IV) When light is irradiated on the metal surface, some time lag is expected before photoelectrons are ejected from the surface (T)

A. I, II **B. II, III**
C. III **D. I, II, III, IV**
E. Non of A, B, C, D

2. Let a given metal surface is irradiated with monochromatic light of intensity I_1. Then the same surface is irradiated by monochromatic light with intensity I_2 (where $I_2 > I_1$) but with a longer wavelength. Which of the following statement(s) is (are) true? (ANS: E)

I) The energy of the photon in the beam with intensity I_2 is larger than that in the beam with intensity I_1. (F)
II) The saturated photocurrents will remain unchanged. (F)
III) The maximum kinetic energy of the photoelectron will increase for the beam with intensity I_2 (F)
IV) The different intensity of light will alter the work function of the metal surface (F)

A. I, II **B. II, III**
C. III **D. III, IV**
E. Non of A, B, C, D

3. Which of the following statements is (are) correct about Bohr's atom and a quantum particle trapped inside a simple infinite quantum well of width d? (ANS: A)

I) The gap separating energy levels of higher quantum number becomes closer and closer in the Bohr's hydrogen atom, whereas in the case of particle in a box the gap becomes larger and larger at higher quantum levels. (T)
II) The electron in the Bohr's atom is subjected to a non-zero potential due to Coulomb's attraction, whereas in the box the particle is subjected to zero potential. (T)
III) The energy levels in the Bohr's atom are negative whereas they are positive for the particle in the well. (T)
IV) In both cases the particles involved form standing waves (T)

A. I, II, III, IV **B. II, III**
C. III **D. III, IV**
E. Non of A, B, C, D

4. Which of the following statements is (are) true? (ANS: C)

I) A particle has a de Broglie wavelength that is related to its linear momentum (T)
II) A particle's momentum must be quantised in all systems, bounded or unbounded (F)
III) A particle's kinetic energy must be quantised in all systems, bounded or unbounded (F)
IV) A particle's kinetic energy is only quantised in bounded system (T)

A. I, II, IV **B. I, II, III**
C. I, IV **D. II, III**
E. Non of A, B, C, D

5. In order to have photoelectrons ejected from a metal surface in a typical photoelectric effect experiment, (ANS: C)

I) the frequency of the light used must be larger than a certain cut-off value (T)
II) the intensity of the light used must be larger than a certain cut-off value (F)
III) the wavelength of the light used must be larger than a certain cut-off value (F)
IV) the saturated photocurrent must be larger than a certain cut-off value (F)

A. I, II, IV **B. I, III**
C. I **D. II, III, IV**
E. Non of A, B, C, D

6. What of the following statements are TRUE regarding photoelectric effect (PE) and Compton effect (CE)? (ANS: D)

I) In PE light behaves like particle, whereas in CE light behave like wave (F)
II) In PE light behaves like wave, whereas in CE light behave like particle (F)
III) In PE only part of the photon's energy is lost to the atom, whereas in CE all of the photon's energy is lost to the free electron (F)
IV) In PE all of the photon's energy is lost to the atom, whereas in CE only part of the photon's energy is lost to the free electron (T)

A. I, III **B. II, III**
C. II, IV **D. IV**
E. Non of A, B, C, D

7. Which statements is (are) TRUE about photoelectric and Compton effects? (ANS: E)

I) Compton effect experiment confirms that the energy of the quantum of light is proportional to the frequency of the wave model of light (F)
II) Compton effect experiment confirms that the radiant energy of light is quantized into concentrated bundle (F)
III) Photoelectric effect infers that the radiant energy of light is quantized into concentrated bundle (T)
IV) Both Compton effect and photoelectric effect confirm that EM radiation has both wave and particle properties (F)

A. I, III **B. II, III**
C. II, IV **D. IV**
E. Non of A, B, C, D

8. Which of the following is (are) the correct statement(s) about X-ray production in a conventional X-ray tube? (ANS: B)

I) Part or all of the kinetic energy of the moving electron is converted into X rays photon (T)
II) X-rays is emitted when the bombarding electrons undergo Compton scattering (F)
III) The production of x-rays can be considered as a photoelectric process (F)
IV) The shortest wavelength in the x-rays spectrum is the same for different material (T)

A. II, III **B. I, IV**
C. II, IV **D. IV**
E. Non of A, B, C, D

9. Which of these statements is (are) true about blackbody radiation? (ANS: B)

I) Rayleigh-Jeans law is behaving in a physically acceptable manner at short wavelengths (F)
II) Rigel (the blue star) is hotter than Betelguese (red star) because of the position of the peak wavelength in their black body spectrum (T)
III) According to Rayleigh-Jeans law the average energy of the oscillators is given by the equipartition theorem (T)
IV) The spectral distribution of radiation from a blackbody can only be explained in terms of quantised energy levels of the oscillators (T)

A. I, II, III, IV **B. II, III, IV**
C. II, IV **D. III, IV**
E. Non of A, B, C, D

10. Which of these statements are correct? (ANS: E)

I) We conclude that light behave like wave when we find that the light from the sun arrives to the Earth after 8 minutes it was emitted. (F)
II) When we consider light to behave like a particle we expect some detectable time lag for the electron to be emitted from the surface of the metal in a PE experiment. (F)
III) When we consider light to behave like wave we expect some detectable time lag for the electron to be emitted from the surface of the metal in a PE experiment. (T)
IV) Photoelectric effect occurs at the same energy scale as that of the x-rays production because x-rays production is the inverse of the photoelectric process. (F)

A. I, II, III, IV **B. II, III, IV**
C. II, IV **D. III, IV**
E. III

11. Which of the following statements is (are) TRUE? (ANS: E)

I) The energy levels of the atomic orbit is quantized (T)
II) The energy associated with the orbits of the electron in a hydrogen atom is negative because it is not a bounded system (F)
III) $E = 0$ means the electron is free from the bondage of the nucleus' potential field. (T)
IV) Electron at very large quantum number n is tightly bounded to the nucleus by the EM force. (F)

A. I, II, III, IV **B. II, III, IV**
C. II, IV **D. III, IV**
E. I, III

12. Which of the following statements is (are) TRUE about the Bohr's model of hydrogen-like atom? (ANS: C)

I) It applies the Newton's second law for the atom's mechanical stability (T)
II) The angular momentum is postulated to be quantised via $L = nh/2\pi$ (T)
III) It assumes the validity of classical electromagnetic theory for the orbiting electron (F)
IV) The only stable orbits of radius r are those that can fit in a multiple number of standing wave of the electron, i.e $2\pi r = n\lambda$ (T)

A. I, II, III, IV **B. II, III, IV**
C. I, II, IV **D. III,IV**
E. Non of A, B, C, D

13. Which of the following statements is (are) true? (ANS C)

I) Thompson suggestion of the Plum Pudding Model is falsified by Rutherford's alpha particle experiment (T)
II) Rutherford suggested the planetary model of atoms. (T)
III) de Broglie is the first to experimentally confirm that electron manifests wave nature. (F)
IV) Frank-Hertz experiment confirms the existence of discrete energy levels in mercury atom (T)

A. I, II, III, IV **B. II, III, IV**
C. I, II, IV **D. III,IV**
E. Non of A, B, C, D

14. Which of the following statement is (are) true about the Plum-pudding model by Thompson and Rutherford's experiment? (ANS A)

I) Plum-pudding model fails to explain the emission & absorption line spectrum from atoms because it predicts only a single unique emission frequency. (T)
II) Plum-pudding model cannot explain the 180 degree back-scattering of alpha particle seen in Rutherford's scattering experiment. (T)
III) The planetary model of atoms is plagued by infrared catastrophe (T)
IV) In the Rutherford's alpha particle scattering experiment, the large deflection of alpha particle is caused by a close encounter between alpha particle and the diffused distribution of the positive charge of an atom. (F)

A. I, II, III **B. II, III, IV**
C. I, II, IV **D. III, IV**
E. Non of A, B, C, D

15. Which of the following statements is (are) true regarding the basic properties of atoms? (ANS: A)

I) Atoms are of microscopic size, $\sim 10^{-10}$ m (T)
II) Atoms are stable (T)
III) Atoms contain negatively charges, electrons, but are electrically neutral. (T)
IV) Atoms never emit and absorb EM radiation. (*F*)

A. I, II, III **B. II, III, IV**
C. I, II, IV **D. III, IV**
E. Non of A, B, C, D

16. Which of the following statements is (are) true about Bohr's hydrogen-like atom? (ANS C)

I) The increase in the quantum number n means an increase in the energy of the atomic states. (T)

II) When n approach infinity, the energy states become infinity. (F)
III) Free electron is the electron which has the smallest quantum number n (F)
IV) The zero point energy is the energy of the lowest possible quantum level (T)

A. I, II, III **B. II, III, IV**
C. I, IV **D. III, IV**
E. Non of A, B, C, D

17. Heisenberg's uncertainty principle is a consequence of (ANS: A)

A. the intrinsic wave nature of particle
B. the intrinsic particle nature of wave
C. the indivisible nature of particle
D. the divisible nature of particle
E. probabilistic interpretation of the wave function

18. Which of the following statements is (are) true about the spectrum from hydrogen atom? (ANS: A)

I) Balmer series involve transitions of electron from higher orbits to the $n = 2$ orbit
II) Balmer series is the first spectral series of hydrogen atom observed
III) When electron in higher orbit is de-excited to lower orbit, photons of discrete frequency are emitted from the atom, as seen in the emission spectrum
IV) When electron in lower orbit is excited to higher orbit, photons of discrete frequency are absorbed by the atom, as seen in the absorption spectrum

A. I, II, III, IV **B. II, III, IV**
C. I, IV **D. III, IV**
E. Non of A, B, C, D

19. Which of the following statements is (are) true regarding a quantum particle trapped inside an infinite well of width L? (ANS B)

I) It forms stationary (standing) wave inside the well (T)
II) The linear momentum of the particle becomes quantised (T)
III) The minimum energy of the particle inside the well is given by $h^2/8mL^2$ (T)
IV) The energy of the particle inside the well can take on negative value (F)

A. I, II, III, IV **B. I, II, III**
C. I, IV **D. III, IV**
E. Non of A, B, C, D

20. Which of the following statements is (are) true regarding pair production and pair annihilation of electron-positron pair? (ANS D)

I) Pair annihilation occurs only above the threshold energy of $2m_ec^2$ (F)
II) Pair production occurs only above the threshold energy of $2m_ec^2$ (T)
III) Energy is always conserved in both processes of pair production and pair annihilation (T)
IV) Momentum is always conserved in both processes of pair production and pair annihilation (T)

A. I, II, III, IV **B. I, II, III**
C. I, IV **D. II, III, IV**
E. Non of A, B, C, D

UNIVERSITI SAINS MALAYSIA

Final Exam
Academic Session 2004/2005
March 2005

ZCT 104E/3 - Physics IV (Modern Physics)
[Fizik IV (Fizik Moden)]

Duration: 3 hours
[Masa: 3 jam]

Please check that the examination paper consists of **XXX** pages of printed material before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **XXX** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]*

<u>Instruction</u>: Answer all questions. Please answer the objective questions from Part A in the objective answer sheet provided. Answer both structured questions from Part B. Please submit the objective answer sheet and the answers to the structured questions separately.

Students are allowed to answer all questions in Bahasa Malaysia or in English.

*[**<u>Arahan</u>**: Jawab **SEMUA** soalan. Sila jawab soalan-soalan objektif daripada bahagian A dalam kertas jawapan objektif yang dibekalkan. Jawab kedua-dua soalan struktur daripada Bahagian B. Hantar kertas jawapan objektif dan jawapan kepada soalan struktur berasingan.]*

[Pelajar dibenarkan untuk menjawab samada dalam bahasa Malaysia atau bahasa Inggeris.]

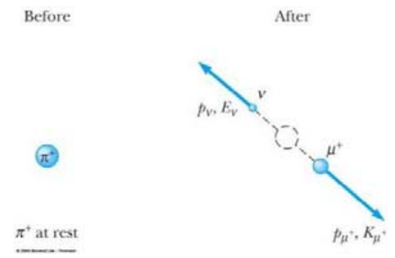
Data
speed of light in free space, $c = 3.00 \times 10^{8}$ m s^{-1}
permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
elementary charge, $e = 1.60 \times 10^{-19}$ C
Planck constant, $h = 6.63 \times 10^{-34}$ J s
unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg
molar gas constant, = 8.31 J K^{-1} mol^{-1}
Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}
gravitational constant, $G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
acceleration of free fall, $g = 9.81$ m s^{-2}

SESSI 04/05/FINAL

Part A: Objective
Instruction: Answer all 40 objective questions in this Part.
[Bahagian A: Objektif.]
[Arahan: Jawab kesemua 40 soalan objektif dalam Bahagian ini.]

Question 1 - 3 are based on the decay of a π meson into a muon and a massless neutrino shown in the figure below. The mass of the muon is known to be m_μ = 106 MeV/c^2, and the kinetic energy of the muon is measured to be K_μ = 4.6 MeV. p_μ denotes the momentum of the muon.

[Soalan 1-3 adalah berdasarkan pereputan satu meson π kepada satu muon dan satu neutrino tanpa jisim, sepertimana ditunjukkan dalam gambarajah di bawah. Diketahui jisim muon ialah m_μ = 106 MeV/c^2, dan tenaga kinetik muon yang terukur ialah K_μ = 46 MeV. p_μ menandakan momentum muon.]



1. How is the momentum of the muon, p_μ related to the kinetic energy of the muon? E_μ denotes the total relativistic energy of muon.
[Bagaimanakah momentum muon p_μ dikaitkan dengan tenaga kinetik muon? E_μ menandakan tenaga keretatifan muon]
A. $p_\mu c=\sqrt{\left(K_\mu+m_\mu c^2\right)^2-m_\mu^2c^4}$ **B.** $p_\mu=\sqrt{\left(K_\mu+m_\mu c^2\right)^2-m_\mu^2c^4}$
C. $p_\mu=\sqrt{2m_\mu K_\mu}$ **D.** $p_\mu c=\sqrt{\left(E_\mu^2+m_\mu c^2\right)^2}$
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS:A, Inspired by Serway and Mosses 2005 edition, pg. 52-53.

2. What is the rest energy of the π meson?
[Apakah tenaga rehat meson π ?]
A. $K_\mu+m_\mu c^2$ **B.** $\left(K_\mu+m_\mu c^2\right)+\sqrt{\left(K_\mu^2+2K_\mu m_\mu c^2\right)}$
C. K_μ **D.** $m_\mu c^2$
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS:B, Inspired by Serway and Mosses 2005 edition, pg. 52-53.

3. What is the kinetic energy of the neutrino?
[Apakah tenaga kinetik neutrino?]
A. $\sqrt{\left(K_\mu+m_\mu c^2\right)^2-m_\mu^2c^4}$ **B.** $\left(K_\mu+m_\mu c^2\right)+\sqrt{\left(K_\mu^2+2K_\mu m_\mu c^2\right)}$

C. K_μ **D.** $m_\mu c^2$
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS:A, Inspired by Serway and Mosses 2005 edition, pg. 52-53.

4. Which of the following statement(s) is (are) true? *[Manakah kenyataan yang berikut adalah benar?]*

I (T) All inertial frames are equivalent *[Semua rangka inersia adalah setara]*

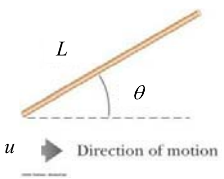
II (T) If light obeys Galilean transformation, light waves would appear stationary in an inertial frame that moves with the same speed with that of the light. *[Jika cahaya mematuhi transformasi Galilean, gelombang cahaya akan kelihatan pegun dalam satu rangka inersia yang kelajuannya sama dengan kelajuan cahaya]*

III(F) In an inertial frame moving approximately with the speed of light, light waves would appear stationary according to the postulates of special theory of relativity *[Dalam satu rangka inersia yang bergerak dengan kelajuan hampir dengan kelajuan cahaya, gelombang cahaya akan kelihatan pegun mengikut postulat teori kerelatifan khas.]*

IV (F) It is experimentally verified that electromagnetic waves propagate through a medium called Ether *[Telah disahkan secara eksperimen bahawa gelombang elektromagnetik merambat melalui satu jenis medium digelar Ether.]*

A. II,III **B. I, II,III** **C. II, III, IV** **D. I, II**
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS:**D**, my own question

5. A moving rod is observed to have a length of L and to be orientated at an angle of $\theta = 45°$ with respect to the direction of motion, as shown in the figure below. The rod has a speed of $u = \frac{c}{\sqrt{2}}$.
[Suatu rod bergerak diperhatikan mempunyai panjang L dan diorientasikan pada suatu sudut θ = 45 ° merujuk kepada arah gerakannya sepertimana ditunjukkan dalam gambarajah di bawah. Kelajuan rod ialah $u = \frac{c}{\sqrt{2}}$.]



Serway, page 1279, question 23 (modified)

What is the tangent of the angle in the proper frame (in terms of $\tan\theta$)?
[Apakah tangen sudutnya (dinyatakan dalam sebutan $\tan\theta$) dalam rangka `proper']

A. $\tan\theta$ **B.** $\frac{\tan\theta}{\sqrt{2}}$ **C.** $\sqrt{2}\tan\theta$ **D.** $2\tan\theta$
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS:B

6. What measurement(s) do two observers in relative motion always agree on?
[Apakah ukuran(-ukuran) yang sentiasa disetujui oleh dua orang pemerhati yang berada dalam pergerakan relatif]
I The speed of light *c* in vacuum *[Laju cahaya c dalam vakum]*
II The speed *v* of their relative motion *[Laju relatif v di antara mereka]*
III The momentum of an object *[Momentum suatu objek]*
IV The rest mass of an object *[Jisim rehat suatu objek]*

A. II, III **B. I, II, IV** **C. II, III, IV** **D. I, II**
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
Serway Q1, pg. 1276
Solution: B

7. Given {*x,t*}, {*x',t'*} are two sets of coordinates used by two reference frames which are moving with a constant relative velocity, which statement(s) correctly describe(s) the transformation between them?
[Diberi {x,t}, {x',t'} merupakan dua set koordinat yang digunakan oleh dua rangka rujukan yang bergerak dengan halaju relatif mantap, kenyataan yang manakah memerihalkan transformasi di antara dua set koordinat tersebut dengan betul?]

I {*x,t*} is related to {*x',t'*} by Galilean transformation at $u << c$
[{x,t} dikaitkan dengan {x',t'} oleh transformasi Galilean pada u << c]

II {*x,t*} is related to {*x',t'*} by Galilean transformation at $u \rightarrow c$
[{x,t} dikaitkan dengan {x',t'} oleh transformasi Galilean pada u → c]

III {*x,t*} is related to {*x',t'*} by Lorentz transformation at $u << c$
[{x,t} dikaitkan dengan {x',t'} oleh transformasi Lorentz pada u << c]

IV {*x,t*} is related to {*x',t'*} by Lorentz transformation at $u \rightarrow c$
[{x,t} dikaitkan dengan {x',t'} oleh transformasi Lorentz pada u → c]

A. I,II **B. I, III,IV** **C. II, III, IV** **D. I, IV Only**
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
My own question
Solution: B

8. What is the upper limit of the speed of an electron?
[Apakah limit atas bagi laju suatu elektron?]
A. $m_e c$ **B.** c **C.** 0 **D.** Infinity
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
Serway, Q12, pg. 1276
Solution: B

9. The units of the Planck constant *h* are those of:
[Unit bagi pemalar Planck h adalah sama dengan unit bagi …]

A. energy **B.** power **C.** momentum **D.** angular momentum
E. frequency
Solution: D, Chap 38, Q1, RHW 7th ed testbank,

10. Rank following electromagnetic radiations according to the energies of their photons, from least to greatest.
[Menyusun sinaran elektromagnetik berikut mengikut tenaga foton mereka, daripada yang paling lemah kepada yang paling besar]

1. blue light 2. yellow light 3. x-rays 4. radio waves

A. 1, 2, 3, 4 **B.** 4, 2, 1, 3 **C.** 4, 1, 2, 3 **D.** 3, 2, 1, 4 **E.** 3, 1, 2, 4
Solution: B, Chap 38, Q9, RHW 7th ed testbank,

11. In a photoelectric effect experiment the stopping potential is:
[Dalam eksperimen kesan fotoelektrik keupayaan penghenti adalah]

A. the energy required to remove an electron from the sample
[tenaga yang diperlukan untuk menyingkirkan satu elektron daripada sampel]

B. the kinetic energy of the most energetic electron ejected
[tenaga kenetik bagi elektron terlenting yang paling bertenaga]

C. the potential energy of the most energetic electron ejected
[tenaga keupayaan bagi elektron terlenting yang paling bertenaga]

D. the photon energy *[tenaga foton]*

E. the electric potential that causes the electron current to vanish
[keupayaan elektrik yang menyebabkan arus elektron hilang]
Solution: E, Chap 38, Q13, RHW 7th ed testbank,

12. In a photoelectric effect experiment no electrons are ejected if the frequency of the incident light is less than A/h, where h is the Planck constant and A is:
[Dalam eksperimen kesan fotoelektrik tiada elektron akan terlenting jika frekuensi cahaya tuju adalah kurang daripada A/h, di mana h ialah pamalar Planck dan A ialah:]

A. the maximum energy needed to eject the least energetic electron
[tenaga maksimum yang diperlukan untuk melentingkan elektron yang paling kurang bertenaga]

B. the minimum energy needed to eject the least energetic electron

SESSI 04/05/FINAL

[tenaga miminum yang diperlukan untuk melentingkan elektron yang paling kurang bertenaga]

C. the maximum energy needed to eject the most energetic electron
[tenaga maksimum yang diperlukan untuk melentingkan elektron yang paling bertenaga]

D. the minimum energy needed to eject the most energetic electron
[tenaga minimum yang diperlukan untuk melentingkan elektron yang paling bertenaga]

E. the intensity of the incident light *[keamatan cahaya tuju]*

Solution: D, Chap 38, Q16, RHW 7th ed testbank,

13. Consider the following: *[Pertimbangkan yang berikut]*

I. A photoelectric process in which some emitted electrons have kinetic energy greater than *hf,* where *f* is the frequency of the incident light.
[Satu proses fotoelektrik di mana sebahagian elektron terlenting mempunyai tenaga kinetik yang lebih besar daripada hf, di mana f ialah frekuensi cahaya tuju]

II. A photoelectric process in which all emitted electrons have energy less than *hf.*
[Satu proses fotoelektrik di mana kesemua elektron terlenting mempunyai tenaga kurang daripada hf]

III. Compton scattering from stationary electrons for which the emitted light has a frequency that is greater than that of the incident light.
[Penyerakan Compton daripada elektron-elektron rehat yang mana cahaya tertenting mempunyai frekuensi yang lebih besar daripada frekuensi cahaya tuju]

IV. Compton scattering from stationary electrons for which the emitted light has a frequency that is less than that of the incident light.
[Penyerakan Compton daripada elektron-elektron rehat yang mana cahaya tertenting mempunyai frekuensi yang lebih kecil daripada frekuensi cahaya tuju]

The only possible processe(s) is (are) *[Proses(-proses) yang mungkin ialah]*:

A. I **B. III** **C. I** and **III** **D. I** and **IV** **E. II** and **IV**
Solution: E, Chap 38, Q29, RHW 7th ed testbank (model answer in the testbank is incorrect)

14. In Compton scattering from stationary electrons the largest change in wavelength that can occur is:
[Dalam penyerakan Compton daripada elektron-elektron rehat, perubahan paling besar yang mungkin dalam jarak gelombang adalah]

A. 2.43×10^{-15} m **B.** 2.43×10^{-12} m **C.** 4.9×10^{-12} m
D. dependent on the frequency of the incident light *[bergantung kepada frekuensi cahaya tuju]*
E. dependent on the work function *[bergantung kepada fungsi kerja]*
Solution: C, Chap 38, Q25, RHW 7th ed testbank (model answer in the testbank is incorrect)

15. Of the following, Compton scattering from electrons is most easily observed for:
[Daripada yang berikut, penyerakan Compton daripada elektron-elektron adalah paling mudah dicerap dalam]

A. microwaves **B.** infrared light **C.** visible light
D. ultraviolet light **E.** x rays
Solution: E, Chap 38, Q22, RHW 7th ed testbank,

16. In Compton scattering from stationary particles the maximum change in wavelength can be made larger by using:
[Dalam penyerkan Compton daripada zarah-zarah rehat, perubahan maksimum dalam jarak gelombang boleh dijadikan lebih besar dengan menggunakan]

A. higher frequency radiation *[sinaran yang berfrekuensi lebih tinggi]*
B. lower frequency radiation *[sinaran yang berfrekuensi lebih rendah]*
C. more massive particles *[zarah yang berjisim lebih besar]*
D. less massive particles *[zarah yang berjisim lebih kecil]*
E. particles with greater charge *[zarah yang casnya lebih besar]*

Solution: D, Chap 38, Q21, RHW 7th ed testbank (modified)

17. Evidence for the wave nature of matter is: *[Bukti untuk sifat gelombang bagi jasad ialah]*

A. Electron diffraction experiments of Davisson and Germer
[eksperimen belauan elektron oleh Davisson dan Germer]

B. Photoelectric effect *[kesan fotoelektrik]*

C. Young's double slit experiment *[eksperimen dwi-celah Young]*

D. the Compton effect *[kesan Compton]*

E. Frank-Hertz experiment *[eksperimen Frank-Hertz]*

Solution: A, Chap 38, Q31, RHW 7th ed testbank,

18. Monoenergetic electrons are incident on a single slit barrier. If the energy of each incident electron is increased the central maximum of the diffraction pattern:
[Elektron monotenaga ditujukan pada satu sawar celah tunggal. Jika tenaga setiap elektron tuju dinaikkan, maka maksimum pusat corak belauan]

A. widens *[dilebarkan]* **B.** narrows *[disempitkan]*

C. stays the same width *[kelebaran tetap tak berubah]*

D. widens for slow electrons and narrows for fast electrons
[dilebarkan untuk elektron yang lambat dan disempitkan untuk elektron yang pantas]

E. narrows for slow electrons and widens for fast electrons

SESSI 04/05/FINAL

[disempitkan untuk elektron yang lambat dan dilebarkan untuk elektron yang pantas]

Solution: B, Chap 38, Q34, RHW 7th ed testbank,

19. Which of the following statement(s) is (are) true? *[Manakah kenyataan yang berikut adalah benar?]*

I (T) An ideal blackbody absorbs all of the light that is incident on it. *[Jasad hitam yang ideal menyerap kesemua cahaya yang tertuju padanya]*

II (F) The distribution of energy in the blackbody radiation depends upon the material from which the blackbody is constructed.
[Taburan tenaga dalam pancaran jasad hitam bergantung kepada jenis bahan yang membentuk dinding jasad hitam]

III(T) A blackbody is a perfect emitter of the radiation it generates. *[Jasad hitam adalah pemancar pancaran yang sempurna.]*

IV (T) The energy of an ultraviolet photon is more than the energy of an infrared photon.
[Tenaga suatu foton ultraungu adalah lebih tinggi daripada tenaga bagi suatu foton inframerah]

A. III, IV **B. I, II, III** **C. I, III, IV** **D. I, III**
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

Solution: C
I: testgen Physics 2 by Walker, Q1, Walker Chap 30
II: testgen Physics 2 by Walker, Q2, Walker Chap 30
III: testgen Physics 2 by Walker, Q11, Walker Chap 30
IV: testgen Physics 2 by Walker, Q12, Walker Chap 30

20. If the wavelength of a photon is doubled, what happens to its energy?
[Jika jarak gelombang digandakan dua kali, apa yang akan berlaku ke atas tenaganya?]

A. It is halved. *[ia diseparuhkan]*
B. It stays the same. *[tetap tak berubah]*
C. It is doubled. *[ia digandaduakan]*
D. It is quadrupled. *[ia digandakan 4 kali]*
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: A, testgen Physics 2 by Walker, Q24, Walker Chap 30

21. Light of a given wavelength is used to illuminate the surface of a metal, however, no photoelectrons are emitted. In order to cause electrons to be ejected from the surface of this metal you should
[Cahaya dengan jarak gelombang tertentu digunakan untuk memancari permukaan satu logam, tapi tiada fotoelektron yang terlentingkan. Unutk menlentingkan elektron daripada permukaan logam tersebut anda kena]

A. use light of a longer wavelength.

[menggunakan cahaya yang berjarak gelombang lebih panjang]

B. use light of a shorter wavelength.
[menggunakan cahaya yang berjarak gelombang lebih pendek]
C. use light of the same wavelength but increase its intensity.
[menggunakan cahaya yang berjarak gelombang sama tapi menambahkan keamatannya]

D. use light of the same wavelength but decrease its intensity.
[menggunakan cahaya yang berjarak gelombang sama tapi mengurangkan keamatannya]

E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS: B, testgen Physics 2 by Walker, Q35, Walker Chap 30

22. Protons are being accelerated in a particle accelerator at sub-relativistic energies. When the energy of the protons is doubled, their de Broglie wavelength will
[Proton dipecutkan dalam satu pemecut zarah pada tenaga sub-kerelatifan. Bila tenaga proton digandaduakan, jarak gelombang de Broglienya akan]

A. increase by a factor of 2. *[bertambah dengan satu factor 2]*
B. decrease by a factor of 2. *[berkurang dengan satu factor 2]*
C. increase by a factor of $\sqrt{2}$. *[bertambah dengan satu factor $\sqrt{2}$]*
D. decrease by a factor of $\sqrt{2}$. *[berkurang dengan satu factor $\sqrt{2}$]*
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: D, testgen Physics 2 by Walker, Q64, Walker Chap 30

23. A proton and an electron are both accelerated to the same final speed. If λ_p is the de Broglie wavelength of the proton and λ_e is the de Broglie wavelength of the electron, then
[Kedua-dua proton dan elektron dipecutkan kepada laju akhir yang sama. Jika λ_p ialah jarak gelombang de Broglie proton dan λ_e ialah jarak gelombang de Broglie elektron maka]

A. $\lambda_p > \lambda_e$. **B.** $\lambda_p = \lambda_e$. **C.** $\lambda_p < \lambda_e$.
D. Not enough data to answer this question. *[tak cukup data untuk menjawab soalan ini]*
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS: C, testgen Physics 2 by Walker, Q67, Walker Chap 30

24. If the position of an electron is measured very precisely there is an uncertainty in measuring its
[Jika kedudukan suatu elektron diukur dengan sangat tepat maka akan wujud ketidakpastian dalam pengukuran …nya]

A. rest mass. **B.** momentum. **C.** potential energy.
D. charge. **E.** Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: B, testgen Physics 2 by Walker, Q71, Walker Chap 30

25. Which of the following statement(s) is (are) true? *[Manakah kenyataan yang berikut adalah benar?]*

SESSI 04/05/FINAL

I (T) A zero value for the Planck's constant would mean that the laws of classical physics would apply to quantum physics.
[Jika pemalar Planck bernilai sifar ini bermakna hukum-hukum fizik klasik akan teraplikasikan dalam fizik kuantum]

II (T) In quantum tunneling, electrons and other quantum particles can tunnel through a region of space that would be forbidden to them if they were classical particles.
[Dalam penerowongan kuantum, elektron dan zarah-zarah kuantum lain boleh menerowongi satu rantau yang terlarang bagi mereka yang merupakan zarah-zarah klasikal.]

III(F) A large value for the Planck's constant would mean that the laws of classical physics would apply to quantum physics.
[Jika pemalar Planck bernilai besar ini bermakna hukum-hukum fizik klasik akan teraplikasikan dalam fizik kuantum]

A. III **B. II, III** **C. I** **D. I, II**
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
Solution: D
I,II: testgen Physics 2 by Walker, Q72, Walker
II: testgen Physics 2 by Walker, Q73, Walker

26. A major advantage of an electron microscope over a visible light microscope is that the electron microscope
[Manfaat yang major bagi satu mikroskop elektron berbanding dengan mikroskop cahaya nampak ialah bahawa mikroskop elektron]

A. has much greater magnification. *[memberikan pembesaran yang lebih tinggi]*
B. operates with much lower intensity. *[beroperasi pada keataman yang lebih rendah]*
C. can penetrate opaque samples. *[boleh menembusi sampel legap]*
D. can have much better resolution. *[memberikan leraian yang lebih baik]*
E. requires no lenses for its operation. *[tidak memerlukan kanta-kanta dalam operasinya]*

ANS: D, testgen Physics 2 by Young and Freeman , Q27, Chap 39

27. An important observation that led Bohr to formulate his model of the hydrogen atom was the fact that
[Salah satu pencerapan yang merangsangkan Bohr memformulasikan model atom hidrogennya ialah fakta bahawa]

A. a low density gas emitted a series of sharp spectral lines.
[gas berketumpatan rendah memancarkan pinggir-pinggir spectrum yang tajam]

B. neutrons formed a diffraction pattern when scattered from a nickel crystal.
[neutron membentuk corak belauan bila diserakkan daripada hablur nickel]

C. electrons were found to have a wave nature.
[elektron didapti mempunyai sifat gelombang]

D. the peak of the blackbody radiation moved to shorter wavelengths as the temperature was increased.
[puncak jasad hitam bergerak menghampiri jarak gelombang yang lebih pendek bila suhu bertambah]

E. the emission of light by an atom does not appear to conserve energy.
[pancanran cahaya oleh atom tidak mengabadikan tenaga]
ANS: A, testgen Physics 2 by Young and Freeman , Q40, Chap 39

28. The particle nature of light is best illustrated by which of the following?
[Sifat zarah cayaha adalah paling baik diilustrasikan oleh yang mana berikut?]

A. The scattering of alpha particles from gold foil. *[Serakan zarah alfa daripada foil emas]*

B. The fact that hot objects emit electromagnetic radiation.
[Fakta bahawa objek panas memancarkan pancaran elektromagnetik]

C. The diffraction pattern observed when a beam of electrons is scattered by a crystal
[Corak belauan yang dicerap bila satu bim elektron diserakkan oleh satu hablur]

D. The fact that a rainbow consists of a continuous spectrum of colors
[Fakta bahawa pelangi mengandungi satu spektrum warna yang selanjar]

E. The ejection of electrons from a metal surface illuminated by light**.**
[Pelentingan elektron daripada permukaan logam yang disinari cahaya]
ANS: E, testgen Physics 2 by Young and Freeman , Q18, Chap 38

29. A wave function is given by
[Satu fungsi gelombang diberikan oleh]
$\Psi(x) = 0$ for $x < 0$
$\Psi(x) = Ax$ for $0 \leqslant x \leqslant L$
$\Psi(x) = 0$ for $x > L$

The product of the normalization constant A and the quantity $L^{3/2}$ is equal to:
[Hasildarab pemalar normalisasi A dengan kuantiti $L^{3/2}$ bersamaan dengan]

A. $\sqrt{12}$ **B.** $\sqrt{15}$ **C.** $\sqrt{20}$ **D.** $\sqrt{24}$ **E.** $\sqrt{3}$

ANS: E, testgen Physics 2 by Young and Freeman , Q1, Chap 40, modified

30. If a wave function ψ for a particle moving along the x axis is "normalized" then:
[Jika satu funsi gelombang ψ untuk satu zarah yang bergerak sepanjang paksi x adalah ternormalisasikan, maka

A. $\int |\psi|^2 dt = 1$ **B.** $\int |\psi|^2 dx = 1$ **C.** $\partial\psi/\partial x = 1$ **D.** $\partial\psi/\partial t = 1$
E. $|\psi|^2 = 1$

Solution: B, Chap 39, Q1, RHW 7th ed testbank,

SESSI 04/05/FINAL

31. The energy of an electron in a hydrogen atom that is about to get ionised is
[Tenaga elektron dalam atom hidrogen yang hampir-hampir diionkan adalah]

A. -13.6 eV **B.** -3.4 eV **C.** -10.2 eV
D. -1.0 eV **E.** 0 eV

Solution: E, Chap 39, Q26, RHW 7th ed testbank, modified.

32. According to the Bohr model of hydrogen atom, the energy E_n of a hydrogen atom of a state with quantum number n is proportional to:
[Mengikut model hidrogen Bohr tenaga E_n suatu atom hidrogen pada keadaan dengan nombor kuantum n adalah berkadaran dengan]

A. n **B.** n^2 **C.** $1/n$ **D.** $1/n^2$

E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

Solution: D, Chap 39, Q25, RHW 7th ed testbank,

33. The series limit for the Balmer series represents a transition $m \to n$, where (m, n) is
[Limit siri bagi siri Balmer mewakili satu peralihan $m \to n$, di mana (m, n) ialah]

A. (2,1) **B.** (3,2) **C.** $(\infty,0)$ **D.** $(\infty,1)$ **E.** $(\infty,2)$

Solution: E, Chap 39, Q33, RHW 7th ed testbank,

34. The location of a particle is measured and specified as being exactly at $x = 0$, with *zero* uncertainty in the x direction. How does this affect the uncertainty of its velocity component in the y direction?
[Lokasi suatu zarah adalah diukur dan dispesifikasikan sebagai tepat-tapat pada x = 0 dengan ketidakpastian sifar dalam arah x. Bagaimanakah keadaan ini mempengaruhi ketidakpastian komponen halajunya dalam arah y?]

A. It does not affect it. *[Keadaan ini tidak mempengaruhinya]*
B. It makes it infinite. *[Keadaan ini menjadikannya infinit]*
C. It makes it zero. *[Keadaan ini menjadikannya sifar]*
D. It makes it negative *[Keadaan ini menjadikannya negatif]*
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
Ans: A, QQ serway 40.10

35. The Balmer series of hydrogen is important because it:
[Siri Balmer bagi hidrogen adalah penting kerana ia]

A. is the only one for which the Bohr theory can be used
[merupakan satu-satunya siri yang dapat diaplikasikan oleh teori Bohr]

B. is the only series which occurs for hydrogen
[merupakan satu-satunya siri yang berlaku dalam hidrogen]

C. is in the visible region
[berada dalam rantau nampak]

D. involves the lowest possible quantum number *n*
[melibatkan numbor kuantum yang terendah mungkin]

E. involves the highest possible quantum number *n*
[melibatkan numbor kuantum yang tertinggi mungkin]

Solution: C, Chap 39, Q34, RHW 7th ed testbank,

36. The quantization of energy, $E = nhf$, is not important for an ordinary pendulum because:
[Pengkuantuman tenaga, E = nhf, adalah tidak penting bagi suatu bandul kerana]

A. the formula applies only to mass-spring oscillators
[formular hanya teraplikasikan ke atas pengayun jisim-spring]

B. the allowed energy levels are too closely spaced
[selang paras tenaga diizinkan adalah terlalu padat]

C. the allowed energy levels are too widely spaced
[selang paras tenaga diizinkan adalah terlalu lebar]

D. the formula applies only to atoms
[formular hanya teraplikasikan ke atas atom]

E. the value of *h* for a pendulum is too large
[nilai h bagi bandul terlalu besar]
Solution: B, Chap 38, Q3, RHW 7th ed testbank,

37. A hydrogen atom is in its ground state. Incident on the atom are many photons each having an energy of 5 eV. The result is that
[Suatu atom hidrogen berada dalam keadaan buminya. Foton-foton bertenaga 5 eV setiap satu ditujukan pada atom itu. Hasilnya ialah]

A. the atom is excited to a higher allowed state
[atom teruja kepada keadaan dizinkan yang lebih tinggi]

B. the atom is ionized
[atom diionkan]

C. the photons pass by the atom without interaction
[foton merentasi atom tanpa berinteraksi]

D. the photons are ionised

[foton diionkan]

E. the atom is de-excited to a lower quantum state
[atom ternyah-uja kepada keadaan dizinkan yang lebih rendah]
ANS (C), Serway, qq 42.1, pg. 1360. Because the energy of 5 eV does not correspond to raising the atom from the ground state to an allowed excited state, there is no interaction between the photon and the atom (modified)

38. A hydrogen atom makes a transition from the $n = 3$ level to the $n = 2$ level. It then makes a transition from the $n = 2$ level to the $n = 1$ level. Which transition results in emission of the longest-wavelength photon?
[Satu atom hidrogen melakukan peralihan dari paras n=3 ke paras n=2. Kemudiannya ia melakukan satu peralihan dari paras n=2 ke paras n=1. Peralihan yang manakan menghasilkan pancaran foton berjarak gelombang paling panjang?]

A. the first transition *[peralihan pertama]*
B. the second transition *[peralihan kedua]*

C. neither, because the wavelengths are the same for both transitions.
[bukan A ataupun B kerana jarak gelombang kedua-dua kes adalah sama]

D. one cannot determine the answer because data provided is not sufficient.
[jawapan tidak boleh ditentukan kerana data yang diberikan tak cukup]

E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS (A), Serway, qq 42.3, pg. 1360. The longest-wavelength photon is associated with the lowest energy transition, which is $n = 3$ to $n = 2$.

39. An electron and a proton are accelerated to a common relativistic energy (i.e. $E >> m_e c^2, m_p c^2$), where m_e and m_p denote the masses of the electron and proton respectively. Determine the ratio of the de Broglie wavelength of the electron to that of the proton.
[Satu elektron dan proton dipecutkan kepada satu tenaga kerelatifan E yang sama, (iaitu E >>$m_e c^2, m_p c^2$), di mana m_e dan m_p menandakan jisim elektron dan proton masing-masing. Tentukan nisbah jarak gelombang de Broglie elektron kepada proton.]

(A) $\frac{m_p}{m_e}$ (B) $\sqrt{\frac{m_p}{m_e}}$ (C) $\sqrt{\frac{m_e}{m_p}}$ (D) $\frac{m_p}{m_e}$
(E) 1

ANS (E), My own question, pg. 897.

40. How is the empirical Ryberg constant, R_H, be related to the other constants of nature in the Bohr model of hydrogen atom?
[Bagaimanakah pemalar empirikal Ryberg R_H dikaitkan kepada pemalar-pemalar alam yang lain mengikut model Bohr atom hidrogen?]

A. $R_H = \dfrac{2\pi^2 m_e e^4}{h^2 c}\left(\dfrac{1}{4\pi\varepsilon_0}\right)^2$ **B.** $R_H = \dfrac{2\pi^2 m_e e^4}{h^3 c}\left(\dfrac{1}{4\pi\varepsilon_0}\right)^2$

C. $R_H = \dfrac{2\pi^2 m_e e^4}{h^3 c}\left(\dfrac{1}{4\pi\varepsilon_0}\right)$ **D.** $R_H = \dfrac{2\pi^2 m_e e^4}{h^3 c^3}\left(\dfrac{1}{4\pi\varepsilon_0}\right)^2$

(E) Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

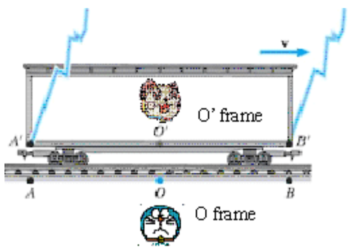
ANS (B), Cutnell and Johnson, pg. 910.

Part B: Structured Questions [60 marks]
Instruction: Answer both questions 1 and 2 in this Part.

[Bahagian B: Soalan Struktur. 60 markah]
[Arahan: Jawab kedua-dua soalan 1 dan 2 dalam Bahagian ini.]

1(a) Consider the Gedanken experiment of a moving train (the O' frame) passing by an observer called Doraemon on the ground (the O frame) with a speed of v, see figure below. The length of the train, as measured by Doraemon, is L. Another observer, Doraemiyan is seen by Doraemon to sit at the middle of the train, $L/2$, when Doraemiyan passes by Doraemon at time t=0. At that instance, two lightning bolts strike points A and B at the edges of the train such that both events appear to occur simultaneously according to Doraemon. What is the time lag between the lights from event A and event B arriving at Doraemiyan, $t_A - t_B$, as seen by Doraemon, where both t's are measured in Doraemon's frame. Express your answer in terms of v, L, and the speed of light c. [*Hint: Do you think you should apply time-dilation or length contraction formulae here?*]
[Pertimbangkan eksperimen Gedanken di mana satu tren (rangka O') bergerak melepasi seorang pemerhati Doraemon yang berada di atas bumi (rangka O) dengan laju v, rujuk gambarajah di bawah. Panjang tren sebagaimana yang diukur oleh Doeaemon ialah L. Seorang lagi pemerhati, Doraemiyan diperhatikan oleh Doraemon sebagai duduk di tengah-tengah tren, L/2, bila Doraemiyan bergerak melepasi Doraemon pada masa t =0. Pada ketika itu, dua petir menyambar titik-titik A dan B pada pinggir tren sedemikian rupa supaya kedua-dua peristiwa itu kelihatan berlaku secara serentak kepada Doraemon. Apakah masa susulan di antara cahaya dari peristiwa A dan peristiwa B yang sampai kepada Doraemiyan, $t_A - t_B$, mengikut Doraemon? Kedua-dua masa t_A, t_B adalah diukur dalam rangka Doraemon. Nyatakan jawapan anda dalam sebutan v, L dan laju cahaya c. [Hint: Adakah anda perlu mengaplikasikan formular-formular pendilatan-masa dan susutan panjang?]

[10 marks]



Solution

By the time t_B, light from event B hits Doramiyan. Since then she has moved for a distance of vt_B to the right from Doramon. Hence, light from B fulfils the relation $ct_B = L/2 - vt_B$.

Likewise, by the time t_A (> t_B) light from A hits Doramiyan. Since then she has moved for a distance of vt_A to the right from Doramon. Hence, light from A fulfils the relation $ct_A = L/2 + vt_A$.

$t_B = L/2(c+v)$; $t_A = L/2(c-v)$
$\Rightarrow t_A - t_B = L/2(c-v) - L/2(c+v) = (uL)/(c^2-v^2)$

[10 marks]

1(b) When a photoelectric surface is illuminated with light of wavelength 437 nm, the stopping potential is 1.67 V.
[Bila satu permukaan fotoelektrik disinari cahaya berjarak gelombang 437 nm, keupayaan penghenti ialah]

[5 + 5 marks]

(*i*) What is the work function of the metal in eV?
[Apakah fungsi kerja logam tersebut dalam unit eV?]

(*ii*) What is the maximum speed of the ejected electrons?
[Apakah laju maksimum elektron terlenting?]

Solution:

(*i*) $W_0 = hc/\lambda - K_{max}$ = 1240 nm.eV/437 nm -1.67 eV = 1.17 eV
(*ii*) $K_{max} = mv^2/2 \Rightarrow v^2 = (2K_{max}/m)^{1/2} = (2 \times 1.67e\text{ J} / 9.11 \times 10^{-31}\text{ kg})^{1/2} = 7.66 \times 10^5$ m/s

ANS: testgen Physics 2 by Young and Freeman , Q2.4, Chap 38

1(c) An electron has a speed of 0.95c. What is the the magnitude of its momentum? **[5 marks]**
[Suatu elektron berlaju 0.95c. Apakah magnitud momentumnya?]

Solution:

$\gamma = 1/\sqrt{1-0.95^2} = 3.20$

$p = m\gamma u = 9.1\times10^{-31}\times3.2\times(0.95\times3\times10^8)\text{Ns}=8.3\times10^{-22}\text{ Ns}$

Chap 37, Q54, RHW 7th ed testbank,

1(d) A 29.0 pm photon is Compton scattered by a stationary electron. What is the maximum energy loss of the photon?
[Satu foton 29.0 pm diserak Compton oleh satu elektron pegun. Apakah kehilangan tenaga foton yang maksimum?]

[5 marks]

Solution:

Maximal kinetic energy loss of the photon occurs when

$$\Delta\lambda = \Delta\lambda_{\max} = 2\lambda_c = \frac{2hc}{m_e c^2} = \frac{2\times(1240\text{keV}\cdot\text{pm})}{522\text{keV}} = 4.75\text{pm}$$

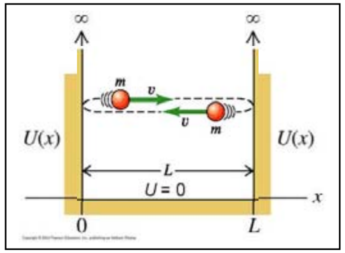
$$\Delta E_{\max} = \frac{hc}{\lambda} - \frac{hc}{\lambda_{\max}} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda + \Delta\lambda_{\max}}\right)$$

$$= (1240\text{keV}\cdot\text{pm})\left(\frac{1}{29\text{pm}} - \frac{1}{29\text{pm} + 4.75\text{pm}}\right) = 6.01\text{ keV}$$

ANS: testgen Physics 2 by Young and Freeman , Q1.12, Chap 38 (Model answer may be incorrect)

2(a) Consider a quantum particle trapped in an infinite quantum well (with width L) given by
[Pertimbangkan satu zarah kuantum yang terperangkap dalam satu telaga kuantum infinit (dengan lebar L) yang diberikan oleh]

$$U(x) = \begin{cases} \infty, & x \le 0, x \ge L \\ 0, & 0 < x < L \end{cases}$$



The behaviour of a particle inside the infinite well [i.e. the region where $U(x) = 0$ for $0 < x < L$] is governed by the 1-D time-independent Schrodinger equation $\frac{\partial^2\psi(x)}{\partial x^2} = -B^2\psi(x)$, where $B^2 = \frac{2mE}{\hbar^2}$. E is the energy of the particle.
[Kelakuan zarah dalam telaga infinit (iaitu dalam rantau $U(x) = 0$ for $0 < x < L$) diperintah oleh persamaan merdeka-masa Schrodinger 1-D $\frac{\partial^2\psi(x)}{\partial x^2} = -B^2\psi(x)$, di mana $B^2 = \frac{2mE}{\hbar^2}$. E ialah tenaga zarah.]

(*i*) Show that $\psi(x) = A\sin Bx + C\cos Bx$ is a solution to the Schrodinger equation for the particle inside the well, where A, C are some constants.
[Tunjukkan bahawa $\psi(x) = A\sin Bx + C\cos Bx$ merupakan penyelesaian kepada persamaan Schrodinger untuk zarah dalam telaga, di mana A dan C adalah pemalar.]

[5 marks]

Solution: Plug $\psi(x) = A\sin Bx + C\cos Bx$ into the LHS of $\frac{\partial^2\psi(x)}{\partial x^2} = -B^2\psi(x)$:

$$\frac{\partial^2\psi(x)}{\partial x^2} = \frac{\partial^2}{\partial x^2}\left[A\sin Bx + C\cos Bx\right] = \frac{\partial}{\partial x}\left[BA\cos Bx - BC\sin Bx\right]$$

$$= -B^2A\sin Bx - B^2C\cos Bx = -B^2\left[A\sin Bx + C\cos Bx\right]$$

$$= -B^2\psi(x) = \text{RHS of the Schroginger equation}$$

(*ii*) Determine the values of C and B by applying boundary conditions that must be fulfilled by the Schrodinger equation governing the particle.
[Tentukan nilai-nilai C dan B dengan mengaplikasikan syarat-syarat sempadan yang mesti dipenuhi oleh persamaan Schrodinger yang memerintah zarah itu.]

[4 + 6 marks]

Solution:

Boundary condition (1)

Plug $\psi(x = 0) = 0$ into $\psi = A\sin Bx + C\cos Bx$, we obtain

$\psi(x=0) = 0 = A\sin 0 + C\cos 0 = C$, ie, $C = 0$

[4 marks]

Hence the solution is reduced to $\psi = A\sin B$

Next we apply the second boundary condition: $\psi(x = L) = 0 = A\sin(BL)$

Only either A or $\sin(BL)$ must be zero but not both; A cannot be zero

This means it must be $\sin BL = 0$, or in other words $B = n\pi/L \equiv B_n$, $n = 1,2,3,\cdots$

[6 marks]

(*iii*) Hence show that the energy of the particle in the infinite well is quantized.
[Seterusnya tunjukkan bahawa tenaga zarah dalam telaga infinit adalah terkuantumkan]

[5 marks]

Solution

$$B_n^2 = \frac{2mE_n}{\hbar^2} = \frac{n^2\pi^2}{L^2} \Rightarrow E_n = \frac{n^2\pi^2\hbar^2}{2mL^2}, n = 1,2,3...$$ **[5 marks]**

2(b) What is the kinetic energy of an electron at the ground state of the hydrogen atom, given that the ground state energy of the hydrogen atom is -13.6 eV? Give your answer in unit of eV.
[Apakah tenaga kinetik elektron pada keadaan bumi atom hidrogen? Diberitahu tenaga bumi atom hidrogen ialah -13.6 eV. Berikan jawapan anda dalam unit eV.]

[10 marks]

Solution: Serway and Moses, Problem 22

From the requirement that the centripetal force comes from the electrostatic force $\frac{mv_0^2}{r_0} = \frac{ke^2}{r_0^2}$,

[1 marks]

the kinetic energy of the ground state electron can be written as $K_0 = \frac{mv_0^2}{2} = \left(\frac{1}{2}\right)\frac{ke^2}{r_0}$.

[2 marks]

Potential energy of the electron at ground state is $U_0 = -\frac{ke^2}{r_0}$.

[1 marks]

Hence ground state energy is $E_0 = K_0 + U_0 = \left(\frac{1}{2}\right)\frac{ke^2}{r_0} - \frac{ke^2}{r_0} = -\frac{ke^2}{2r_0} = -13.6 \text{ eV}$.

[3 marks]

This gives $K_0 = \frac{ke^2}{2r_0} = 13.6 \text{ eV}$

[3 marks]

UNIVERSITI SAINS MALAYSIA

KSCP
Academic Session 2004/2005
APRIL 2005

ZCT 104E/3 - Physics IV (Modern Physics)
[Fizik IV (Fizik Moden)]

Duration: 3 hours
[Masa: 3 jam]

Please check that the examination paper consists of **XXX** pages of printed material before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **XXX** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]*

Instruction: Answer all questions. Please answer the objective questions from Part A in the objective answer sheet provided. Answer ALL structured questions from Part B. Please submit the objective answer sheet and the answers to the structured questions separately.

Students are allowed to answer all questions in Bahasa Malaysia or in English.

*[**Arahan**: Jawab **SEMUA** soalan. Sila jawab soalan-soalan objektif daripada bahagian A dalam kertas jawapan objektif yang dibekalkan. Jawab kesemua soalan struktur daripada Bahagian B. Hantar kertas jawapan objektif dan jawapan kepada soalan struktur berasingan.]*

[Pelajar dibenarkan untuk menjawab samada dalam bahasa Malaysia atau bahasa Inggeris.]

Data
speed of light in free space, $c = 3.00 \times 10^8$ m s^{-1}
permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
elementary charge, $e = 1.60 \times 10^{-19}$ C
Planck constant, $h = 6.63 \times 10^{-34}$ J s
unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg
molar gas constant, = 8.31 J K^{-1} mol^{-1}
Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}
gravitational constant, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
acceleration of free fall, $g = 9.81$ m s^{-2}

Part A: Objective 25 marks
Instruction: Answer all 25 objective questions in this Part.
[Bahagian A: Objektif.]
[Arahan: Jawab kesemua 25 soalan objektif dalam Bahagian ini.]

ANS: A, Young and Freeman study guide, pg 271

1. A massive particle has a speed of 0.95c. Can its energy and speed be increased by more than 500%?
[Laju suatu zarah yang berjisim ialah 0.95c. Bolehkah tenaga dan lajunya bertambah sebanyak 500%?]

A. The energy can but not the speed
B. The speed can but not the energy
C. Both the energy and speed can be increased by this amount
D. Both the energy and speed cannot be increased by this amount
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: A, Modified from Young and Freeman study guide, pg 271

2. Consider a photon travelling in vacuum. Can its energy and speed be increased by more than 500%?
[Pertimbangkan suatu foton yang bergerak di dalam vakuum. Bolehkah tenaga dan lajunya bertambah sebanyak 500%?]
A. The energy can but not the speed
B. The speed can but not the energy
C. Both the energy and speed can be increased by this amount
D. Both the energy and speed cannot be increased by this amount
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: B, Modified from Young and Freeman study guide, pg 271, Example 1

3. Constancy of the speed of light in all inertial reference systems implies that
[Kemantapan laju cahaya dalam semua rangka rujukan inersia mengimplikasikan]
A $x^2 + y^2 + z^2 + c^2t^2 = x'^2 + y'^2 + z'^2 + c^2t'^2$
B. $x^2 + y^2 + z^2 - c^2t^2 = x'^2 + y'^2 + z'^2 - c^2t'^2$
C. $x + y + z - ct = x' + y' + z' - ct'$
D. $x + y + z + ct = x' + y' + z' + ct'$
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: C, Modified from Young and Freeman study guide, pg 280, Example 9

4. If a neutron spontaneously decays into a proton, an electron and a neutrino (which is massless), the decay products are observed to have a total kinetic energy of E_k. If the proton mass is M_P and the electron mass is m_e how large is the neutron mass?
[Jika suatu neutron mereput kepada satu proton, satu elektron dan satu neutrino (yang tak berjisim) secara spontan, jumlah tenaga kinetik hasil reputannya dicerap sebagai E_k. Jika jisim proton ialah M_P dan jisim elektron ialah m_e apakah jisim neutron?]
A. $(M_P + m_e) - \frac{E_k}{c^2}$ B. $\frac{E_k}{c^2} - (M_P + m_e)$ **C.** $M_P + m_e + \frac{E_k}{c^2}$
D. $\sqrt{(M_P + m_e)^2 + \left(\frac{E_k}{c^2}\right)^2}$ **E.** Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: B, Cutnell, page 1271, QQ 39.10

5. The following pairs of energies represent the rest energy and total energy of three different particles: particle 1: E, 2E; particle 2: E, 3E; particle 3: 2E, 4E. Rank the particles according to their speed.
[Pasangan tenaga berikut mewakili tenaga rehat dan jumlah tenaga bagi tiga zarah yang berbeza: zarah 1: E, 2E; zarah 2: E, 3E; zarah 3: 2E, 4E. Aturkan zarah-zarah tersebut mengikut laju mereka.]
A. $v_3 > v_2 = v_1$ **B.** $v_2 > v_3 = v_1$ **C.** $v_1 > v_2 = v_3$
D. $v_3 > v_2 > v_1$ **E.** Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: A, Modified from Walker Test Item, pg 629, Q28

6. Observer A sees a pendulum oscillating back and forth in a relativistic train and measures its period to be T_A. Observer B moves together with the train and measures the period of the pendulum to be T_B. These two results will be such that
[Tempoh suatu bandul yang mengayun berulang-alik di dalam suatu keretapi kerelatifan diukur sebagai T_A oleh pemerhati A. Manakala pemerhati B yang gerak bersama dengan keretapi tersebut mengukur tempoh bandul tersebut sebagai T_B. Keputusan pengukuran tempoh-tempoh tersebut adalah]

A. $T_A > T_B$ **B.** $T_A = T_B$ **C.** $T_A < T_B$
D. T_A could be greater or smaller than T_B depending on the direction of the motion
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: D, Walker Test Item, pg 642, Q1,Q2,Q4, Tutorial 2 Problems 1.

7. Which of the following statements are (is) correct? *[Pilih kenyataan(-kenyataan) yang benar daripada yang berikut]*

I(T) An ideal blackbody absorbs all of the light that is incident on it. *[Jasad hitam yang ideal menyerap kesemua cahaya yang jatuh ke atasnya]*
II(T) The distribution of energy in the blackbody radiation does not depends upon the material from which the blackbody is constructed. *[Taburan tenaga dalam pancaran jasad hitam tidak bergantung kepada jenis bahan yang membentuk jasad hitam itu.]*
III(F) The correct expression for the energy of a photon is $E = h\lambda$ *[Ekspresi yang betul bagi tenaga suatu foton ialah $E = h\lambda$]*
IV(T) For a blackbody, the total intensity of energy radiated over all wavelengths increases as the forth power of the temperature. *[Bagi satu jasad hitam, keamatan tenaga yang dipancarkan bila sumbangan kesemua jarak gelombang dijumlahkan bertambah mengikut kuasa empat suhunya.]*

A. I,II,III **B. I,II** **C. II, III, IV** **D. I,II,IV**
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: E, Young and Freeman study guide, page 286, Question

8. Which of the following statements are (is) correct?
[Pilih kenyataan(-kenyataan) yang benar daripada yang berikut]

I(T) In the Compton Effect, there is a zero wavelength shift for forward scattering ($\theta = 0°$) *[Dalam kesan Compton, anjakan jarak gelombang sifar berlaku dalam serakan ke depan ($\theta = 0°$)]*

II (T) In the Compton Effect, no energy or momentum is transferred to the electron in the forward scattering. *[Dalam kesan Compton, tiada tenaga atau momentum dipindahkan kepada elektron dalam serakan ke depan.]*

III(T) In the Compton Effect, conservation of momentum and energy must be simultaneously satisfied. *[Dalam kesan Compton, keabadian tenaga dan momentum mesti dipatuhi secara serentak.]*

IV(T) In the Compton Effect, energy and momentum are transferred to the scattered electron when θ is non zero. *[Dalam kesan Compton, tenaga dan momentum dipindahkan kepada elektron terserakkan jika sudut θ bukan sifar.]*

A. I,II,III **B. I,II** **C. II, III, IV** **D. I,II,IV**
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: B, Walker Test Item, page 646, Q25, own suggested options

9. Which of the following statements are (is) correct?
[Pilih kenyataan(-kenyataan) yang benar daripada yang berikut]

I(F) A photon is a particle with positive charge *[Foton adalah zarah yang bercas positif]*
II (F) A photon's mass is not necessarily zero *[Jisim foton tidak semestinya sifar]*
III(F) Photon always move with a speed of c irrespective of the medium through which it is moving *[Tidak kisah medium apa yang dilaluinya, foton sentiasa bergerak dengan laju c]*
IV(T) The number of photons per unit cross sectional area in a beam of light is proportional to the intensity of the light beam. *[Nombor foton per unit keratan rentas dalam satu alur cahaya adalah berkadaran dengan keamatan alur cahaya itu.]*

A. I,II,III **B. IV** **C. II, III, IV** **D. I,II,IV**
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: A, Walker Test Item, page 648, Q30

10. In photoelectric effect, which one of the following is the correct expression for the cut-off frequency of the metal in terms of its work function, W_0?
[Dalam kesan fotoelektric, kenyataan yang mana satukah adalah ekspresi yang betul yang menyatakan frekuensi penggal sesuatu logam dalam sebutan fungsi kerjanya?]

A. W_0 / h **B.** W_0 / c **C.** h / W_0 **D.** $(h/c)W_0$
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

SESSI 04/05/KSCP

ANS: B, Cutnel, page 889, CYU 2

11. In Compton effect, an incident X-ray photon of wavelength λ is scattered by an electron, the scattered photon having a wavelength of λ'**.** Suppose that the incident photon is scattered by a proton instead of an electron. For a given scattering angle θ, the change $\lambda' - \lambda$ in the wavelength of the photon scattered by the proton
[Dalam kesan Compton, suatu foton sinar-X tuju dengan jarak gelombangλ diserakkan oleh suatu elektron manakala jarak gelombang bagi foton terserak ialah λ'. Katakan foton tuju diserakkan oleh suatu proton yang manggantikan elektron. Untuk suatu sudut serakan θ yang diberikan, perubahan $\lambda' - \lambda$ dalam jarak gelombang foton terserak oleh proton adalah]

A. is greater than that scattered by the electron
B. is less than that scattered by the electron
C. is same as that scattered by the electron
D. cannot be determined
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: A, Own question

12. In an electron-positron pair production by an energetic photon in the vicinity of a nucleus, the frequency of the photon λ must be
[Dalam penghasilan pasangan elektron-positron oleh suatu foton bertenaga tinggi di persekitaran suatu nucleus, frekuensi foton λ semestinya]

A. $\lambda \le h/2m_e c$ **B.** $\lambda \ge h/2m_e c$ **C.** $\lambda \le h/m_e c$ **D.** $\lambda \ge h/m_e c$
E. $\lambda \le h/2m_e$

13. ANS C: Young and Freeman test bank, pg. 414, Q14

In an important experiment in 1927 a beam of electrons was scattered off a crystal of nickel. The intensity of the scattered beam varied with the angles of scattering, and analysis of these results lead to confirmation of
[Dalam suatu eksperimen yang dilakukan dalam tahun 1927, suatu alur elektron diserakkan oleh suatu hablur nikel. Keamatan alur yang terserak berubah-ubah mengikut sudut ia diserakkan, dan analisis keputusan itu membawa kepada pengesahan]

A. the particle nature of light
B. the Bohr model of atom
C. the wave nature of electrons
D. the Rutherford model of the nucleus
E. the quantisation of energy levels

ANS A: Young and Freeman test bank, pg. 425, Q2

14. Consider a particle in a box of width L and infinite height. Let the particle be in a state $n = 11$. What is the first value of x ($0 \le x \le L$), where the probability of finding the particle is highest?
[Pertimbangkan suatu zarah dalam kotak dengan lebarL dan ketinggian infini. Biar ia berada dalam keadaan n = 11. Apakah nilai x ($0 \le x \le L$) yang pertama di mana keberangkalian menjumpai zarah terserbut adalah paling tinggi?]

A. $L/22$ **B.** $L/11$ **C.** L **D.** $L/10$
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS B: Walker test item, pg. 654, Q65

15. Protons are being accelerated in a particle accelerator. When the speed of the proton is doubled, their de Broglie wavelength will
[Proton sedang dipecutkan oleh pemecut zarah. Bila laju proton digandakan dua kali, jarak gelombang de Broglie mereka akan]

A. increase by a factor of 2
B. decrease by a factor of 2
C. increase by a factor of $\sqrt{2}$
D. decrease by a factor of $\sqrt{2}$
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS B: Walker student guide, pg. 506, quiz 9

16. If the minimum uncertainty in an object's position is decreased by half, what can we say about the uncertainty in its momentum?
[Jika ketidakpastian minimum bagi kedudukan suatu objek dikurangkan separuh, apa yang boleh dikatakan ke atas ketidakpastian dalam momentumnya?]

A. The uncertainty in momentum is at most half of what it was before the change
B. The uncertainty in momentum is at least twice what it was before the change
C. The uncertainty in momentum does not change
D. The minimum uncertainty in momentum is precisely half of what it was before the change
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS A: Walker student guide, pg. 657, Q6

17. To which of the following values of *n* does the longest wavelength in the Balmer series correspond?
[Nilai n yang manakah bersepadanan dengan jarak gelombang paling panjang dalam siri Balmer?]

A. 3 **B.** 5 **C.** 1 **D.** infiniti
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS D: Young and Freeman test bank, pg. 418, Q36

18. In order for an atom to emit light, it
[Untuk memancarkan cahaya, sesuatu atom kena]

A. must be in the gaseous state *[berada dalam keadaan gas]*
B. must be stimulated by external radiation *[dirangsang oleh pancaran luar]*
C. must be in the ground state *[berada dalam keadaan bumi]*
D. must be in an excited state *[berada dalam keadaan teruja]*
E. must be fluorescent *[berpendarfluor]*

ANS C: Young and Freeman test bank, pg. 660, Q18,19,20

19. Which of the following statements are (is) correct?
[Pilih kenyataan(-kenyataan) yang benar daripada yang berikut]

SESSI 04/05/KSCP

A. Einstein proposed the model of the atomic structure that provides the best explanation of the observation that each atom in the periodic table has a unique sets of spectral lines.
[Einstein menyarankan model struktur atom yang membekalkan penjelasan paling baik ke atas pencerapan hahawa setiap atom di dalam jadual berkala mempunyai satu set garisan spektrum yang unik.]
B. According to one of the assumptions of the Bohr model, the electron in a hydrogen atom moves in an elliptical orbit about the nucleus
[Menurut salah satu anggapan model Bohr, elektron di dalam atom hidrogen berkisar di dalam orbit elips yang mengelilingi nucleus.]
C. Bohr's model of an atom includes idea from both classical and quantum physics.
[Model atom Bohr mengandungi idea-idea daripada kedua-dua bidang fizik klasik dan fizik kuantum.]
D. The plum-pudding model of atom by Thomson was verified by Rutherford's alpha scattering experiment
[Model atom 'plum-pudding' oleh Thomson telah diverifikasikan oleh eksperimen penyerakan alfa Rutherford.]
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS A: Serway. 1333, Quiz 41.5

20. Consider an electron, a proton and an alpha particle each trapped separately in identical infinite square wells. Which particle corresponds to the highest ground-state energy?
[Pertimbangkan suatu elektron, suatu proton dan suatu zarah alfa yang masing-masing diperangkapkan secara berasingan di dalam telaga segiempat infinit yang identikal. Zarah yang manakan bersepadanan dengan paras tenaga bumi yang paling tinggi?]

A. the electron **B.** the proton **C.** the alpha particle
D. The ground state energy is the same in all three cases
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS D: Serway. 1333, Quiz 41.6

21. Consider the three particles in Question 20 again. Which particle has the longest wavelength when the system is in the ground state?
[Pertimbangkan semula zarah-zarah dalam Soalan 20. Zarah yang manakan mempunyai jarak gelombang yang paling panjang bila sistem berada dalam keadaan bumi?]
A. the electron **B.** the proton **C.** the alpha particle
D. All three particles have the same wavelength
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS D: Young and Freeman test bank, pg. 663, Q22,34,40,44

22. Which of the following statements are (is) correct?
[Pilih kenyataan(-kenyataan) yang benar daripada yang berikut]
A. The kinetic energy of the electron in the first Bohr orbit of hydrogen is -13.6 eV.
[Tenaga kinetik elektron dalam orbit Bohr pertama ialah -13.6 eV]
B. The electron in a doubly ionised lithium atom experiences a weaker attractive force than the single electron in a hydrogen atom.
[Elektron dalam atom lithium yang dua kali terionkan mengalami daya tarikan yang lebih lemah berbanding dengan elektron tunggal dalam atom hidrogen]
C. In a hydrogen atom, the difference in the energy between adjacent orbit radii increases with the increasing value of *n*

[Dalam atom hidrogen, perbezaan tenaga di antara dua radius orbit yang berjiranan bertambah bila nilai n bertambah]

D. The Bohr model correctly predicts the energy for the ground state of the hydrogen atom.
[Model Bohr meramal dengan tepatnya tenaga keadaan bumi atom hidrogen]

E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS B: Walker test item, pg. 664, Q36

23. Hydrogen atoms can emit four lines with visible colours from red to violet. These four visible lines emitted by hydrogen atoms are produced by electrons
[Atom hidrogen boleh memancarkan empat garis warna nampak daripada merah ke ungu. Empat garis nampak yang dipancarkan oleh atom hidrogen ini adalah dihasilkan oleh elektron]

A. that starts in the $n = 2$ level.
B. that end up in the $n = 2$ level.
C. that end up in the ground state.
D. that start in the ground state.
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS D: Cutnel page 911

24. An electron in the hydrogen atom is in the $n = 4$ energy level. When this electron makes a transition to a lower level, the wavelength of the photon emitted is in the
[Suatu elektron dalam atom hidrogen berada dalam paras n = 4. Bila elektron tersebut melakukan peralihan kepada paras tenaga yang lebih rendah, jarak gelombang foton yang terpancarkan berada dalam]

I. the Lyman series   **II.** the Blamer siries
III. the Pashech series   **IV.** the Pfund series

A. I   **B. II**   **C. III**   **D. I,II,III**
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS A: Cutnel page 934, Q 7

25. What is the longest radiation wavelength that can be used to ionized the ground-state hydrogen atom?
[Apakah jarak gelombang pancaran yang paling panjang yang boleh digunakan untuk mengiokan atom hidrogen pada keadaan bumi?]

A. $hc/(13.6\text{ eV})$
B. $2hc/(13.6\text{ eV})$
C. $13.6\ hc$
D. $(13.6\text{ eV})/hc$
E. Non of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

Part B: Structured Questions [75 marks]
Instruction: Answer ALL questions in this Part.
[Bahagian B: Soalan Struktur. 75 markah]
[Arahan: Jawab KESEMUA soalan dalam Bahagian ini.]

1. **(a)** Based on the physics constants data sheet provided (first page), calculate the ratio of the mass of proton to that of the electron.
[Berdasarkan lampiran data (dalam m/s pertama) pemalar-pemalar fizik yang dibekalkan, hitungkan nisbah antara jisim proton kepada jisim elektron.]

[5 marks]

Solution: $\dfrac{M_P}{m_e} = \dfrac{1.67\times10^{-27}}{9.11\times10^{-31}} = 1833.2$

(b) Calculate the kinetic energy of the electrons in a beam, in units of electron rest energy m_ec^2, such that the relativistic mass of the electrons in the beam is as large is that of the proton.
[Hitungkan tenaga kinetik bagi elektron-elektron dalam satu alur elektron, dalam unit tenaga rehat elektron m_ec^2, sedemikian rupa supaya jisim kerelatifan elektron dalam alur tersebut bersamaan dengan jisim proton.)

[5 marks]

Solution: Young and Freeman study guide, pg 281, Quiz 2,3

$$E = m'_e c^2 = m_e c^2 + K$$
$$\text{set } m'_e c^2 = M_P c^2 = (1833.2)m_e c^2$$
$$\Rightarrow K = (1833.2-1)m_e c^2 = (1832.2)m_e c^2$$

(c) What is the electric potential (in unit of Volt) that is required to accelerate the electron in (b) (from rest) ?
[Apakah beza keupayaan elektrik (dalam unit Volt) yang diperlukan untuk memecutkan elektron dalam (b) di atas (dari keadaan rehat)?]

[5 marks]

Solution: Young and Freeman study guide, pg 281, Quiz 2,3
$$eV = K = (1832.2)m_e c^2 \Rightarrow V = (1832.2)m_e c^2/e = 938.9\text{ MV}$$

(d) If a 'moving clock' runs slower, what will the age difference between two twins if one stays on the Earth while the second makes a round trip to a point in space ten light years from Earth at a speed of $0.95c$?
[Jika masa bagi 'jam yang bergerak' mengalir lebih perlahan', apakah perbezaaan umur di antara dua orang anak kembar jika salah satu daripada mereka tinggal di Bumi manakala yang seorang lagi menjalani satu penggembaraan dengan laju 0.95c ke satu tempat sejauh 10 tahun-cahaya daripada Bumi dan kembali ke Bumi selepas penjelajahan tersebut?]

[10 marks]

Solution: Young and Freeman study guide, pg 278, Example 7

$$\gamma = \frac{1}{\sqrt{1-(0.95)^2}} = 3.2$$

Time taken for the round trip, according to the twin on Earth, is

$T_E = D/v = 20\ c\cdot\text{yr}/0.95c = 21.05$ yr.

Time taken for the round trip, according to the twin on ship, is
$T_S = D'/v = D/(\gamma v) = 20\ c\cdot\text{yr}/(3.2\cdot 0.95c) = 6.58$ yr, where $D' = 20$ ly/γ due to length contraction.

$\Rightarrow T_E - T_S = (21.05 - 6.58)$ yr $= 14.47$ yr

2. **(a)** A 60-W bulb is at an efficiency of 6.20%. What is the number of photons per second given off by the bulb assuming the wavelength of light to be 580 nm?

[6 marks]

Solution: Walker Test Item, page 642, Q5:

$0.062\times 60\text{Watt}=2.325\times 10^{19}\text{eV/s}$

energy of 1 photon$=\dfrac{hc}{\lambda}=\dfrac{1240}{580}\text{eV}=2.13\text{eV}$

Let number of photon per second = N

therefore $N\dfrac{hc}{\lambda}=2.325\times 10^{19}\text{eV/s}$

$N=\dfrac{2.325\times 10^{19}\text{eV/s}}{2.13\text{eV}}=1.09\times 10^{19}/\text{s}$

(b) The work functions of several metals are listed below.

Metal	ϕ (in eV)
W	4.5
Ag	4.8
Cs	1.8
Cs on W	1.36

(*i*) Which metals yield photoelectrons when bombarded with light of wavelength 500 nm?
(*ii*) For those surfaces where photoemission occurs with the above light source, calculate the stopping potential in volts.
(*iii*) For the metal tungsten calculate the threshold wavelength which would just start producing photoelectrons.

[3 + (2+2) + 2 = 9 marks]

Solution: Young and Freeman study guide, pg 287, Example 2

(*i*) $E = hf = hc/\lambda = 2.48$ eV; Cs and Cs on W yields photoelectrons
(*ii*) For Cs: stopping potential is $(2.48\text{ eV} - 1.8\text{ eV})/e = 0.68$ V
For Cs on W: stopping potential is $(2.48\text{ eV} - 1.36\text{ eV})/e = 1.12$ V
(*iii*) $\lambda_t = hc/\phi = 1240$ eV·nm / 4.5 eV = 276 nm

(c) A large number if 30.0 pm photons are scattered twice by stationary electrons. Find the **RANGE** of wavelength of the scattered photon in pm.
[Sejumlah besar foton-foton yang berjarak gelombang 30.0 pm diserakkan dua kali oleh satu elektron rehat. Hitungkan julat bagi jarak gelombang foton yang terserakkan dalam unit pm.]

[10 marks]

Solution: Young and Freeman test bank, pg 409, Q14:

When bombarded once, the maximal increase in the photon wavelength is given by $\Delta\lambda_{\max}=\dfrac{2h}{m_e c}=2\times 2.43\text{pm}=4.86\text{pm}$ when the scattering angle $\theta = 180°$. When the once-scattered photon is scattered again, the maximum shift in wavelength suffered by that photon is also $\Delta\lambda_{\max}$, making the maximal total shift in wavelength = $2\,\Delta\lambda_{\max}$ = 2 x 4.86 pm = 9.72 pm. Hence the range of scattered photon lies between λ_0 to $\lambda_0 + 2\,\Delta\lambda_{\max}$, i.e. 30.0 pm – 39.72 pm.

3. **(a)** Find the frequency of revolution of electron in $n = 1$ and $n = 2$ Bohr orbits. What is the frequency of the photon emitted when an electron in the $n = 2$ orbit drops to $n = 1$ orbit?
[Hitungkan frekuensi kisaran bagi elektron dalam orbit-orbit Bohr n = 1 dan n = 2. Apakah frekuensi foton yang dipancarkan bila suatu elektron dalam orbit n=2 jatuh ke orbit n = 1?]

[3 + 2 + 2 + 3 marks]

Solution: Bieser, pg 137/tutorial 5

From Bohr's postulate of quantisation of angular momentum, $L = (mv)r = nh/2\pi$, the velocity is related to the radius as $v = nh/2mr\pi$. Furthermore, the quantised radius is given in terms of Bohr's radius as $r_n = n^2 r_0$. Hence, $v = h/2\pi mnr_0$. The frequency of revolution $f = 1/T$ (where T is the period of revolution) can be obtained from $v = 2\pi r/T = 2\pi n^2 r_0\, f$. Hence, $f = v/2\pi r = (h/2\pi mnr_0)/2\pi r = h/4\pi^2 mn^3 (r_0)^2$.

For $n = 1$, $f_1 = h/4\pi^2 m(r_0)^2 = 6.56\times 10^{15}$ Hz.
For $n = 2$, $f_2 = h/4\pi^2 m(2)^3(r_0)^2 = 6.56\times 10^{15}/8$ Hz $= 8.2\times 10^{14}$.

Photon's frequency = $\Delta E/h = 13.6\,(1/1^2 - 1/2^2)$ eV / h = 2.46 x 0^{15} Hz

(b) Consider the case of 'particle in a box' (infinite square well). The lowest energy level of a particle (call it particle A) confined to a 1-D region of space with fixed dimension L is E_0. If an identical particle (call it particle B) is confined to a similar region with fixed distance $L/4$, what is the energy of the lowest energy level of the particle B? Express your answer in terms of E_0.
[Pertimbangkan kes 'zarah di dalam kotak' (telaga segiempat infinit). Tenaga paling rendah bagi satu zarah (label ia zarah A) terkongkong di dalam satu ruang 1-D dengan dimensi L yang tetap ialah E_0. Jika suatu zarah lain (zarah B) yang identical dengan zarah A dikongkongkan di dalam satu ruang yang serupa tapi dengan jarak tetap L/4, apakah tenaga bagi paras tenaga yang terendah bagi zarah B? Nyatakan jawapan anda dalam sebutan E .]

[5 marks]

Solution: Young and Freeman test bank, pg 425, Short Questions 1: $16E_0$

$$E_0=\frac{h^2}{8mL^2}$$

$$E'_0=\frac{h^2}{8mL'^2}=\frac{h^2}{8m(L/4)^2}=16\frac{h^2}{8mL^2}=16E_0$$

(c) Estimate the kinetic energy (in eV) should electrons have if they are to be diffracted from crystal with interatomic distance of the order of a few Å .

[Anggarkan tenaga kinetik (dalam unit eV) yang harus diperolehi oleh elektron-elektron jika mereka hendak dibelaukan oleh hablur yang berjarak antara-atom dalam tertib beberapa Å]

[5 marks]

Solution
Serway, Mosses and Mayer, page 150, Example 4.3

For diffraction to happen, we require $\lambda \sim$ interactomic distance $\sim$ a few Å

$$p = \frac{hc}{\lambda c} \sim \frac{1240\text{eV}\cdot\text{nm}}{\text{few}\left(0.1\text{nm}\right)\times c} = \frac{0.01124\text{MeV}}{\text{few}\times c}$$

$$\Rightarrow K = \frac{p^2}{2m_e} \sim \left(\frac{0.0124\text{MeV}/c}{\text{few}}\right)^2 \frac{1}{2\times 0.5\text{MeV}/c^2} = \frac{1.5\times 10^{-4}}{\text{few}^2}\text{MeV}$$

(d) What is the frequency of the de Broglie waves associated with a body of rest mass m_0 moving with velocity v?
[Apakah frekuensi bagi gelombang de Broglie yang dikaitkan dengan jasad yang jisim rehatnya m_0 dan bergerak dengan laju v?]

[5 marks]

Solution: Arthur Beiser 5th edition, page 99

$$E = hf = mc^2 = \gamma m_0 c^2 = \frac{m_0 c^2}{\sqrt{1-\frac{v^2}{c^2}}} \Rightarrow f = \frac{m_0 c^2}{h\sqrt{1-\frac{v^2}{c^2}}}$$

ZCT 104/3E Modern Physics
Semester II, Sessi 2005/06
Test I (20 Dec 2006)

Data
Speed of light in free space, $c = 3.00 \times 10^{8}$ ms^{-1}
Elementary charge, $e = 1.60 \times 10^{-19}$ C
The Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg

1. Say you put two clocks (clock A and clock B) in front of you and set them to 00.00am at standard local time. Then you ask your friend to send one of them (clock B) to ET's home some 300 million meters away. At one fine day, you decide to compare the reading of both clocks. The reading of clock A (which lies in front of you) reads 12.00 pm. Let say you can view clock B (now located at 300 million meters away) through a telescope. Which statement is correct about the reading of clock B as seen by you when peeking though the telescope?

    A. The reading of clock B seen though the telescope is the same as the reading of clock A.
    B. The reading of clock B seen though the telescope is different from the reading of clock A.
    C. No conclusive statement can be made for the relation between the reading of clock B and clock A
    D. (None of **A**, **B**, **C**)

    ANS:B, My own questions

2. Your friend is running at a speed of v towards you. He throws out a ball towards you, and the speed of the ball is u with respect to him. What is the speed of the ball measured by you?

    A. $u + v$
    B. $u - v$
    C. $v - u$
    D. (None of **A**, **B**, **C**)
    ANS:A, My own questions

3. Reconsider question 2 above. Your friend is running at a speed of v towards you. He shines a beam of light towards you. The speed of the light is c with respect to him. What is the speed of the light as measured by you?

    A. $c + v$
    B. $c - v$
    C. c
    D. (None of **A**, **B**, **C**)
    ANS:C, My own questions

4. While standing beside a railroad track, we are startled by a boxcar traveling past us at half the speed of light. A passenger standing at the rear of the boxcar fires a laser pulse toward the front of the boxcar. The pulse is absorbed at the front of the box car. While standing beside the track we measure the speed of the pulse through the open side door. The measured value of the time of flight of the pulse is _________ than that measured by the rider.
    A. greater than
    B. equal to
    C. less than
    D. (None of **A**, **B**, **C**)
    ANS:A, My own questions

5. Given two events, A and B, of which space and time coordinate are respectively designated by (x_A, t_A) and (x_B, t_B). Which of the following statements are (is) correct?

    I. Both events must be causally related
    II. Both events must not be causally related
    III. Both events may be causally related
    IV. Both events may be causally unrelated
    A. I, II
    B. III, IV
    C. I, II, III, IV
    D. (None of **A**, **B**, **C**)
    ANS: B

6. Given a species of fly has an average lifespan of τ. Let say you put 1000 of them in box A and send them to a destination at some remote destination in deep space using a rocket that travel at speed v. The destination is located at a distance of L from Earth. Considering only special relativistic effect and assuming that None of the flies die of any cause other than aging, which of the following statements is (are) correct? (Lorentz factor is defined as $\gamma = [1-(v/c)^2]^{-1/2}$).

    I. Most of the flies would have not survived if the location of the destination $L/v > \tau$
    II. Most of the flies would survive if $(L/v) < \tau$
    III. Most of the flies would survive if $(1/\gamma)(L/v) < \tau$
    IV. Most of the flies would have not survived if $(1/\gamma)(L/v) > \tau$
    A. I , IV
    B. II, III, IV
    C. III, IV
    D. (None of **A**, **B**, **C**)
    ANS: B

7. Say Azmi is travelling in a mini bus moving with speed v (with respect to Earth) and Baba is sitting in Pelita Nasi Kandar restaurant. Using his own wristwatch, Azmi finds that his heart beats at a rate of N_A times per min. When Baba measures the heartbeat rate of Azmi in the Pelita frame, he found that Azmi's heart is beating at a rate of N_B times a min. What is the relation between the two reading, N_A and N_B?

    A. $N_A > N_B$
    B. $N_A < N_B$
    C. $N_A = N_B$
    D. (None of **A**, **B**, **C**)
    ANS: A

8. Consider a football, kicked lightly by David Beckham, is moving in a straight line with constant speed. Say in frame O, the momentum of the football is P. In a frame O′ moving with a relative constant speed with respect to O, the momentum of football is P'. Which of the following statements are (is) true regarding P and P'?

    I. Classically, P and P' have a same numerical value.
    II. Relativistically, P and P' have a same numerical value.
    III. Classically, P and P' have a different numerical value.
    IV. Relativistically, P and P' have a different numerical value.
    A. I , II
    B. III, IV
    C. I, II, III, IV
    D. (None of **A**, **B**, **C**)
    ANS: B

9. In a given reference frame, O, the velocity of an object (which rest mass is m_0) is v_1. The velocity of the same object in another frame, O', which moves with a relative velocity u with respect to O, is v_2. What is the momentum of the object in these frames? (In the following, $\gamma(v) = 1/\sqrt{1-(v/c)^2}$).
   A. The momentum of the object in frame O is $m_0\gamma(v_1)v_1$ whereas in frame O' the momentum is $m_0\gamma(v_2)v_2$
   B. The momentum of the object in frame O' is $m_0\gamma(v_1)v_1$ whereas in frame O the momentum is $m_0\gamma(v_2)v_2$
   C. The momentum of the object in both frames is $m_0\gamma(u)u$.
   D. (None of **A**, **B**, **C**)

ANS: A

10. Which of the following statement is true regarding the linear momentum of an object?
   A. In general the relativistic momentum is larger in magnitude than the corresponding classical momentum.
   B. In general the relativistic momentum is smaller in magnitude than the corresponding classical momentum.
   C. In general classical momentum and relativistic momentum has the same magnitude.
   D. (None of **A**, **B**, **C**)

ANS: A

11. Which of the following statements is (are) true regarding the kinetic energy of an object?

   I. The kinetic energy of an object can increase indefinitely
   II. In special relativity, the kinetic energy of an object = the increase in the total relativistic energy of the object due to its motion
   III. The relativistic kinetic energy reduces to the non-relativistic form of $mv^2/2$ when $v \ll c$
   IV. The largest possible kinetic energy of an object is $mc^2/2$.

   A. I , IV
   B. II, III, IV
   C. I , II, III
   D. (None of **A**, **B**, **C**)

ANS: C

12. Which statements in the following is (are) true?
   I. Observer in different inertial frames can disagree about the speed of light in free space
   II. Observer in different inertial frames can disagree about the location of an event
   III. Observer in different inertial frames can disagree about the time separating two events
   IV. Proper time is the amount of time separating two events that occurs at the same location

   A. II, III, IV
   B. II, III
   C. I, II, III, IV
   D. (None of **A**, **B**, **C**)

ANS: A

13. Which statements in the following is (are) true?
   I. The rest energy as predicted by special relativity has no analogue in classical mechanics
   II. Work done by a force on a system is converted into mechanical energy of the system
   III. Force exerted on a system causes the momentum of the system to change at a rate proportional to the force
   IV. The change of momentum of a system causes a force to exert on the system

   A. I , II
   B. I, II, III
   C. I , II, III, IV

   D. (None of **A**, **B**, **C**)

ANS: B

14. The relativistic kinetic energy of an object, in general, is

   A. greater than that defined by the classical mechanics
   B. less than that defined by the classical mechanics
   C. always equal to that defined by classical mechanics
   D. (None of **A**, **B**, **C**)
   ANS: A

15. A clock moving with a finite speed v is observed to run slow. If the speed of light were tripled, you would observe the clock to be

   A. Even slower.
   B. Still slow but not as much
   C. As slow as it was
   D. To start to actually run fast.

ANS: B (Walker test bank, Chap 29, Q26)

16. Which of the following results shows the validity of the relativistic effect of time dilation?

   A. The conservation of linear momentum in electron-electron collision
   B. Bending of light near the Sun
   C. The decay of muons
   D. Null result in the Michelson-Morley experiment on Ether detection
   ANS: C (Walker test bank, Chap 29, Q27)

17. A spaceship travelling at constant speed passes by Earth and later passes by Mars. In which frame of reference is the amount of time separating these two events the proper time?

   A. The Earth frame of reference
   B. The spaceship frame of reference
   C. Any inertial frame of reference
   D. The Mars frame of reference
   ANS: B (Walker test bank, Chap 29, Q13)

18. Boat 1 goes directly across a stream a distance L and back taking a time t_1. Boat 2 goes down stream a distance L and back taking a time t_2. If both boats had the same speed relative to the water, which of the following statements is true?

A. $t_2 > t_1$.
B. $t_2 < t_1$.
C. $t_2 = t_1$.
D. (None of **A**, **B**, **C**)

ANS: A (Serway test bank, Chap 39, Q6)
Solution: $t_1 = L/v_{\text{boat,stream}}$; $t_2 = L / [(v_{\text{boat,stream}} - (v_{\text{stream}}^2/v_{\text{boat,stream}})]$ $\therefore$ $t_1 < t_2$

19. The speed of light is

A. 3×10^8 m/s
B. 3×10^6 m/s
C. 3×10^9 m/s
D. 3×10^7 m/s

ANS: A

20. The quantity which does not change in numerical value from that observed in system S when observed in system S' moving away from system S at speed v is

A. $(\Delta x)^2 - (c\Delta t)^2$
B. $m_0 v$
C. $(\gamma-1)\, m_0 c^2$
D. (None of **A**, **B**, **C**)

ANS: A (Serway test bank, Chap 39, Q33)

ZCT 104/3E Modern Physics
Semester II, Sessi 2005/06
Test II (24 March 2006)

Data
Speed of light in free space, $c = 3.00 \times 10^{8}$ ms^{-1}
Elementary charge, $e = 1.60 \times 10^{-19}$ C
The Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg

1. Which of the following statements is true regarding Rayleigh-Jeans explanation of the blackbody radiation?

   A. The classical theory explanation of the blackbody radiation by Rayleigh-Jeans fails in the limit wavelength $\to 0$.
   B. The classical theory explanation of the blackbody radiation by Rayleigh-Jeans fails in the limit frequency $\to 0$.
   C. They postulate that the energy of electromagnetic waves is quantised.
   D. None of the above.

   ANS: A

2. Which of the following statements is (are) true regarding Planck theory of the blackbody radiation?

   I. The energy of the blackbody radiation is quantised. (T)
   II. The average energy of blackbody radiation is given by $\varepsilon = kT$. (F)
   III. There is no ultraviolet catastrophe. (T)

   A. I Only B. II Only C. I, II D. I, III

   ANS:D, Tut 2 04/05, CQ 1,2

3. What are the flaws in Rayleigh-Jeans law for blackbody radiation?

   I. It predicts ultraviolet catastrophe (T)
   II. It predicts much more power output from a black-body than is observed experimentally. (T)
   III. Blackbody radiation is universal and depends only on temperature. (Not a flaw)

   A. I Only B. II Only C. I, II D. I, III

   ANS:C, Tut 2 04/05, CQ 3

4. **What are the distinctive physical characteristics that exclusively differentiate a classical particle from a classical wave?**

	Classical Particle	Classical Wave
I.	Completely localized	A wave can be "simultaneously everywhere" at a given instance in time
II.	Is has mass	No mass is associated with a classical wave.
III.	Energy is concentrated in it and is not spreading beyond the boundary that defines its physical location.	Energy carried by wave spreads over a (possibly infinite) region of space along the direction the wave propagates
IV.	Momentum and position can be measured with infinite precision.	No momentum or precise location can be defined for a wave

   A. I, II, III, IV B. I, II, III C. I, II, IV D. None of A, B, C.

   ANS:A, Tut 2 04/05, CQ 4

5. The Compton-scattering formula suggests that objects viewed from different angles should reflect light of different wavelengths. Why don't we observe a change in colour of objects as we change the viewing angle?

   A. There is actually no change in the wavelength as predicted by the Compton-scattering formula.
   B. Because the change in wavelength is too tiny to be observed by human eye.
   C. Visible light doesn't undergo Compton scattering.
   D. None of A, B, C.

   ANS:B, Tut 2, 05/06, Q6

6. In Compton scattering, the maximum wavelength shift is in the order of

   A. ~ pm
   B. ~ nm
   C. ~ μm
   D. ~mm

   ANS:A, $\Delta\lambda_{max} = 2\lambda_e = 2.43\text{pm}$. (My Own Question)

7. Compton wavelength of the electron is given by $\lambda_e = \frac{h}{m_e c}$. What will the size of the Compton wavelength of a proton be in comparison to λ_e?

   A. λ_{proton} shall be larger than λ_e by about 2 orders of magnitude.
   B. λ_{proton} shall be smaller than λ_e by about 2 orders of magnitude.
   C. λ_{proton} shall be of the same order of magnitude with λ_e.
   D. None of A, B, C

   ANS:D, $\lambda_e = \frac{h}{m_e c}; \lambda_p = \frac{h}{m_p c} \Rightarrow \lambda_p = \lambda_e \frac{m_e}{m_p} \sim \frac{1\text{ MeV}}{1000\text{ MeV}} \lambda_e = 10^{-3}\lambda_e$. (My Own Question)

8. Which of the following statements is (are) true?

   I. The photoelectric effect doesn't work for free electron (T)
   II. The Compton effect doesn't work for free electron (F)
   III. Pair production does not occurs in free space (T)
   IV. Pair annihilation between an electron and positron does not occurs in free space (F)

   A. I, II, III, IV B. I, II, III C. I, II, IV D. None of A, B, C.

   ANS:D, I, III are true; II, IV are false. (My Own Question)

9. Which of the observed properties of the photoelectric effect fail to be accounted for by the wave nature of light?

   I. Photoelectron is emitted almost instantaneously. (T)
   II. The saturation photoelectric current increases as intensity increases. (F)
   III. Stopping potential is independent of the radiation intensity. (T)
   IV. Existence of the cut-off frequency. (T)

   A. I, II, III, IV B. II, III, IV C. I, III, IV D. None of A, B, C.

   ANS:C, I, II are true; II, IV are false. (My Own Question)

10. Which of the following statements is (are) true?

   I. The photoelectric effect is essentially a non-relativistic phenomena. (T)
   II. The Compton effect is essentially a relativistic phenomena. (T)
   III. Pair production is essentially a non-relativistic phenomena. (F)
   IV. Pair production is essentially a relativistic phenomena. (T)

   A. I, II, III, IV B. I, II, III C. I, II, IV D. None of A, B, C.

ANS: C. (My Own Question)

11. Which of the following statements is (are) true?

I. X-ray diffraction can be experimentally discernable if it is scattered by atoms in a crystal lattice. (T)
II. X-ray diffraction is experimentally discernable if it is scattered by an optical diffraction grating with line density 3,000 lines per mm. (F)
III. The energy of an X-ray photon is much larger than that of an ordinary photon in the visible part of the EM spectrum. (T)
IV. X-rays wavelength lies approximately in the order of 400 nm - ~ 700 nm. (F)

A. I, II, III, IV B. I, II, III C. I, II, IV D. None of A, B, C.

ANS: (Only I, III are true) D. (My Own Question)

12. Why can't a photon undergoes pair production in free space?

I. Because the photon doesn't has sufficient energy in free space. (F)
II. Because the photon doesn't has sufficient momentum in free space. (F)
III. Because it is not possible to conserve both energy and moment simultaneously in free space. (T)
IV. Because it is not possible to create matter out of pure energy. (F)

A. I, II, III B. II, III, IV C. I, III, IV D. None of A, B, C.

ANS:D. Only III is true. The rest is not. (My Own Question). For (I), even if the photon has sufficient energy pair production wouldn't happen as long as it is in free space. For II, 'sufficiency' in momentum is not an issue. The important issue is whether the momentum is conserved in a process, and whether the process is in vacuum. For (IV), it is possible to create matter out of pure energy from $E=mc^2$.

13. Which of the following statements is (are) true regarding electron?

I. Electron behaves like wave in a diffraction experiment. (T)
II. Electron behaves like particle in a photoelectric experiment. (T)
III. Electron behaves like particle in a Compton scattering experiment. (T)
IV. Electron can manifest both particle and wave nature in a single experiment. (F)

A. I, II, III B. I, II, III, IV C. I, III, IV D. None of A, B, C.

ANS: A. (My Own Question)

14. Consider a matter particle with rest mass m_0, moving with a speed v. Which of the following statements is (are) true regarding its de Broglie wave?

I. The de Broglie wavelength of the matter particle is $\lambda = h/(m_0 v)$ regardless of whether the particle is relativistic or not (F).
II. The de Broglie wavelength of the matter particle is $\lambda = h/(m_0 v)$ only if it is non relativistic (T).
III. The de Broglie wavelength of the matter particle is not given by $\lambda = h/(m_0 v)$ if it is relativistic (T).
IV. If the speed v of the matter particle is relativistic, its de Broglie wavelength is larger than $h/(m_0 v)$. (F)

A. I, II, III B. II, III C. I, II, IV D. None of A, B, C.

ANS: B. (My Own Question)

For IV: $\lambda_{NR} = h/(m_0 v) = h/p_{NR}$; $\lambda_R = h/(p_R)$; $\lambda_R = h/(p_R)$; $\lambda_R = \lambda_{NR}(p_{NR}/p_R) = \lambda_{NR}/\gamma \Rightarrow \lambda_R < \lambda_{NR} = h/(m_0 v)$.

15. Which of the statements is (are) true regarding a proton-antiproton annihilation process into photon.

I. The annihilation must produce at least two daughter photons. (T)
II. The proton-antiproton annihilation would produce photons which are much energetic than that produced by electron-positron annihilation. (T)
III. Each daughter photon produced must be at least of energy $2m_p c^2$ (m_p is the mass of the proton). (F)
IV. The magnitude of momentum of each daughter photon produced must be at least $m_p c$ (m_p is the mass of the proton). (T)

A. I, II, III, IV B. II, III, IV C. I, II, IV D. None of A, B, C.

ANS: C. (My Own Question)

16. Consider a very weak light beam strikes a fluorescence screen with one photon in a time. The detection of the photon is displayed as a dot on the screen. In this process, the light being detected is

A. a particle B. a wave C. neither a wave nor a particle
D. both wave and particle

ANS: A

17. Consider a very weak electron beam strikes a fluorescence screen with one electron in a time. The detection of the electron is displayed as a dot on the screen. In this process, the electron being detected is

A. a particle B. a wave C. neither a wave nor a particle
D. both wave and particle

ANS: A

18. A wavepulse is a result of superposition of many different waves with a spread in wave number, Δk. The width of the wavepulse, Δx, is quantitatively related to Δk as

A. $\Delta x \propto \Delta k$ B. $\Delta x \propto 1/\Delta k$ C. Δx not related to Δk
D. None of A, B, C, D

ANS: B

19. Which of the following statements is (are) true?

I. In an experiment, we use a light of certain wavelength to probe a quantum particle. If we use a light with smaller wavelength we will obtain a less precise knowledge about the position of the quantum particle and also a more precise knowledge on the linear momentum of the quantum particle. (F)
II. In an experiment, we use a light of certain wavelength to probe a quantum particle. If we use a light with smaller wavelength we will obtain a more precise knowledge about the position of the quantum particle and a less precise knowledge on the linear momentum of the quantum particle. (T)
III. In an experiment, we use a light of certain wavelength to probe a quantum particle. If we use a light with larger wavelength we will obtain a more precise knowledge about the position of the quantum particle and also a less precise knowledge on the linear momentum of the quantum particle. (F)
IV. In an experiment, we use a light of certain wavelength to probe a quantum particle. If we use a light with larger wavelength we will obtain a less precise knowledge about the position of the quantum particle and a more precise knowledge on the linear momentum of the quantum particle. (T)

A. I, III B. II, IV C. I, IV D. II, III

ANS: B

20. The diameter of an atomic nucleus is about 10×10^{-15} m. In order to study the diffraction of photons by nuclei, the energy of the photon has to be in the range of order

A. ~ eV
B. ~ keV
C. ~ MeV
D. None of A, B, C

ANS:D, Tut 2, 05/06, Q3

$$E = \frac{hc}{\lambda} = \frac{1240\text{nm}\cdot\text{eV}}{10\times10^{-15}\text{m}} = \frac{1.24\times10^{3}\times10^{-9}\text{m}\cdot\text{eV}}{10^{-14}\text{m}} = 1.24\times10^{8}\text{eV} \sim 10^{2}\text{MeV}$$

UNIVERSITI SAINS MALAYSIA

Final Exam
Academic Session 2005/2006

April 2006

ZCT 104E/3 - Physics IV (Modern Physics)
[Fizik IV (Fizik Moden)]

Duration: 3 hours
[Masa: 3 jam]

Please check that the examination paper consists of xx pages of printed material before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi xx muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]

Instruction:
Answer ALL questions in Section A and Section B.

Please answer the objective questions from Section A in the objective answer sheet provided. Please submit the objective answer sheet and the answers to the structured questions separately.

Students are allowed to answer all questions in Bahasa Malaysia or in English.

*[__Arahan__: Jawab **SEMUA** soalan dalam Bahagian A dan Bahagian B.*

Sila jawab soalan-soalan objektif daripada bahagian A dalam kertas jawapan objektif yang dibekalkan. Sila serahkan kertas jawapan objektif dan jawapan kepada soalan-soalan struktur berasingan.

Pelajar dibenarkan untuk menjawab sama da dalam bahasa Malaysia atau bahasa Inggeris.]

Data

Speed of light in free space, $c = 3.00 \times 10^{8}$ m s^{-1}
Permeability of free space, $m_0 = 4\pi \times 10^{-7}$ H m^{-1}
Permittivity of free space, $e_0 = 8.85 \times 10^{-12}$ F m^{-1}
Elementary charge, $e = 1.60 \times 10^{-19}$ C
Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg
Molar gas constant, = 8.31 J K^{-1} mol^{-1}
Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}
Gravitational constant, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
Acceleration of free fall, $g = 9.81$ m s^{-2}

Section A: Objectives. [40 marks]
[Bahagian A: Soalan-soalan objektif]

Instruction: Answer all 40 objective questions in this Section.
[Arahan: Jawab kesemua 40 soalan objektif dalam Bahagian ini.]

1. While standing beside a railroad track, we are startled by a boxcar traveling past us at half the speed of light. A passenger standing at the rear of the boxcar fires a laser pulse toward the front of the boxcar. The pulse is absorbed at the front of the box car. While standing beside the track we measure the speed of the pulse through the open side door. The measured value of the speed of the pulse is _________ its speed measured by the rider.
   [Kita berdiri di tepi suatu landasan keretapi. Suatu gerabak bergerak melepasi kita dengan halaju separuh halaju cahaya. Seorang penumpang yang berdiri di bahagian belakang gerabak menembak suatu denyutan laser ke arah bahagian hadapan gerabak. Denyutan tersebut diserap pada bahagian hadapan gerabak. Ketika berdiri di tepi landasan kita mengukur laju denyutan laser tersebut menerusi pintu tepi yang terbuka. Nilai bagi laju denyutan laser yang kita ukur adalah ____________ laju yang diukur oleh penumpang.]

   A. greater than *[lebih besar daripada]*
   B. equal to *[sama dengan]*
   C. less than *[kurang daripada]*
   D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

   ANS:B, My own questions

2. Refering to question No.1 above, our measurement of the distance between emission and absorption of the laser pulse is ___________ the distance between emission and absorption measured by the rider.
   [Merujuk kepada soalan 1 di atas, ukuran yang kita lakukan ke atas jarak di antara pemancaran dan penyerapan denyutan laser adalah ___________ jarak di antara pemancaran dan penyerapan yang diukur oleh penumpang tersebut.]

   A. greater than *[lebih besar daripada]*
   B. equal to *[sama dengan]*
   C. less than *[kurang daripada]*
   D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

   ANS:A, My own questions

3. Given two events, A and B, of which the space and time coordinate are respectively designated by (x_A, t_A) and (x_B, t_B). If we define the space-time interval squared as $s^2 = (c\Delta t)^2 - (\Delta x)^2$, which of the following statements are (is) true?
   [Diberikan dua kejadian, A dan B, yang koordinat-koordinat ruang dan masa masing-masing diberi oleh (x_A, t_A) dan (x_B, t_B). Jika kita takrifkan kuasadua selang ruang-masa sebagai $s^2 = (c\Delta t)^2 - (\Delta x)^2$, yang manakah kenyataan(-kenyataan) berikut adalah benar?]

   I. Both events may be causally related if the space-time interval squared between them is space-like.
   [Kedua-dua kejadian mungkin berkait secara sebab-akibat jika kuasadua selang ruang-masa antara mereka adalah bak ruangan.]

   II. Both events must not be causally related if the space-time interval squared between them is space-like.
   [Kedua-dua kejadian mesti tak berkait secara sebab-akibat jika kuasadua selang ruang-masa antara mereka adalah bak ruangan.]

   III. Both events may be causally related if the space-time interval squared between them is time-like.
   [Kedua-dua kejadian mungkin berkait secara sebab-akibat jika kuasadua selang ruang-masa antara mereka adalah bak masa.]

   IV. Both events must be causally related if the space-time interval squared between them is time-like.
   [Kedua-dua kejadian mesti berkait secara sebab-akibat jika kuasadua selang ruang-masa antara meraka adalah bak ruangan.]

A. I, II
B. II, III
C. II, III, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: B

4. Say Azmi is travelling in a mini bus moving with a constant speed v (with respect to Earth) and Baba is sitting in Pelita Nasi Kandar restaurant. Using his own wristwatch, Baba finds that his heart beats at a rate of M_B times per min. When Azmi measures the heartbeat rate of Baba in the mini bus frame, he found that Baba's heart is beating at a rate of M_A times a min. What is the relation between the two reading, M_A and M_B?

[Katakan Azmi berada di dalam sebuah bas mini yang bergerak dengan laju malar v (merujuk kepada Bumi) manakala Baba sedang duduk di dalam restoran Nasi Kandar Pelita. Dengan menggunakan jam tangannya, Baba mendapati jantungnya berdenyut pada kadar M_B kali per minit. Semasa Azmi mengukur kadar denyutan Baba di dalam rangka bus mini, dia mendapati jantung Baba berdenyut pada kadar M_A kali seminit. Apakah hubungan antara kedua-dua bacaan M_A dan M_B?]

A. $M_A > M_B$
B. $M_A < M_B$
C. $M_A = M_B$
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: B

5. Consider a football, kicked lightly by David Beckham, is moving in a straight line with a constant speed. Say in frame O, the momentum of the football is P. In a frame O′ moving with a relative constant speed v with respect to O, the momentum of the football is P'. Which of the following statements are (is) true regarding P and P'? The Lorentz factor is defined as $\gamma = [1-(v/c)^2]^{-1/2}$.

[Pertimbangkan sebiji bola sepak yang ditendang secara lembut oleh David Beckham dan bergerak dalam satu garis lurus dengan laju mantap. Katakan dalam rangka O, momentum bola sepak ialah P. Di dalam rangka O' yang bergerak dengan laju relatif mantap v merujuk kepada O, momentum bola sepak tersebut ialah P'. Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai P dan P'? Faktor Lorentz adalah ditakrifkan sebagai g = $[1-(v/c)^2]^{-1/2}$.]

I. Since momentum is not an invariant quantity, the numerical values of P and P' are not the same. *[Oleh sebab momentum bukan kuantiti tak varian, nilai numerik P adalah tidak sama dengan nilai numerik P'.]*
II. Since momentum is an invariant quantity, the numerical values of P and P' are the same. *[Oleh sebab momentum adalah suatu kuantiti tak varian, nilai numerik P adalah sama dengan nilai numerik P'.]*
III. P and P' are related by $P=P'/g$ *[P dan P' adalah dikaitkan oleh P=P'/g]*
IV. P and P' are related by $P=gP'$ *[P dan P' adalah dikaitkan oleh P=gP']*

A. I , III
B. II, IV
C. I ONLY
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: C [Neither III or IV is true.]

6. Which of the following statements is (are) true regarding the linear momentum of an object? (v denotes the speed of the object).
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai momentum linear suatu objek? (v menandai laju objek)]

I. The relativistic momentum and the classical momentum of an object have the same numerical value when v c
[Kedua-dua momentum kerelatifan dan momentum klasik suatu objek mempunyai nilai numerik yang sama bila v c.]

II. The relativistic momentum and the classical momentum of an object has the same numerical value when v is close to c
[Kedua-dua momentum kerelatifan dan momentum klasik suatu objek mempunyai nilai numerik yang sama bila v mendekati c.]

III. The ratio of relativistic momentum to classical momentum of an object approaches infinity when v approaches c
[Nisbah momentum kerelatifan kepada momentum klasik suatu objek menokok ke infiniti bila v menokok ke c.]

IV. The ratio of relativistic momentum to classical momentum of an object approaches 0 when v is tiny compared to c.
[Nisbah momentum kerelatifan kepada momentum klasik suatu objek menokok ke sifar bila v adalah kecil berbanding dengan c.]

A. I , III, IV
B. II, IV
C. I , III
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: C

7. Which of the following statements is (are) true regarding the kinetic energy of an object?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tenaga kinetik suatu objek?]

I. In classical mechanics *per se*, the kinetic energy of an object can increase without limit.
[Dengan hanya mempertimbangkan mekanik klasik, tenaga kinetik suatu objek boleh bertambah tanpa limit.]

II. In special relativity, the kinetic energy of an object can increase without limit.
[Dalam kerelatifan, tenaga kinetik suatu objek boleh bertambah tanpa limit.]

III. In special relativity, the kinetic energy of an object cannot increase without limit.
[Dalam kerelatifan, tenaga kinetik suatu objek tidak boleh bertambah tanpa limit.]

IV. A proton accelerated by a potential difference of 1 keV is non-relativistic.
[Suatu proton yang dipecutkan oleh beza keupayaan 1 keV adalah tak kerelatifan]

A. I , III, IV
B. III, IV
C. I , II, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: C

8. The relativistic kinetic energy of an object, in general, is
[Tenaga kinetik kerelatifan suatu objek, secara amnya, adalah]

A. greater than that defined by the classical mechanics by a factor of γ
[lebih besar daripada yang ditakrifkan oleh mekanik klasik sebanyak suatu factor γ]
B. less than that defined by the classical mechanics by a factor of γ
[lebih kecil daripada yang ditakrifkan oleh mekanik klasik sebanyak suatu factor γ]

C. always equal to that defined by classical mechanics
[sama dengan yang ditakrifkan oleh mekanik klasik]
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: D

9. Captain Jirk reports to headquarters that he left the planet Senesca 1.88×10^4 seconds earlier. Headquarters sends back the message: "Was that spaceship proper time?" It will be the spaceship proper time if it was
[Kaptan Jirk melapor kepada pusat kawalan bahawa dia telah meninggalkan planet Senesca sejak 1.88´ 10^4 saat yang lalu. Pusat kawalan hantar balik mesej: "Adakah masa yang dilaporkan itu masa wajar kapal angkasa?" Ia adalah masa wajar kapal angkasa jika ianya]

A. measured by one clock fixed at one spot on Senesca.
[diukur oleh suatu jam yang dipasangkan pada suatu titik di atas Senesca.]

B. measured by one clock fixed at one spot on the spaceship.
[diukur oleh suatu jam yang dipasangkan pada suatu titik di dalam kapal angkasa.]

C. measured by a clock on Senesca at departure and by a clock on the spaceship when reporting.
[diukur oleh suatu jam di atas Senesca semasa bertolak dan diukur oleh satu lagi jam yang dipasangkan di dalam kapal angkasa semasa melakukan laporan.]

D. measured by a clock on the spaceship when departing and by a clock on Senesca when reporting.
[diukur oleh suatu jam di dalam kapal angkasa semasa bertolak dan diukur oleh satu lagi jam di atas Senesca semasa melakukan laporan.]

(ANS: B, Q31, Chap 39, Serway test bank)

10. Which of the following statements is (are) true regarding the speed of light?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai laju cahaya?]

I. The speed of light in free space (i.e. vacuum) is a fundamental constant.
[Laju cahaya di dalam ruang bebas (iaitu vakuum) adalah suatu pemalar asas.]

II. The speed of light in free space (i.e. vacuum) is the same when measured in different frame of reference.
[Laju cahaya di dalam ruang bebas (iaitu vakuum) adalah sama jika diukur di dalam rangka rujukan yang berlainan.]

III. The speed of light is the same when measured in different medium.
[Laju cahaya adalah sama bila diukur di dalam medium yangberlainan.]

IV. The speed of light is the not same when measured in different medium.
[Laju cahaya adalah tidak sama jika diukur di dalam medium yang berlainan.]

A. I , II, III
B. I, II
C. I , II, IV
D. (None of A, B, C)

ANS: C

11. When two particles collide relativistically, *[Bila dua zarah berlanggar secara kerelatifan,]*
I. the total energy is conserved. *[jumlah tenaga adalah terabadikan.]*
II. the total momentum is conserved. *[jumlah momentum adalah terabadikan.]*
III. the total kinetic energy is conserved. *[jumlah tenaga kinetik adalahterabadikan.]*

A. I , II, III
B. II, III

C. I , II
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: C

12. Which of the following statements is (are) true regarding the decay of a pion (initially at rest) into a neutrino (assumed massless) and a muon: $p \rightarrow n + m$.
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai reputan suatu pion (dalam keadaan rehat pada mulanya) kepada suatu neutrino (dianggap tanpa jisim) dan suatu muon: $p \rightarrow n + m$?]

I. The decay is possible only if the mass of pion is larger than the mass of muon.
[Reputan adalah mingkin hanya jika jisim pion adalah lebih besar daripada jisim muon.]

II. The momentum of neutrino and the momentum of muon have the same magnitude.
[Momentum neutrino dan momentum muon mempuyai magnitud yang sama.]

III. The kinetic energy of neutrino is the same as that of the muon.
[Tenaga kinetik neutrino adalah sama dengan tenaga kinetik muon.]

IV. The decay is possible only if the mass of pion is equal to the mass of muon.
[Reputan adalah mingkin hanya jika jisim pion adalah sama dengan jisim muon.]

A. I , III
B. II, III, IV
C. I , II
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: C

13. Which of the following statements is (are) true regarding Lorentz transformation?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai transformasi Lorentz?]

I. It relates the spatial and temporal coordinate $\{x, t\}$ in one frame to that measured in another frame $\{x', t'\}$.
[Ia mengaitkan koordinat-koordinat ruangan dan masa $\{x, t\}$ dalam satu rangka dengan $\{x', t'\}$ yang diukur dalam rangka lain.]

II. It relates the velocity of an object u_x measured in one frame to that measured in another frame u_x' .
[Ia mengaitkan halaju suatu objek u_x yang diukur dalam satu rangka dengan u_x' yang diukurkan dalam rangka lain.]

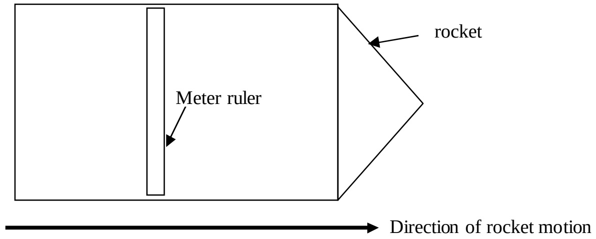
III. It predicts length contraction. *[Ia meramalkan pengecutan panjang.]*

IV. It predicts time dilation. *[Ia meramalkan pendilatan masa.]*

A. I , III
B. I , II, III, IV
C. II, III, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: B

14. Consider a meter ruler carried in a rocket moving in a direction perpendicular to the length of the ruler, see figure below.
[Pertimbangkan suatu pembaris meter yang dibawa oleh suatu roket yang bergerak dalam arah yang berserenjang dengan panjang pembaris, rujuk gambarajah.]



I. The length of the ruler is 1 m when measured by an observer in the rocket frame.
[Panjang pembaris adalah 1 m bila diukur oleh seorang pemerhati di dalam rangka roket.]

II. The length of the ruler is less than 1 m when measured by an observer in the rocket frame.
[Panjang pembaris adalah kurang daripada 1 m bila diukur oleh seorang pemerhati di dalam rangka roket.]

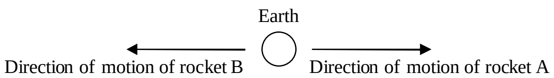
III. The length of the ruler is less than 1 m when measured by an observer in the lab frame.
[Panjang pembaris adalah kurang daripada 1 m bila diukur oleh seorang pemerhati di dalam rangka makmal.]

IV. The length of the ruler is 1 m when measured by an observer in the lab frame.
[Panjang pembaris adalah 1 m bila diukur oleh seorang pemerhati di dalam rangka makmal.]

A. I , III
B. II, III
C. II, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: D (I, IV are true. IV is true because the rule's length is perpendicular to the direction of motion.)

15. Consider two rockets moving in opposit directions away from Earth. See figure below. Rocket A is moving away from Earth at a speed of 0.5*c* while rocket B with a speed of 0.51*c*. Which of the following statements is (are) true?
[Pertimbangkan dua roket yang bergerak dalam dua arah bertentangan, masing-masing menjauhi Bumi. Rujuk gambarajah. Roket A bergerak menjauhi Bumi dengan laju 0.5c manakala roket B dengan laju 0.51c. Yang manakah kenyataan(-kenyataan) berikut adalah benar?]



I. The magnitude of the relative velocity of rocket A with respect to rocket B is less than 1.01 *c*.
[Magnitud halaju relatif roket A merujuk kepada roket B adalah kurang daripada 1.01c.]

II. The magnitude of the relative velocity of rocket A with respect to rocket B is less than *c*.
[Magnitud halaju relatif roket A merujuk kepada roket B adalah kurang daripada c.]

III. The magnitude of the relative velocity of rocket A with respect to rocket B is equal to *c*.
[Magnitud halaju relatif roket A merujuk kepada roket B adalah sama dengan c.]

IV. The magnitude of the relative velocity of rocket A with respect to rocket B is equal to 1.01 *c*.
[Magnitud halaju relatif roket A merujuk kepada roket B adalah sama dengan 1.01c.]

A. I , II
B. I, III
C. II, IV

D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: A

16. Which of the following statements is (are) true regarding waves?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai gelombang?]

I. Wave pulse can be formed by superpositioning many waves with different wavelengths and frequencies.
[Denyutan gelombang dapat dibentukkan dengan mengsuperposisikan gelombang-gelombang yang berjarak gelombang dan berfrekuensi yang berlainan.]

II. A 1-D wave with sharp wavelength and frequency can be completely localised.
[Lokasi suatu gelombang 1-D dengan jarak gelombang dan frekuensi tajam boleh ditentukan sepenuhnya.]

III. A 1-D wave packet is relatively more 'localised' then a 1–D wave with sharp wavelength and frequency.
[Lokasi suatu bungkusan gelombang 1-D adalah lebih tentu secara relatif berbanding dengan gelombang 1-D berjarak gelombang dan berfrekuensi tajam.]

IV. In general, the velocity of an envelope of a group wave is less than that of the phase wave.
[Secara amnya, halaju sampul bagi gelombang kumpulan adalah lebih kecil berbanding dengan halaju gelombang fasanya.]

A. I , II
B. I, III, IV
C. II, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: B

17. Which of the following statements is (are) true regarding waves and particles?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai gelombang dan zarah?]

I. Waves interfere but matter does not. *[Gelombang berinterferens manakala zarah tidak.]*
II. Waves interfere, so does matter *[Gelombang berinterferens, begitu juga bagi zarah.]*

III. Classically, the energy carried by the EM waves is continuous.
[Secara klasik, tenaga yang dibawa oleh gelombang EM adalah selanjar.]

IV. Classically, the energy carried by the EM waves is discrete.
[Secara klasik, tenaga yang dibawa oleh gelombang EM adalah diskrit.]

A. I , III
B. I, IV
C. II, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: A (I, III)

18. Which of the following statements is (are) true regarding black body radiation?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai sinaran jasad hitam?]

I. The spectrum distribution of black bodies is universal and depends only on temperature.
[Taburan spektrum jasad hitam adalah universal dan bergantung semata-mata pada suhu.]

II. The deviation of any real surface from the behaviour of an ideal black body is parametrised by the emmissivity parateter, *e*.
[Sisihan mana-mana permukaan benar daripada kelakuan jasad hitam yang ideal adalah diparameterkan oleh parameter emmissiviti, e.]

III. A black body in thermal equilibrium absorbs and emit radiation at the same rate.

[Suatu jasad hitam yang berada dalam keseimbangan terma menyerap dan memancarkan sinaran pada kadar yang sama.]

IV. A black body in thermal equilibrium only emit radiation but not absorbing any.
[Suatu jasad hitam yang berada dalam keseimbangan terma hanya memancarkan sinaran tapi tidak menyerap apa-apa sinaran.]

A. I , II, III
B. I, II, IV
C. II, III
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: A (I, II, III)

19. Which of the following statements is (are) true regarding the Rayleigh-Jeans law of black body radiation?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai hukum sinaran jasad hitam Rayleigh-Jeans?]

I. It predicts that the intensity of radiation shoots to infinity when wavelength approaches zero.
[Ia meramalkan bahawa keamatan sinaran menembak ke infiniti jika jarak gelombang menokok ke sifar.]

II. It assumes that the black body radiates electromagnetic waves at all wavelength.
[Ia menganggap bahawa jasad hitam memancarkan gelombang elektromagnet pada semua jarak gelombang.]

III. It assumes that the average energy of each wavelength in a black body is proportional to the frequency.
[Ia menganggap bahawa tenaga min bagi setiap jarak gelombang dalam jasad hitam adalah berkadar dengan frekuensi.]

IV. It assumes that the average energy of each wavelength in a black body is proportional to the temperature.
[Ia menganggap bahawa tenaga min bagi setiap jarak gelombang dalam jasad hitam adalah berkadar dengan suhu.]

A. I, II, III
B. I, II, IV
C. I ONLY
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: B (I, II, IV)

20. Which of the following statements is (are) the assumption(s) made by Planck in deriving his theory of black body radiation?
[Yang manakah kenyataan(-kenyataan) berikut adalah anggapan yang dibuat oleh Planck semasa menerbitkan teori sinaran jasad hitamnya?]

I. That the oscillator of the black body only absorbs and emits radiation with energy of discrete values.
[Bahawa pengayun di dalam jasad hitam hanya menyerap dan memancarkan sinaran dengan tenaga bernilai diskrit.]

II. That the average energy per standing wave in the Planck oscillator, $\langle e \rangle$ is not only temperature dependent but also frequency dependent.
[Bahawa tenaga min untuk setiap gelombang pegun dalam pengayun Planck, $\langle e \rangle$, bukan sahaja bergantung kepada suhu malah juga bergantung kepada frekuensi.]

III. That black body radiation is not electromagnetic in nature.
[Bahawa tabii sinaran jasad hitam adalah bukan elektromagnetik.]

IV. That the black body only radiates at the long wavelength region but not in the ultraviolet limit.

[Bahawa jasad hitam hanya memancar dalam rantau jarak gelombang panjang tapi tidak memancar dalam limit ultraungu.]

A. I, II, III
B. I, II, IV
C. II ONLY
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: D (I, II)

21. Which of the following statements are (is) true
[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. hc 1240 eV $\cdot$ nm (Planck constant $\times$ speed of light)
II. m_e 0.5 eV/c^2 (electron's mass)
III. m_{proton} 938 MeV/c^2 (Proton's mass)
IV. a_0 0.53Å (Bohr's radius)

A. I, II, IV
B. I, III, IV
C. I, II, III, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: B (I, III, IV)

22. Which of the following statements are (is) true regarding photoelectric effect?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai kesan fotoelektrik?]

I. The maximum photoelectron energy is directly proportional to the frequency of the incident light.
[Tenaga kinetik maksimum fotoelektron adalah berkadar terus dengan frekuensi cahaya tuju.]

II. The maximum photoelectron energy is a linear function of the frequency of the incident light.
[Tenaga kinetik maksimum fotoelektron adalah suatu fungsi linear frekuensi cahaya tuju.]

III. The maximum photoelectron energy depends on the material from which the photoelectron emits.
[Tenaga kinetik maksimum fotoelektron bersandar pada jenis bahan daripada mana fotoelektron dipancarkan.]

IV. The maximum photoelectron energy depends on the intensity of the incident radiation.
[Tenaga kinetik maksimum fotoelektron bersandar pada keamatan sinaran tuju.]

A. II, III, IV
B. II, III
C. I, II, III
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: B (II, III) (Beiser, Chap 2, Ex. 3)

23. Which of the following statements are (is) true regarding light and electron?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai cahaya dan elektron?]

I. The wave aspect of light was discovered earlier than its particle aspect. (T)
[Aspek gelombang bagi cahaya ditemui lebih awal daripada aspek zarahnya.]

II. The wave aspect of electron was discovered earlier than its particle aspect. (F)
[Aspek gelombang bagi elektron ditemui lebih awal daripada aspek zarahnya.]

III. The particle aspect of light was discovered earlier than its wave aspect. (F)
[Aspek zarah bagi cahaya ditemui lebih awal daripada aspekgelombangnya.]

IV. The particle aspect of electron was discovered earlier than its wave aspect. (T)
[Aspek zarah bagi elektron ditemui lebih awal daripada aspekgelombangnya.]

A. I, IV
B. II, III
C. I, II
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: A (I , IV, Beiser, Chap 2, Ex. 4)

24. Which of the following statements are (is) true?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. It is impossible for a photon to give up all of its energy to a free electron.
[Adalah tidak mungkin bagi suatu foton memberikan kesemua tenaganya kepada suatu elektron bebas.]

II. It is impossible for a photon to give up all of its momentum to a free electron.
[Adalah tidak mungkin bagi suatu foton memberikan kesemua momentumnya kepada suatu elektron bebas.]

III. It is impossible for a photon to give up all of its energy to an atom.
[Adalah tidak mungkin bagi suatu foton memberikan kesemua tenaganya kepada suatu atom.]

IV. It is impossible for a photon to give up all of its momentum to an atom.
[Adalah tidak mungkin bagi suatu foton memberikan kesemua momentumnya kepada suatu atom.]

A. I, IV
B. III, IV
C. I, II
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: C (I , II, Beiser, Chap 2, Ex. 19)

25. Which of the following are (is) true regarding the photoelectric effect?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai kesan fotoelektrik?]

I. The existence of a cutoff frequency in the photoelectric effect favours a particle theory for light rather than a wave theory.
[Kewujudan frekuensi ambang dalam kesan fotoelektrik menyebelahi teori zarah bagi cahaya berbanding dengan teori gelombang.]

II. The existence of a cutoff frequency in the photoelectric effect favours a wave theory for light rather than a particle theory.
[Kewujudan frekuensi ambang dalam kesan fotoelektrik menyebelahi teori gelombang bagi cahaya berbanding dengan teori zarah.]

III. The almost immediate emission of a photoelectron in the photoelectric effect favours a particle theory for light rather than a wave theory.
[Pancaran fotoelektron yang lebih kurang serentak menyebelahi teori zarah bagi cahaya berbanding dengan teori gelombang.]

IV. The almost immediate emission of a photoelectron in the photoelectric effect favours a wave theory for light rather than a particle theory.
[Pancaran fotoelektron yang lebih kurang serentak menyebelahi teori gelombang bagi cahaya berbanding dengan teori zarah.]

A. I, III
B. I, IV
C. II, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: A (I, III, Serway, Moses and Moyer, Chap 3, Question. 7)

26. Which of the following are (is) true regarding X-rays?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai sinaran-X?]

I. X-rays might be reasonably be called 'the inverse photoelectric effect'.
[Adalah munasabah untuk sinaran-X dikenali sebagai 'kesan fotoelektrik songsangan']

II. In X-rays production, part or all of the energy of a photon is converted into the kinetic energy of a fast moving electron.
[Dalam penghasilan sinaran-X, sebahagian atau keseluruhan tenaga suatu foton ditukarkan kepada tenaga kinetik elektron yang pantas bergerak.]

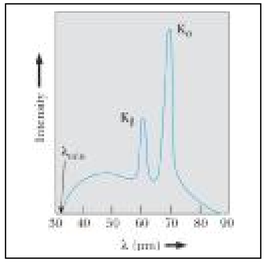
III. In X-rays production, part or all of the energy of a fast moving electron is converted into a photon.
[Dalam penghasilan sinaran-X, sebahagian atau keseluruhan tenaga kinetik suatu elektron yang pantas bergerak ditukarkan kepada suatu foton.]

IV. The penetrative character of X-rays through matter is partly due to its short wavelength.
[Salah satu sebab bagi ciri penembusan sinaran-X melalui jirim adalah kerana jarakgelombangnya yang pendek.]

A. I, III
B. I, II, IV
C. II, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: D (I, III, IV, Beiser, Chap 2.5, pg. 68)

27. The figure below shows the x-ray spectrum of a metal target from a x-ray tube. Which of the following statements are (is) true?
[Gambarajah berikut memaparkan spektrum sinaran-X daripada sasaran logam suatu tiub sinaran-X. Yang manakah kenyataan(-kenyataan) berikut adalah benar?]



I. The broad continuous spectrum is well explained by classical electromagnetic theory.
[Spektrum selanjar yang lebar adalah diterangkan dengan baiknya oleh teori electromagnet klasik.]

II. The existence of l_{min} in the spectrum shows proof of the photon theory.
[Kewujudan l_{min} dalam spektrum menunjukkan bukti bagi teori foton.]

III. l_{min} is found to be independent of target composition.
[Didapati l_{min} adalah merdeka daripada komposisi sasaran.]

IV. l_{min} depends only on the tube voltage.
[Didapati l_{min} hanya bergantung kepada voltan tiub.]

A. I, III, IV
B. I, II, III, IV
C. II, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: B (I, II, III, IV, Serway, Moses and Moyer, Chap 3, pg. 88)

28. Consider a Compton scattering experiment in which the incident radiation with various wavelength λ is aimed at a block of graphite target. The scattered radiation are observed and their Compton shifts are measured at an angle of θ = 90°. Which of the following are (is) true?
[Pertimbangkan suatu eksperimen serakan Compton. Sinaran tuju dengan berbagai-bagai jarak gelombang l dikenakan ke atas sasaran blok grafit. Sinaran terserak dicerap dan anjakan Compton mereka diukur pada sudut θ = 90°. *Yang manakah kenyataan(-kenyataan) berikut adalah benar?]*

I. Regardless of the incident radiation wavelength used, the same Compton shift, Δl, is observed.
[Anjakan Compton yang sama, Δl *, akan didapati tidak kisah apa nilai* λ *yang digunakan.]*

II. The fractional change in wavelength, $\Delta\lambda/\lambda$, is the same for different λ.
[Nisbah perubahan dalam jarak gelombang, $\Delta\lambda/\lambda$ *, adalah sama untuk semua nilai* λ*.]*

III. Compared with the energy of a X-ray photon, the binding energy of an electron to the graphite atom in the target is negligible.
[Berbanding dengan tenaga foton sinaran-X, tenaga ikatan elektron kepada atom grafit di dalam sasaran adalah terabaikan.]

A. I, III
B. II, III
C. I, II, III
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: A (I, III, Serway, Moses and Moyer, Chap 3, Example 3.8)

29. Which of the following statements are (is) true regarding Compton scattering?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai serakan Compton?]

I. The Compton effect could not be accounted for by classical theories. (T)
[Kesan Compton tidak boleh diterangkan oleh teori-teori klasik.]

II. The Compton effect could not be accounted for if not treated relativistically. (T)
[Kesan Compton tidak boleh diterangkan jika tidak dirawat secara kerelatifan.]

III. The Compton effect could still be accounted for if not treated relativistically. (F)
[Kesan Compton boleh diterangkan walaupun tidak dirawat secara kerelatifan.]

A. I, III
B. I ONLY
C. I, II
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: C (My own question)

30. Consider a photon with initial wavelength λ being scattered off by a particle with mass *m*. The Compton shift Δλ of the radiation at a given angle
[Pertimbangkan suatu foton berjarak gelombang awal l diserakkan oleh suatu zarah dengan jisim m. Anjakan Compton Δλ *sinaran tersebut pada suatu sudut tertentu]*

A. would be smaller for a larger *m*,
[adalah lebih kecil bagi nilai m yang lebih besar]

B. would be larger for a larger *m*.
[adalah lebih besar bagi nilai m yang lebih besar]

C. would remain unchanged for a larger *m*.
[tidak akan berubah walaupun bagi nilai m yang lebih besar.]

D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: A (My own question)

31. Radiation interacts with matter chiefly through photoelectric effect, Compton scattering and pair production. The relative importance of the interactions shift from ________ to _________ to ___________ when energy of the photon increases.
[Sinaran berinteraksi dengan jirim terutamanya melalui kesan-kesan fotoelektrik, serakan Compton dan penghasilan pasangan. Kepentingan relatif interaksi-interaksi tersebut berubah dari _________ ke_________ ke _____________ bila tenaga foton bertambah.]

A. Compton scattering, Photoelectric effect, Pair production
B. Pair production, Compton scattering, Photoelectric effect
C. Pair production, Photoelectric effect, Compton scattering
D. Photoelectric effect, Compton scattering, Pair production

ANS: D (My own question)

32. Heisenberg's uncertainty principle *[Prinsip ketidakpastian Heisenberg]*

I. is seldom important on macroscopic level
[jarang menjadi mustahak pada tahap makroskopik.]

II. is frequently very important on the microscopic level.
[sering menjadi mustahak pada tahap mikroskopik.]

III. implies that one can simultaneously measure the position and momentum of a particle with zero uncertainties.
[mengimplikasikan bahawa seseorang dapat mengukur secara serentak kedudukan dan momentum sesuatu zarah dengan sifar ketidakpastian.]

IV. implies that one cannot simultaneously measure the position and momentum of a particle with any certainty.
[mengimplikasikan bahawa seseorang tidak dapat mengukur kedudukan dan momentum sesuatu zarah dengan apa jua kepastian.]

A. I, II, III
B. I, II, IV
C. I, II
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: C (Taylor et al., Chap. 6, pg. 191)

33. Which of the following is (are) true according to Heisenberg's time-energy uncertainty relation $\Delta E \Delta t \geq \hbar/2$?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai hubungan ketidakpastian masa-tenaga Heisenberg $\Delta E \Delta t \geq \hbar/2$*?]*

I. For a quantum particle that exists for a short period of Δ*t*, the particle must have a large uncertainty Δ*E* in its energy.
[Bagi suatu zarah kuantum yang wujud untuk suatu selang masa Δ*t yang singkat, zarah tersebut mesti mempunyai ketidakpastian tenaga* Δ*E yang besar.]*

II. For a quantum particle that has a large uncertainty of Δ*E* in its energy, it must exists only for a short period of Δ*t*
[Bagi suatu zarah kuantum yang mempunyai ketidakpastian tenaga Δ*E yang besar, ia mesti hanya wujud untuk suatu selang masa* Δ*t yang singkat.]*

III. If a quantum particle has a definite energy, then $\Delta E = 0$, and Δt must be infinite.
[Jika suatu zarah kuantum mempunyai tenaga yang pasti, maka $\Delta E = 0$ dan Δt mestilah menjadi infinit.]

IV. If a quantum particle does not remain in the same state forever, Δt is finite and ΔE cannot be zero.
[Jika suatu zarah kuantum tidak berkekal pada keadaan yang sama untuk selama-lamanya, maka Δt adalah finit, dan ΔE tidak boleh jadi sifar.]

A. I, II, III
B. II, III, IV
C. I, II, III, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: C (Taylor et al., Chap. 6, pg. 193)

34. Consider a quantum particle confined in an infinite potential well of width *L*. Its states are characterised by the non-zero quantum integer *n*. Which of the following statements is (are) true?
[Pertimbangkan suatu zarah kuantum yang terkongkong di dalam telaga segiempat infinit selebar L. Keadaannya adalah dicirikan oleh nombor kuantum integer bukan sifar n. Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. The allowed energies of the particle are discrete
[Tenaga yang diizinkan zarah itu adalah diskrit.]

II. There allowed energy levels are farther and farther apart as the quantum number *n* increases.
[Paras tenaga yang diizinkan menjadi makin terpisah bila nombor kuantum n makin menambah.]

III. The energy level of the particle's state E_n increases without limit as *n* à ∞.
[Paras tenaga zarah, E_n, menambah tanpa batas bila n à ∞.]

IV. The number of nodes of the wave function of the particle increases with *n*.
[Bilangan nod fungsi gelombang zarah bertambah bila n bertambah.]

A. I, II, IV
B. I, III, IV
C. II, III, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: D (All are true, Taylor et al., Chap. 6, pg. 210, 211)

35. Consider the Bohr's model of hydrogen-like atom. Its states are characterised by the non-zero quantum integer *n*. Which of the following statements is (are) true?
[Pertimbangkan atom bak hidrogen model Bohr. Keadaannya adalah dicirikan oleh nombor kuantum integer bukan sifar n. Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. The allowed energies of the electron in the atom are discrete at low values of *n*
[Paras tenaga yang diizinkan bagi elektron dalam atom adalah diskrit bagi nilai n yang kecil.]

II. The allowed energies of the electron in the atom becomes quasi continous at large values of *n*.
[Paras tenaga yang diizinkan bagi elektron dalam atom menjadi kuasi-selanjar untuk nilai n yang besar.]

III. The allowed energy levels are farther and farther apart as the quantum number *n* increases.
[Paras tenaga yang diizinkan menjadi makin terpisah bila nombor kuantum n makin menambah.]

IV. The energy level, E_n, increases without limit as *n* à ∞.
[Paras tenaga, E_n, menambah tanpa batas bila n à ∞.]

A. I, II, III
B. I, II, IV
C. I, II
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: C (Only I, II is true. My own question)

36. Consider the Bohr's model of hydrogen-like atom. Its states are characterised by the non-zero quantum integer *n*. Which of the following statements is (are) true?
[Pertimbangkan atom bak hidrogen model Bohr. Keadaannya adalah dicirikan oleh nombor kuantum integer bukan sifar n. Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. The larger the value of *n* the larger the electron's velocity becomes.
[Halaju elektron menjadi makin besar bila nilai n majadi makin besar.]

II. The electron's linear momentum has only allowed values of multiples of *h/2p*.
[Linear momentum elektron hanya mengambil nilai-nilai diizinkan yang merupakan gandaan h/2p.]

III. The orbit of the electron becomes larger for a larger value of *n*.
[Orbit elektron menjadi makin besar bila nilai n majadi makin besar.]

IV. The electron breaks away from the hydrogen's attractive potential when *n* approaches infinity.
[Elektron terputus daripada keupayaan tarikan hidrogen bila n menokok ke infiniti.]

A. I, II
B. III, IV
C. II, III, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: B (For I, $v_n = \frac{ke^2}{n\hbar}$, hence I is false. Taylor et al., pg 152, 153. My own question)

37. Consider the Bohr's model of hydrogen-like atom. Its states are characterised by the non-zero quantum integer *n*. Which of the following statements is (are) true?
[Pertimbangkan atom bak hidrogen model Bohr. Keadaannya adalah dicirikan oleh nombor kuantum integer bukan sifar n. Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. The ground state energy is -13.6 eV. *[Tenaga buminya ialah -13.6 eV.]*
II. The ground state energy is 13.6 eV. *[Tenaga buminya ialah 13.6 eV]*
III. The ground state energy is 0. *[Tenaga buminya ialah 0]*
IV. The difference in the energy level between state *n* and *n*+1 becomes infinity when *n* à ∞.
[Perbezaan tenaga di antara paras n dan n+1 menjadi infiniti bila n à ∞.]

A. I, IV
B. III, IV
C. II, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: D (Only I is true.)

38. Consider Balmer's formula $\frac{1}{l} = R_H\left(\frac{1}{n'^2} - \frac{1}{n^2}\right)$ ($n > n'$, both integers), where R_H is the Rydberg constant. In Bohr's model, the theoretical value of R_H is given by the expression
[Pertimbangkan formula Balmer $\frac{1}{l} = R_H\left(\frac{1}{n'^2} - \frac{1}{n^2}\right)$, (n > n', kedua-duanya integer), dengan R_H pemalar Rydberg. Dalam model Bohr, nilai teori R_H adalahdiberikan oleh]

A. 13.6 eV/(*hc*)
B. $\frac{1}{4pe_0}\frac{e^2}{a_0hc}$ (a_0 is the Bohr's radius)

C. $\frac{me^4}{4pe_0^2ch^3}$

D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: A (Taylor et al, Chap 5.7, Eq. 5.26)

39. A particle in an infinite square well with length L is known to be in the ground state. The spatial coordinate of the particle in the infinite square well is constrained by $0 \geq x \geq L$. The probability to find the particle is highest in interval of ________.
[Diketahui suatu zarah di dalam telaga segiempat infinit berada dalam keadaan bumi. Koordinat ruangan zarah dalam telaga segiempat infinit adalah dikongkong oleh $0 \geq x \geq L$. Kebarangkalian untuk menemui zarah tersebut adalah tertinggi di dalam selang_______.]
   A. $L/2 \pm 0.001L$
   B. $L/4 \pm 0.001L$
   C. $L/8 \pm 0.001L$
   D. $L/16 \pm 0.001L$

ANS: A (my own question)

40. Which of the following statements is true?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

   I. A quantum particle initially confined in an infinite square well cannot possibly escape from the well when excited (T)
   [Suatu zarah kuantum yang pada asalnya terkongkong di dalam telaga segiempat infinit tidak mungkin terlepas daripada telaga bila diujarkan.]

   II. A quantum particle initially confined in an infinite square well can possibly escape from the well when excited (F)
   [Suatu zarah kuantum yang pada asalnya terkongkong di dalam telaga segiempat infinit mungkin terlepas daripada telaga bila diujarkan.]

   III. A quantum particle initially confined in an finite square well cannot possibly escape from the well when excited (F)
   [Suatu zarah kuantum yang pada asalnya terkongkong di dalam telaga segiempat finit tidak mungkin terlepas daripada telaga bila diujarkan.]

   IV. A quantum particle initially confined in an finite square well can possibly escape from the well when excited (T)
   [Suatu zarah kuantum yang pada asalnya terkongkong di dalam telaga segiempat finit mungkin terlepas daripada telaga bila diujarkan.]

   A. II, IV
   B. II, III
   C. I, III
   D. I, IV

ANS: D (my own question)

Section B: Structural Questions. [60 marks]
[Bahagian B: Soalan-soalan Struktur]

Instruction: Answer ALL THREE (3) questions in this Section. Each question carries 20 marks.
[Arahan: Jawab KESEMUA TIGA (3) soalan dalam Bahagian ini. Setiap soalan membawa 20 markah].

1. [20 marks]

Consider a completely inelastic head-on collision between two balls (with rest mass m_0 each) moving toward the other at a common velocity v with respect to a given frame S. Assuming that the resultant mass is at rest after the collision (with a value of M), find the following quantities. Express your answers in terms of c, m_0 and g where $g = 1/\sqrt{1-(v/c)^2}$.
[Pertimbangkan satu perlanggaran tak kenyal penuh antara dua bola (masing-masing berjisim m_0) yang bergerak mengarah ke satu sama lain dengan halaju v merujuk kepada satu rangka S. Anggapkan bahawa jisim terhasil selepas perlanggaran berkeadaan rehat (dan bernilai M) dalam rangka S, hitungkan kuantiti-kuantiti berikut. Nyatakan jawapan anda dalam sebutan-sebutan c, m_0 dan g, dengan $g = 1/\sqrt{1-(v/c)^2}$.]

   I. What is the total rest energy of the system before collision in S?
   Apakah jumlah tenaga rehat sistem tersebut sebelum perlanggaran dalam rangka S?]
   [2 marks]

   II. What is the total relativisitic energy of the system before collision in S?
   Apakah jumlah tenaga kerelatifan sistem tersebut sebelum perlanggaran dalam rangka S?]
   [2 marks]

   III. Express the resultant rest mass M in terms of c, m_0 and g.
   [Nyatakan jisim rehat M dalam sebutan c, m_0 dan g.]
   [3 marks]

   IV. What is the magnitude of the change of the kinetic energy in S?
   [Apakah magnitud perubahan tenaga kinetik sistem tersebut dalam rangka S?]
   [3 marks]

b) Now consider the same inelastic collision process in an inertial frame S′ such that one of the mass remains at rest while the other mass collides with it head-on. Let K and K' be the total kinetic energy of the system before and after the collision in frame S′. Find the following quantities. Express your answers in terms of c, m_0, g, K and K'.

[Sekarang pertimbangkan proses perlanggaran yang sama di dalam satu rangka inersia S' yang mana salah satu daripada jisim berada pada keadaan rehat manakala yang satu lagi melanggarnya secara muka lawan muka. Biar K dan K' masing-masing mewakili tenaga kinetik sistem tersebut sebelum dan selepas perlanggaran di dalam rangka S'. Hitungkan kuantiti-kuantiti berikut. Nyatakan jawapan anda dalam sebutan-sebutan c, m_0 ,g, K dan K'.]

   I. What is the total relativistic energy of the system, before the collision in S'?
   [Apakah jumlah tenaga kerelatifan sistem tersebut sebelum perlanggaran dalam rangka S'?]
   [2 marks]

   II. What is the total relativistic energy of the system after the collision in S'?
   Apakah jumlah tenaga kerelatifan sistem tersebut selepas perlanggaran dalam rangka S'?]
   [2 marks]

   III. What is the magnitude of the change of the kinetic energy in S'?
   [Apakah magnitud perubahan tenaga kinetik dalam rangka S'?]
   [3 marks]

   IV. Does the magnitude of the change of the kinetic energy frame-dependent?
   [Adakah magnitud perubahan tenaga kinetik bersandar pada rangka?]

299

[3 marks]

Solution

a)

I. In frame S, total rest energy of the system before collision = $2m_0c^2$

[2 marks]

II. In frame S, total relativistic energy of the system before collision = $2\gamma m_0c^2$

[2 marks]

III. Due to conservation of energy, total energy before collision = total energy after collision: $2\gamma m_0c^2 = Mc^2$. Therefore, $M = 2\gamma m_0$.

[3 marks]

IV. In frame S, the magnitude of change in total rest energy of the system after collision = The magnitude of change in kinetic energy of the system = $Mc^2 - 2m_0c^2 = (M-2m_0)c^2 = 2m_0c^2(\gamma-1)$.

[3 marks]

b)

I. In frame S′, total energy of the system before collision = $2m_0c^2 + K$

[2 marks]

.

II. In frame S′, total energy of the system after collision = $Mc^2 + K' = 2\gamma m_0 c^2 + K'$.

[2 marks]

III. Due to conservation of total energy, $2m_0c^2 + K = 2\gamma m_0 c^2 + K'$, hence the magnitude of the change of the kinetic energy of the system = $|K' - K| = |2m_0c^2 - 2\gamma m_0c^2| = 2(\gamma-1)m_0c^2$.

[3 marks]

V. No. The change of the kinetic energy in both frame are the same and equals $2(\gamma-1)m_0c^2$**.**

[3 marks]

2. [20 marks]

a) A positron collides head on with an electron and both are annihilated. Each particle had a kinetic energy of 1.00 MeV. Find the wavelength of the resulting photons. Express your anwer in unit of pm.
[Suatu positron berlanggar muka sama muka dengan suatu elektron, dan kedua-dua zarah memusnah-habis. Kedua-dua zarah masing-masing bertenaga kinetik 1.00 MeV. Hitungkan jarak gelombang foton yang terhasil. Nyatakan jawapan anda dalam unit pm.]

[5 marks]

b) How much energy must a photon have if it is to have the momentum of a proton with kinetic energy 10 MeV?
[Apakah tenaga suatu foton yang momentumnya sama dengan momemtum suatu proton yang bertenaga kinetik 10 MeV?]

[5 marks]

c) What is the value of electron's Compton wavelength, λ_e? Expressed your answer in terms of pm.
[Apakah nilai jarak gelombang Compton bagi elektron? Nyatakan jawapan anda dalam sebutan pm.]

[4 marks]

d) Find the wavelength of an x-ray photon which can impart a maximum energy of 50 keV to an electron.
[*Hint: You may need to consider the corresponding recoil angle of the scattered photon for a maximum transfer of its energy to the recoil electron.*]
[Hitungkan jarak gelombang suatu foton sinaran-X yang dapat memberikan tenaga maksimum bernilai 50 keV kepada suatu elektron.]

[Petunjuk: Anda mungkin perlu mempertimbangkan sudut sentakan foton terserak bagi perpindahan tenaganya secara maksimum kepada elektron yang tersentak.]

[6 marks]

Solution

a) Total energy of the positron + electron before annihilation
= rest energies of the electron-positron pair + their kinetic energy
$E = E_+ + E_- = 2m_ec^2 + K_+ + K_- = 2m_ec^2 + 2K =$ 2(0.51 MeV + 1.00 MeV) = 2(1.51 MeV)

Total energy of the photon pair after annihilation =

$$2E_\gamma = 2\frac{hc}{l} = 2\left(\frac{1240\text{eV}\cdot\text{nm}}{l}\right) = 2\left(\frac{1.24\times10^{-3}\text{MeV}\cdot10^{-9}\text{m}}{l}\right)$$

Equate both equations above, the wavelength of each photon will be

$$l = \frac{hc}{m_ec^2 + K} = \frac{1.24\times10^{-3}\text{MeV}\times10^{-9}\text{m}}{1.511\text{ MeV}} = 0.82\text{ pm}.$$

(Beiser Chap 2, Ex. 39, pg. 91)

[5 marks]

b) A proton with this kinetic energy is nonrelativistic, and its momentum is given by $p^2 = 2m_pK$. The energy of a photon with this momentum is

$$pc = \sqrt{2m_pc^2K} = \sqrt{2(938\text{ MeV})(10\text{ MeV})} = 137\text{ MeV} \quad 140\text{ MeV}.$$

(Beiser Chap 2, Ex. 26, pg. 90)

[5 marks]

c) $$l_e = \frac{h}{m_ec} = \frac{hc}{m_ec^2} = \frac{1240\text{ eV}\cdot\text{nm}}{0.51\text{ MeV}} = \frac{1240\text{ eV}\cdot\text{nm}}{0.51\text{ MeV}} = 2.43\text{ pm}$$

[4 marks]

d) Let the incident wavelength be λ and the scattered wavelength of the photon be λ′. A maximal change in the wavelength corresponds to maximum energy transfer to the electron. This happens when $\phi = 180°$. Hence, $\Delta l_{\max} = l_e\left[1-\cos\left(180^\circ\right)\right] = 2l_e$; where l_e is the Compton wavelength of the electron. $\Rightarrow l'_{\max} = \Delta l_{\max} + l = 2l_e + l$.

The maximal change in the photon's energy = maximal kinetic energy transferred to the electron, i.e.

$$K_{\max} = \frac{hc}{l} - \frac{hc}{l'_{\max}} = hc\left(\frac{l'_{\max} - l}{l\,l'_{\max}}\right) = hc\left(\frac{\Delta l_{\max}}{l(l+\Delta l_{\max})}\right) = hc\left(\frac{2l_e}{l(l+2l_e)}\right).$$ Rearranging, we get a quadratic equation for λ:

$$l(l+2l_e) = \left(\frac{2l_ehc}{\text{K}_{\max}}\right) = \left(\frac{2\times2.43\text{pm}\times1240\text{ nm}\cdot\text{eV}}{50\text{ keV}}\right) = 120.5\text{pm}^2$$

$$\Rightarrow l^2 + 2l_el - 120.5\text{pm}^2 = 0$$

$$\Rightarrow l = \frac{-2l_e \pm\sqrt{(2l_e)^2 + 4(120.5\text{pm}^2)}}{2} = -2.43\text{pm} \pm\sqrt{(2.43\text{pm})^2 + (120.5\text{pm}^2)} = +8.81\text{pm}$$

(Beiser Chap 2, Ex. 32, pg. 90)

[6 marks]

3. [20 marks]

a) How much energy is required to remove an electron in the n=2 state from a hydrogen atom?
[Apakah tenaga yang diperlukan untuk membebaskan suatu elektron dalam keadaan n = 2 daripada atom hidrogen?]

300

[5 marks]

b) Find the quantum number that characterises the Earth's orbit around the sun. The Earth's mass is 6.0×10^{24} kg, its orbital radius is 1.5×10^{11} m, and its orbital speed is 3.0×10^{4} m/s.
[*Hint: Assume that the angular momentum of the Earth about the Sun is quantised in a manner similar to Bohr's hidrogen-like atom.*]

[Hitungkan numbor kuantum yang mencirikan orbit Bumi mengelilingi Matahari. Diberikan jisim bumi 6.0×10^{24} kg, radius orbitnya 1.5×10^{11} m, dan laju orbitnya 3.0×10^{4} m/s.]
[Petunjuk: Anggap bahawa momentum sudut Bumi sekitar Matahari adalah dikuantumkan mengikut cara seperti dalam atom bak hidrogen Bohr.]

[5 marks]

c) In terms of ground state energy E_0, h and n, what is the frequency of the photon emitted by a hydrogen atom, ν, in going from the level n + 1 to the level n?
[Dalam sebutan tenaga bumi E_0, h dan n, nyatakan frekuensi foton, n, yang dipancarkan oleh suatu atom hidrogen yang beralih dari paras n+1 ke paras n.]

[7 marks]

d) What is value of the frequency of the photon in (c) above in the limit n à ∞.
[Apakah nilai frequensi bagi foton dalam (c) di atas dalam limit n à ∞.]

[3 marks]

Solution
3.

a) The n = 2 energy is $E_2 = E_0/2^2 = E_0/4$ = -13.6 eV /4 = -3.40 eV, so an energy of 3.40 eV is needed.
(Beiser, Chap 4, Ex. 22, pg. 158)

[5 marks]

b) With the mass, orbital speed and orbital radius of the Earth known, the Earth's orbital angular momentum is known, and the quantum number that would characterise the Earth's orbit about the Sun would be the angular momentum divided by $\hbar$

$$n=\frac{L}{\hbar}=\frac{mvr}{\hbar}=\frac{\left(6.0\times10^{24}\text{ kg}\right)\left(3.0\times10^{4}\text{ m/s}\right)\left(1.5\times10^{11}\text{ m}\right)}{\left(1.055\times10^{-34}\text{ J}\cdot\text{s}\right)}=2.6\times10^{74}$$

(Beiser, Chap 4, Ex. 11, pg. 158)

[5 marks]

c) The frequency ν of the photon emitted in going from n+1 level to the level n is given by

$$n=\frac{E_{n+1}-E_n}{h}=\frac{1}{h}\left(\frac{E_0}{(n+1)^2}-\frac{E_0}{(n)^2}\right)=\frac{E_0}{h}\left(\frac{n^2-(n+1)^2}{n^2(n+1)^2}\right)=-\frac{2E_0}{h}\left(\frac{n+\frac{1}{2}}{n^2(n+1)^2}\right)$$

(Beiser, Chap 4, Ex. 29, pg. 159)

[7 marks]

e) In the limit n à ∞, the frequency ν à 0

[3 marks]

UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2005/2006

Jun 2006

ZCT 104E/3 – Physics IV (Modern Physics)
[Fizik IV (Fizik Moden]

Duration: 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains **TWENTY EIGHT** pages before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **DUA PULUH LAPAN** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]*

Instruction:
Answer ALL questions in Section A and Section B.

Please answer the objective questions from Section A in the objective answer sheet provided. Please submit the objective answer sheet and the answers to the structured questions separately.

Students are allowed to answer all questions in Bahasa Malaysia or in English.

*[**Arahan**: Jawab **SEMUA** soalan dalam Bahagian A dan Bahagian B.*

Sila jawab soalan-soalan objektif daripada bahagian A dalam kertas jawapan objektif yang dibekalkan. Sila serahkan kertas jawapan objektif dan jawapan kepada soalan-soalan struktur berasingan.

Pelajar dibenarkan untuk menjawab samada dalam bahasa Malaysia atau bahasa Inggeris.]

…/2 -

Data

Speed of light in free space, $c = 3.00 \times 10^{8}$ m s^{-1}
Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
Permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
Elementary charge, $e = 1.60 \text{ x } 10^{-19}$ C
Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg
Molar gas constant, = 8.31 J K^{-1} mol^{-1}
Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}
Gravitational constant, $G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
Acceleration of free fall, $g = 9.81$ m s^{-2}

Section A: Objectives. [20 marks]
[Bahagian A: Soalan-soalan objektif]

Instruction: Answer all 20 objective questions in this Section.
[Arahan: Jawab kesemua 20 soalan objektif dalam Bahagian ini.]

1. Which of the following statements is (are) true regarding the Bohr model of hydrogen-like atom?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai model Bohr untuk atom bak-hidrogen?]

I. It predicts the ionization energy for hydrogen. (T)
[Ia meramalkan tenaga pengionan untuk hydrogen.]

II. It cannot account for the spectra of more complex atoms. (T)
[Ia tidak dapat menerangkan spektrum atom-atom yang lebih kompleks.]

III. It is unable to predict many subtle spectral details of hydrogen and other simple atoms such as energy level splittings due to spin-orbital interactions. (T)
[Ia gagal untuk meramalkan banyak butir-butir halus hidrogen dan atom-atom ringkas lain seperti belahan paras-paras tenaga disebabkan oleh interaksi spin-orbit.]

IV. The notion of electrons in well-defined orbits around the nucleus is consistent with the uncertainty principle. (F)
[Fikiran bahawa elektron mengelilingi nukleus dalam orbit yang tepat tertakrif adalah konsisten dengan prinsip ketidakpastian.]

A. I, II, III B. II, III, IV C. I, II, III, IV
D.(None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: A. Serway pg. 1359, modified.

2. Which of the following statements is (are) true regarding the spectrum of hydrogen atom, according to the Bohr model?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai spektrum atom hidrogen menurut model Bohr?]

I. The Balmer series emission spectrum of a hydrogen atom lies in the visible region of the electronmagnetic spectrum.
[Spektrum pancaran siri Balmer atom hidrogen terletak dalam rantau nampak spektrum elektromagnetik.]

II. The Lyman series emission spectrum of a hydrogen atom lies in the ultraviolet region of the electronmagnetic spectrum.
[Spektrum pancaran siri Lyman atom hidrogen terletak dalam rantau ultraungu spektrum elektromagnetik.]

III. The Paschen series emission spectrum of a hydrogen atom lies in the infrared region of the electronmagnetic spectrum.
[Spektrum pancaran siri Paschen atom hidrogen terletak dalam rantau infra merah spektrum elektromagnetik.]

IV. The Balmer series absorption spectrum of a hydrogen atom lies in the visible region of the electronmagnetic spectrum.
[Spektrum serapan siri Balmer atom hidrogen terletak dalam rantau nampak spektrum elektromagnetik.]

A. I, II, III, IV B. I, II, III C. II, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANS: A (ALL)

3 Which of the following statements is (are) true regarding the wave function of a quantum particle?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai fungsi gelombang bagi suatu zarah kuantum?]

I. The wavefunction is directly measurable.
[Fungsi gelombang dapat diukur secara terus.]

II. The square of the wavefunction is a measure of the probability of observing the quantum particle within a region in space.
[Kuasadua fungsi gelombang merupakan satu sukatan kebarangkalian untuk memerhatikan zarah kuantum di dalam suatu rantau ruangan.]

III. The square of the wavefunction is a measure of the energy of the quantum particle.
[Kuasadua fungsi gelombang merupakan satu sukatan untuk tenaga zarah kuantum.]

IV. The wavefunction of a free particle is zero everywhere.
[Fungsi gelombang suatu zerah bebas adalah sifar di mana-mana.]

A. I, III B. II, IV C. I ONLY
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: D, II only. **[My own question.]**

4. Which of the following statements is (are) true regarding the linear momentum of an object?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai momentum linear agi suatu objek?]

I. The object's momentum is dependent on its speed.
[Momentum objek bersandar kepada lajunya.]

II. The object's momentum is dependent on the frame in which it is being measured.
[Momentum objek bersandar kepada rangka dalam mana ia diukur.]

III. In special theory of relativity, there is an upper limit to the magnitude of an object's linear momentum.
[Dalam teori kerelatifan wujudnya limit atas ke atas magnitud momentum linear suatu objek.]

IV. In non-relativistic theory of classical mechanics, there is no upper limit to the magnitude of its linear momentum.
[Dalam teori mekanik klasik bukan kerelatifan tidak wujud limit atas ke atas magnitud momentum linear suatu objek.]

A. I, III B. I, II, IV C. I ONLY
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: B [My own question.]

5. Which of the following statements is (are) true regarding the kinetic energy of an object?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tenaga kinetik suatu objek?]

I. The kinetic energy of an object is the energy associated with the motion of the object.
[Tenaga kinetik suatu objek adalah tenaga yang berkaitan dengan pergerakan objek.]

II. In special theory of relativity, the kinetic energy of an object cannot be larger than its rest energy.
[Dalam teori kerelatifan, tenaga kinetik suatu objek tidak boleh melebihi tenaga rehatnya.]

III. The relativistic expression of kinetic energy reduces to that of the classical theory of machanics in the limit $v << c$.
[Ungkapan tenaga kinetik keretatifan terturun kepada ungkapan mekanik teori klasik dalam limit $v<<c$.]

IV. The classical expression of kinetic energy reduces to that of the special theory of relativity in the limit $v << c$.
[Ungkapan tenaga kinetik klasik terturun kepada ungkapan kerelatifan dalam limit $v<<c$.]

A. I, II, III B. I, II, IV C. I, III
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: C [My own question.]

6. Consider a proton and an electron, both moving at a common speed, v. Let K_p and K_e denote the the proton and electron's kinetic energy respectively. Which of the following statements is (are)?
[Pertimbangkan suatu proton dan suatu elektron, kedua-duanya bergerak dengan laju yang sama, v. Biar K_p dan K_e masing-masing menandakan tenaga kinetik proton dan elektron. Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. $K_p = (m_p/m_e)K_e$ for $v << c$. *[$K_p = (m_p/m_e)K_e$ untuk $v << c$.]*
II. $K_p = (m_p/m_e)K_e$ for v close to c. *[$K_p = (m_p/m_e)K_e$ untuk v mendekati c.]*

III. $K_p > K_e$ for all values of $v < c$. *[$K_p > K_e$ untuk semua nilai $v < c$.]*
IV. The ratio of K_p/K_e depends on the magnitude of v. *[nisbah K_p/K_e bergantung kepada magnitud v.]*

A. I, II, III B. IV only C. II , III
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*

ANS: A [IV is false. My own question.] $\frac{\gamma m_P c^2}{\gamma m_e c^2} = \frac{K_P + m_P c^2}{K_e + m_e c^2} \Rightarrow \frac{K_P}{K_e} = \frac{m_P}{m_e}$

7. Let say you have found a map revealing a huge galactic treasure at the opposite edge of the Galaxy 200 ly away. Is there any chance, from the relativistic point of view, for you to travel such a distance from Earth and arrive at the treasure site by traveling on a rocket within your lifetime of say, 60 years?
[Katakan anda telah menjumpai satu peta yang membongkar harta karun galaktik sejauh 200 tahun cahaya di sebelah sisi Galaksi yang bertentangan. Dari segi teori kerelatifan, adakah wujud apa-apa peluang supaya anda dapat menjelajahi jarak tersebut dari Bumi dengan menaiki roket dan sampai ke tempat harta karun dalam masa hayat anda, katakan 60 tahun?]

A. No, it is impossible to reach the treasure site within our lifespan of 60 years because it takes a minimum of 200 year of traveling time to reach there.
[Tidak. Adala tidak mungkin untuk sampai ke tempat harta karun dalam masa hayat 60 tahun kerana tempoh penjelajahan untuk sampai ke sana adalah sekurang-kurangnya 200 tahun.]

B. No, it is impossible to reach the treasure site within our lifespan of 60 years because we can't travel faster than the speed of light.
[Tidak. Adala tidak mungkin untuk sampai ke tempat harta karun dalam masa hayat 60 tahun kerana kita tidap mungkin bergerak lebih pantas daripada laju cahaya.]

C. Yes, it is possible to reach the treasure site within our lifespan of 60 years because theory of relativity allows the rocket to travel faster than the speed of light.
[Ya. Adala mungkin untuk sampai ke tempat harta karun dalam masa hayat 60 tahun kerana teori kerelatifan membenarkan roket bergerak lebih pantas daripada laju cahaya.]

D. Yes, it is possible to reach the treasure site within our lifespan of 60 years because the traveling time to reach there could be significantly smaller than 200 years due to relativistic effect.
[Ya. Adala mungkin untuk sampai ke tempat harta karun dalam masa hayat 60 tahun kerana tempoh penjelajahan untuk sampai ke sana boleh jadi jauh lebih singkat daripada 200 tahun disebabkan oleh kesan kerelatifan.]

ANS: D [My own question, pg. 1 in lecture note]

8. Which of the following statements is (are) true according to the special theory of relativity?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai teori kerelatifan?]

I. A massless particle must always travel at the speed of light.
[Suatu zarah tanpa jisim mesti sentiasa bergerak dengan laju cahaya.]

II. A particle with non-zero mass must always travel at the speed smaller than that of light.
[Suatu zarah dengan jisim bukan sifar mesti sentiasa bergerak dengan laju yang kurang daripada laju cahaya.]

III. The length of a moving object along its direction of motion is shorter than that measured at rest.
[Panjang suatu objek dalam arah gerakannya adalah lebih pendek daripada panjangnya yang diukur semasa ia rehat.]

IV. The rest mass of an object is greater when it is moving than at rest.
[Jisim rehat bagi suatu objek adalah lebih besar semasa ia bergerak berbanding dengan jisim rehatnya semasa ia rehat .]

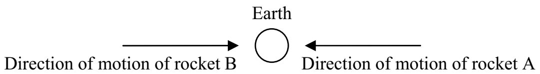
A. I, III, IV B. I, II, III, IV C. I, II, III
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANS: C [My own question.]

9. When two particles collide relativistically, *[Bila dua zarah berlanggar secara kerelatifan,]*

I. the total rest energy is conserved. *[jumlah tenaga rehat adalah terabadikan.]*
II. the total rest mass is conserved. *[jumlah jisim rehat adalah terabadikan.]*
III. the total kinetic energy is an invariant. *[jumlah tenaga kinetik adalah tak varian.]*

A. I , II, III B. II, III C. I , II
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANS: D. None of I, II, III is true.

10. Consider two rockets moving in opposit directions towards the Earth. See figure below. Rocket A is moving towards Earth at a speed of 0.5*c* (relative to Earth) while rocket B with a speed of 0.51*c* (relative to Earth). Which of the following statements is (are) true?
[Pertimbangkan dua roket yang bergerak dalam dua arah bertentangan, masing-masing menghadap ke Bumi. Rujuk gambarajah. Roket A bergerak menuju ke arah Bumi dengan laju 0.5c (relatif kepada Bumi) manakala roket B dengan laju 0.51c (relatif kepada Bumi). Yang manakah kenyataan(-kenyataan) berikut adalah benar?]



I. The magnitude of the relative velocity of rocket A with respect to rocket B is less than 1.01 *c*.
[Magnitud halaju relatif roket A merujuk kepada roket B adalah kurang daripada 1.01c.]

II. The magnitude of the relative velocity of rocket A with respect to rocket B is less than *c*.
[Magnitud halaju relatif roket A merujuk kepada roket B adalah kurang daripada c.]

III. The magnitude of the relative velocity of rocket A with respect to rocket B is equal to *c*.

[Magnitud halaju relatif roket A merujuk kepada roket B adalah sama dengan c.]

IV. The magnitude of the relative velocity of rocket A with respect to rocket B is equal to 1.01 *c*.
[Magnitud halaju relatif roket A merujuk kepada roket B adalah sama dengan 1.01c.]

A. I, II B. I, III C. IV only
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANS: A [PYQ, 05/06 Final, Q15, modified]

11. For a blackbody, the total intensity of energy radiated over all wavelengths, *I*, is expected to rise with temperature according to the *Stefan's law*: $I = \sigma T^4$, where σ is the Stefan's constant. How does the total intensity of thermal radiation vary when the temperature of a black body is doubled?
[Bagi suatu jasad hitam, jumlah keamatan tenaga terpancarkan untuk semua jarak gelombang, I, dijangka akan meningkat jika suhu meningkat, menurut hukum Stefan, $I = \sigma T^4$*, di mana* σ *adalah pemalar Stefan. Bagaimanakah jumlah keamatan pancaran terma berubah bila suhu jasad hitam menjadi dua kali lebih besar?]*

A. The total intensity of thermal radiation increase by 2 times.
[Jumlah keamatan pancaran terma bertambah sebanyak 2 kali.]
B. The total intensity of thermal radiation increase by 4 times.
[Jumlah keamatan pancaran terma bertambah sebanyak 4 kali.]
C. The total intensity of thermal radiation increase by 16 times
[Jumlah keamatan pancaran terma bertambah sebanyak 16 kali.]
D. The total intensity of thermal radiation remains the same.
[Jumlah keamatan pancaran terma adalah sama.]

ANS:C, Tut 2 04/05, P1

12. In the spectral distribution of blackbody radiation, the wavelength λ_{max} at which the intensity reaches its maximum value decreases as the temperature is increased, in inverse proportional to the temperature: $\lambda_{max} \propto 1/T$. This is called the *Wein's displacement law*. It explains the observation that when a blackbody is heated up to 1800K it starts to glow and appears dim red. According to Wein's law, when the temperature continue to increase, the colour would change from dim red towards blue and then white hot. What is the change of the apparent colour to human eye when temperature drops from 450K to 370 K?
[Dalam taburan spektrum pancaran jasad hitam, jarak minimum λ_{max} *pada mana keamatan mencapai nilai maksimumnya akan berkurang bila suhu dinaikkan mengikut* $\lambda_{max} \propto 1/T$*. Ini dipanggil hukum sesaran Wein. Ia menerangkan cerapan bahawa semasa suatu jasad hitam dipanaskan kepada 1800K, ia mula berbara dan kelihatan merah pudar. Menurut hukum Wein, jika suhu terus meningkat, warnanya akan berubah daripada merah pudar kepada biru dan kemudiannya panas putih. Apakah perubahan warna ketara kepada mata manusia bila suhu jatuh daripada 450K kepada 370 K?]*

A. It changes from red hot to blue hot. *[Ia berubah daripada merah panas kepada biru panas.]*
B. It changes from red hot to dark. *[Ia berubah daripada merah panas kepada hitam.]*
C. Its apparent colour doesn't change. *[Warna ketaranya tidak berubah.]*

D. It changes from white hot to red hot. *[Ia berubah daripada putih panas kepada merah panas.]*

ANS:C, http://library.wolfram.com/webMathematica/Astronomy/Blackbody.jsp
(BB at temperature lower than 1800 K doesn't appear to have any 'colour' to our human eye.)

13. Which of the following statements is (are) true regarding X-rays?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai sinaran-X?]

I. X-ray can be used to determine the geometry of the lattice of a crystal. (T)
[Sinaran-X boleh digunakan untuk menentukan geometri kekisi sesuatu hablur.]

II. X-rays can be produced by bombarding a metal target with electrons accelerated by an electric potential field of 10,000 V. (T)
[Sinaran-X boleh dihasilkan dengan menghentam suatu sasaran logam dengan elektron yang dipecutkan oleh suatu medan keupayaan elektrik 10,000 V.]

III. Tungsten and molybdenum, two types of material usually used as target material in an X-rays tube, give off different λ_{min} of X-rays when the X-ray tube is operating at a common potential V. (F)
[Tungsten dan molibdenum, dua jenis bahan yang biasanya digunakan sebagai bahan sasaran dalam tiub sinaran-X, mengeluarkan λ_{min} sinaran-X yang berbeza semasa tiub sinaran-X beroperasi pada keupayaan yang sama.]

IV. X-rays behave like wave in Braggs diffraction of X-ray by a crystal lattice. (T)
[Sinaran-X berkelakuan seperti gelombang dalam belauan sinaran-X Braggs oleh kekisi bablur.]

A. I, II, III, IV   B. I, II, III   C. I, II, IV
D. None of A, B, C.
ANS: C. (My Own Question)

14. Which of the following statements is (are) true regarding light?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai cahaya?]

I. Light behaves like wave in a diffraction experiment. (T)
[Cahaya berkelakuan seperti gelombang dalam eksperimen belauan.]

II. Light behaves like particle in a photoelectric experiment. (T)
[Cahaya berkelakuan seperti zarah dalam eksperimen fotoelektrik.]

III. Light behaves like particle in a Compton scattering experiment. (T)
[Cahaya berkelakuan seperti zarah dalam eksperimen serakan Compton.]

IV. Light can manifest both particle and wave nature in a single experiment. (F)
[Cahaya boleh memperlihatkan kedua-dua tabii zarah dan gelombang dalam satu eksperimen yang sama.]

A. I, II, III   B. II, III, IV   C. I, III, IV
D. None of A,B, C.
ANS: A. (My Own Question)

15. Which of the following statements is (are) true regarding photoelectric effect?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai kesan fotoelektrik?]

I. The photoelectric effect requires special theory of relativity for an explaination.
[Kesan fotoelektrik memerlukan teori kerelatifan untuk penerangannya.]

II. In a typical photoelectric effect experiment the energy involved is usually relativistic.
[Dalam suatu eksperimen kesan fotoelektrik yang tipikal, tenaga yang terlibat biasanya adalah relativistik.]

III. The probability of photoelectric effect to occur in a metal target would diminish when the energy of the striking photon becomes increasingly relativistic.
[Kebarangkalian kesan fotoelektrik berlaku di dalam sararan logam akan menyusut bila tenaga foton yang menghentum menjadi semakin relativistik.]

IV. The saturation photoelectric current increases as the energy of incident photons increases (with the radiation fixed at a constant intensity).
[Arus fotoelektrik tepu bertambah semasa tenaga foton tuju bertambah (dengan sinaran ditetapkan pada keamatan malar).]

A. I, II, III, IV   B. I, II, III   C. I, II, IV
D. None of A, B, C.
ANS: D. Only III is true.

.../12 -

16. Consider a matter particle with rest mass m_0, moving with a speed v. Which of the following statements is (are) true regarding its de Broglie wave? Take $\gamma = 1/\sqrt{1-(v/c)^2}$.
[Pertimbangkan suatu zarah jirim berjisim rehat m_0, bergerak dengan laju v. Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai gelombang de Broglienya? Ambil $\gamma = 1/\sqrt{1-(v/c)^2}$.]

I. The de Broglie wavelength of the matter particle is $\lambda = h/(\gamma m_0 v)$ regardless of whether the particle is relativistic or not (T).
[Jarak gelombang de Broglie zarah jirim ialah $\lambda = h/(\gamma m_0 v)$, tidak kira samada zarah tersebut adalah dalam keadaan kerelatifan atau tidak].

II. The de Broglie wavelength of the matter particle is $\lambda = h/(\gamma m_0 v)$ even if v is non relativistic (T).
[Jarak gelombang de Broglie zarah jirim ialah $\lambda = h/(\gamma m_0 v)$ walaupun zarah tersebut adalah dalam keadaan bukan kerelatifan.]

III. The de Broglie wavelength of the matter particle is $\lambda = h/(m_0 v)$ if v is non-relativistic (T).

[Jarak gelombang de Broglie zarah jirim ialah $\lambda = h/(m_0 v)$ *jika zarah tersebut adalah dalam keadaan bukan kerelatifan.]*

IV. If the matter particle is relativistic, the de Broglie wavelength is larger than $h/(\gamma m_0 v)$. (F)
[Jika zarah jirim adalah dalam keadaan kerelatifan, jarak gelombang de Broglie zarah adalah lebih besar daripada $\lambda = h/(\gamma m_0 v)$*.]*

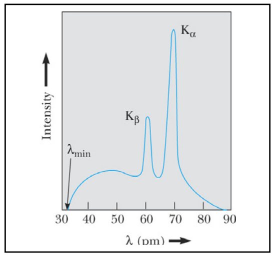
A. I, II, III B. II, III C. II, III, IV D. None of A, B, C.
ANS: A. (My Own Question, modified from PYQ 05/06 Test II, Q14)
For both cases of relativistic and non-relativistic, their dB wavelengths are correctly given by $\lambda = h/(\gamma m_0 v)$.

17. Which of the following statements are (is) true
[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. $hc \approx 1240\,\text{keV}\cdot\text{nm}$ (Planck constant × speed of light)
II. $m_e \approx 511\text{keV}/c^2$ (electron's mass)
III. $\gamma = 1/\sqrt{1-\left(\frac{v}{c}\right)^2} \approx 1$ for the typical speed v of a car on the PLUS highway.
IV. $a_0 \approx 0.53\text{pm}$ (Bohr's radius)

A. I, II, IV B. II, III C. I, II, III, IV
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANS: B. PYQ 05/06 Final, Q21, modified.

18. The figure below shows the x-ray spectrum of a metal target from a x-ray tube. Which of the following statements are (is) true?
[Gambarajah berikut memaparkan spektrum sinaran-X daripada sasaran logam suatu tiub sinaran-X. Yang manakah kenyataan(-kenyataan) berikut adalah benar?]



I. The broad continuous spectrum cannot be explained by classical electromagnetic theory.
[Spektrum selanjar yang lebar tidak dapat diterangkan oleh teori elektromagnet klasik.]

II. The existence of $\lambda_{\min}$ in the spectrum can well be explained in terms of classical theories.
[Kewujudan $\lambda_{\min}$ *dalam spektrum dapat diterangkan dengan baiknya oleh teori-teori klasik.]*

III. $\lambda_{\min}$ is dependent on the energy of the borbarding electrons.
[$\lambda_{\min}$ *adalah bersandar pada tenaga elektron yang menghentum sasaran logam.]*

IV. The broad continuous spectrum demonstrates a proof for the photon theory for X-rays.
[Spektrum selanjar yang lebar memperlihatkan bukti kepada teori foton untuk sinaran-X.]

A. I, III, IV B. I, II, III, IV C. III Only
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANS: C. PYQ 05/06 Final, Q27, modified.

19. Which of the following statements are (is) true regarding a quantum particle in an (ideal) infinite squre well?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai zarah kuantum di dalam telaga segiempat infinit (yang ideal)?]

I. The rest energy of the particle is equal to the zero point energy.
[Tenaga rehat zarah adalah sama dengan tenaga titik sifar.]

II. The zero point energy tends to zero if the width of the well increase indefinitely.
[Tenaga titik sifar menokok kepada sifar jika lebar telaga bertambah tak terhingga.]

III. On theory, the largest allowed energy level of the particle in the well is infinity.
[Secara teori, paras tenaga terizinkan yang tertinggi bagi zarah dalam telaga ialah infiniti.]

IV. The zero point energy tends to zero if the temperature of the particles tends to absolute zero.
[Tenaga titik sifar menokok kepada sifar jika suhu zarah menokok kepada sifar.]

A. II, III B. II, III, IV C. I, II, III
D. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANN: A [My own question]

20. Consider a photon of wavelength λ undergoes pair creation process into a pair of particles-antiparticles, each with rest mass m. If one of the particles is measured to have kinetic energy of K_1, what is the kinetic energy of the other particle?
[Pertimbangkan suatu foton dengan jarak gelombang λ *yang melakukan penghasilan berpasangan kepada suatu pasangan zarah-antizarah, dengan jisim rehat mereka m. Jika tenaga kinetik salah satu zarah diukur sebagai* K_1*, apakah tenaga kinetik bagi zarah yang satu lagi?]*

A. $\frac{hc}{\lambda} - K_1 - 2mc^2$ B. $\frac{hc}{\lambda} + K_1 + 2mc^2$ C. $\frac{hc}{\lambda} + K_1 - 2mc^2$

D. $\frac{hc}{\lambda} - K_1 + 2mc^2$

ANS: A. [My own question]

Section B: Structural Questions. [80 marks]
[Bahagian B: Soalan-soalan Struktur]

Instruction: Answer ALL FOUR (4) questions in this Section. Each question carries 20 marks.
[Arahan: Jawab KESEMUA EMPAT (4) soalan dalam Bahagian ini. Setiap soalan membawa 20 markah].

1. [20 marks]

(a) Derive the theoretical Rydberg constant in the Bohr model. Show that it is given by:
[Terbitkan pemalar Rydberg secara teori dalam model Bohr. Tunjukkan bawaha ia diberikan oleh:]

$$R_\infty = \frac{2\pi^2 (ke^2)^2 (m_e c^2)}{(hc)^3}, \text{ where } k = \frac{1}{4\pi\varepsilon_0}.$$

[10/20]

(b) Determine, in Angstroms *[Hitungkan, dalam unit Angstroms]*

(i) the shortest and, *[jarak gelombang yang terpendek, dan]* **[5/20]**

(ii) the longest wavelengths of the Lyman series of hydrogen.
[jarak gelombang yang terpanjang untuk hidrogen dalam siri Lyman.]

[5/20]

Solution
(a) Schaum series Modern Physics, pg. 104, 105

Mechanical stability:

$$\frac{ke^2}{r^2} = \frac{mv^2}{r} \Rightarrow kv^2 = (mvr)v \qquad \text{Eq(1)}$$

Quantization of orbital momentum:

$$L = pr = (mv)r = n\hbar \qquad \text{Eq(2)}$$

Eq(2) →Eq(1):

$$ke^2 = n\hbar \Rightarrow v = \frac{ke^2}{n\hbar} \qquad \text{Eq. (3)}$$

Eq(3) →Eq(2):

$$r = \frac{n\hbar}{mv} = \frac{n\hbar}{m}\frac{n\hbar}{ke^2} = \frac{n^2\hbar^2}{mke^2} \qquad \text{Eq. (4)}$$

Total energy:

$$E = K + V = \frac{mv^2}{2} - \frac{ke^2}{r} \qquad \text{Eq, (5)}$$

Eq(3), Eq(4) →Eq(5):

$$E = \frac{m}{2}\left(\frac{ke^2}{n\hbar}\right)^2 - m\left(\frac{ke^2}{n\hbar}\right)^2 = -\frac{m}{2}\left(\frac{ke^2}{n\hbar}\right)^2 \equiv \frac{E_0}{n^2};$$

where ground state energy is $E_0 = -\frac{m}{2}\left(\frac{ke^2}{\hbar}\right)^2$.

Energy of photon during transition from n_i to n_f is

$$\frac{hc}{\lambda} = \Delta E = E_i - E_f = \frac{E_0}{n_i^2} - \frac{E_0}{n_f^2} = -E_0\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$\Rightarrow \frac{1}{\lambda} = -\frac{E_0}{hc}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \equiv R_\infty\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$R_\infty = -\frac{E_0}{hc} = \frac{m}{2hc}\left(\frac{ke^2}{\hbar}\right)^2 \times \frac{c^2}{c^2} = \frac{2\pi^2 mc^2 (ke^2)^2}{(hc)^3}$$

(b) Schaum series Modern Physics, pg. 107, Q11.1.
In Lyman series, emission wavelengths are given by

$$\Rightarrow \frac{1}{\lambda} = -\frac{E_0}{hc}\left(\frac{1}{1^2} - \frac{1}{n_i^2}\right) = \frac{13.6\text{eV}}{1240\text{eV}\cdot\text{nm}}\left(1 - \frac{1}{n_i^2}\right)$$

(i) For shortest wavelenght, $n_i = \infty$,

$$\frac{1}{\lambda_{shortest}} = \frac{13.6\text{eV}}{1240\text{eV}\cdot\text{nm}}\left(1 - \frac{1}{\infty}\right) = \frac{13.6\text{eV}}{1240\text{eV}\cdot\text{nm}} \Rightarrow \lambda_{shortest} = \frac{1240\text{eV}\cdot\text{nm}}{13.6\text{eV}} = 91.2\text{nm}$$

(ii) For longest wavelenght, $n_i = 2$,

$$\frac{1}{\lambda_{longest}} = \frac{13.6\text{eV}}{1240\text{eV}\cdot\text{nm}}\left(1 - \frac{1}{2^2}\right) = \left(\frac{3}{4}\right)\frac{13.6\text{eV}}{1240\text{eV}\cdot\text{nm}} \Rightarrow \lambda_{longest} = \left(\frac{4}{3}\right)\frac{1240\text{eV}\cdot\text{nm}}{13.6\text{eV}} = 121.6\text{nm}$$

- ooo O ooo -

2. [20 marks]

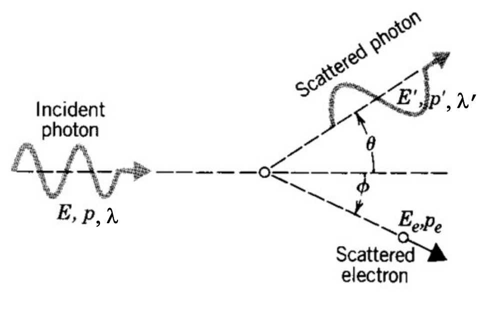


Figure 1

(a) Consider figure 1. A photon with initial energy *E*, momentum *p* and wavelength λ is scattered by an initially stationary electron of rest mass m_e. The scattered angle, energy, momentum and wavelength of the scattered photon are as indicated in the figure. So are the energy and momentum of the recoiled electron.
[Pertimbangkan rajah 1. Suatu foton dengan tenaga awal E, momentum p dan jarak gelombang λ, diserakkan oleh suatu elektron (berjisim rehat m_e) yang pada awalnya dalam keadaan rehat. Sudut serakan, tenaga, mementum dan jarak gelombang foton yang terserak adalah seperti yang ditunjukkan di dalam rajah. Begitu juga bagi tenaga, sudut dan momentum elektron yang tersentak.]

(i) Write down the conservation of momentum for the above process.
[Tuliskan keabadian momentum untuk pross tersebut.]

[4/20]

(ii) Write down the conservation of energy for the above process.
[Tuliskan keabadian tenaga untuk proses tersebut.]

[6/20]

(b) X-rays of wavelength λ_0 =0.200 000 nm are Compton scattered from a block of material.
[Sinaran-X dengan jarak gelombang λ_0 =0.200 000 nm diserakkan secara Compton daripada suatu blok jirim.]

(i) If the scattered x-rays are observed at an angle of 45° to the incident beam, what is the Compton shift?
[Jika sinaran-X yang terserak dicerap pada sudut 45° kepada sinaran tuju, apakah anjakan Comptonnya?]

[5/20]

(ii) What is the Compton shift of the x-rays photon if x-rays of wavelength 0.520 000 nm is used instead?
[Apakah anjakan Compton foton jika sinaran-X berjarak gelombang λ_0 =0.520 000 nm digunakan?]

[2½/20]

(iii) If the detector is moved so that the scattered x-rays are detected at a larger angle of say, 60°. Does the wavelength of the scattered x-rays increase or decrease as the angle increases?
[Jika pengesan digerakkan supaya sinaran-X terserak dikesan pada suatu sudut yang lebih besar, katakan 60°. Adakah jarak gelombang terserak akan bertambah atau berkurang?]

[2½/20]

ANS:
(a) Lecture note page 55.
(I) Mom conservation in y : $p'\sin\theta = p_e \sin\phi$
Mom conservation in x : $p - p'\cos\theta = p_e\cos\phi$
(II) Conservation of total relativistic energy:
$cp + m_e c^2 = cp' + E_e$
(b) Serway, pg. 1300, example 40.4
(I) $\Delta\lambda = \frac{h}{m_e c}(1-\cos 45^\circ) = 7.10\times10^{-13}$ m.
(II) same., 7.10×10^{-13} m.
(III) scattered wavelength increases.

3. [20 marks]

(a) A proton or a neutron can sometimes "violate" conservation of energy emitting and then reabsorbing a pi meson, which has a mass of 135 MeV/c^2. This is possible as long as the pi meson is reabsorbed within a short enough time Δ*t* consistent with the uncertainty principle. Consider p→ p + π.
[Suatu proton atau neutron kadang-kala akan 'mencanggah' keabadian tenaga dengan memancar dan kemudiannya menyerap balik suatu meson pi yang berjisim 135 MeV/c^2. Ini adalah mungkin selagi meson pi tersebut diserap balik dalam suatu selang masa singkat Δt yang konsisten dengan prinsip ketidakpastian. Pertimbangkan p→p + π.]

(i) By what amount Δ*E* is energy conservation violated? (Ignore any kinetic energies.)
[Seberapa bankyakah ketidakpastian tenaga ΔE yang telah mencanggahi keabadian tenaga? (Abaikan tenaga kinetik.)]

[4/20]

(ii) For how long a time Δ*t* can the pi meson exist?
[Untuk berapa lamakah Δt yang boleh meson pi wujud?]

[4/20]

(iii) Assuming pi meson to travel at very nearly the speed of light, how far from the proton can it go?

[Andaikan meson pi itu bergerak pada laju yang amat menyamai laju cahaya, berapa jauhkah daripada proton itu yang dapat pi meson pergi?]

[2/20]

(b) By treating it non-relativistically, find the de Broglie wavelength of a proton with kinetic energy 1.00-MeV.
[Dengan pertimbangan secara tak-relativistik, hitungkan jarak de Broglie suatu proton yang tenaga kinetiknya 1.00-MeV.]

[10/20]

Solution
(a) (Krane, P22, pg. 133)

(i) $\Delta E = m_\pi c^2 = 135\,\text{MeV} = 2.16\times10^{-9}$ J.

(ii) $\Delta t \geq \dfrac{\hbar}{2\Delta E} = 2.40\times10^{-24}$ s.

(iii) distance $= c\Delta t \leq = 0.73\times10^{-15}$ m.

(b) (Beiser, Ex. 6, pg. 117)

3-6: The proton's kinetic energy is only about 0.1% of its rest energy, so a nonrelativistic calculation will suffice. The wavelength is

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m\,\text{KE}}} = \frac{hc}{\sqrt{2\,(mc^2)\,\text{KE}}}$$
$$= \frac{1.240\times10^{-12}\ \text{MeV}\cdot\text{m}}{\sqrt{2\,(939.3\ \text{MeV})\,(1.00\ \text{MeV})}} = 2.86\times10^{-14}\ \text{m}.$$

Note the conversion of units in the product hc in the above calculation.

4. [20 marks]

(a) Consider a relativistic object of momentum, p, total energy, E, and rest mass, m_0.
[Pertimbangkan suatu objek relativistik dengan momentum p, jumlah tenaga E, dan jisim rehatnya m_0.]

(i) Write down the equation relating the magnitude of relativistic momentum, total energy, and the rest mass this object.
[Tuliskan persamaan yang menghubung-kaitkan magnitud momentum relativistik, jumlah tenaga dan jisim rehat objek tersebut.]

[3/20]

(ii) Sketch the graf of E vs. p. Lable and indicate on your graph the value of rest energy E_0.
[Lakarkan graf E lawn p. Lable dan tunjukkan pada lakaran anda nilai tenaga rehat, E_0.]

[3/20]

(iii) What is the momentum of the object when the momentum is such that pc equal to half of the object's total energy? Express your answer in terms of m_0 and c.
[Apakah momentum objek tersebut jika momentumnya adalah sedemikian rupa sehingga pc bersamaan dengan separuh daripada jumlah tenaga objek tersebut? Ungkapkan jawapan anda dalam sebutan m_0 dan c.]

[3/20]

(iv) What is the corresponding speed, v in (iii)?
[Apakah laju yang berkaitan dalam (iii)?]

[5/20]

(b)

(i) A meter stick moves with a velocity of 0.6c relative to you along the direction of its length. How long will it take for the meter stick to pass you?
[Suatu pembaris meter bergerak dalam arah panjang pembaris tersebut pada halaju 0.6c relatif kepada anda. Berapa lamakah masa yang diambil pembaris meter itu untuk melepasi anda?]

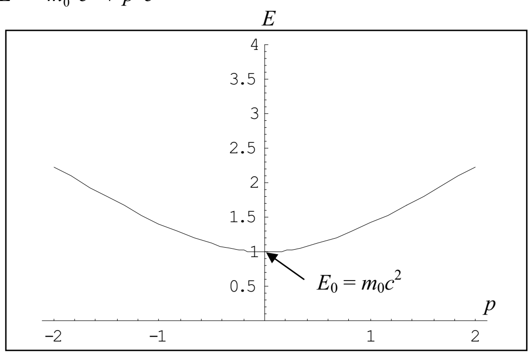
[6/20]

Ans:

(a) My own question.

(i) $E^2 = m_0^{\,2}c^4 + p^2c^2$

(ii)



(iii)

$$E^2 = m_0^{\,2}c^4 + p^2c^2$$
$$(2pc)^2 = m_0^{\,2}c^4 + p^2c^2$$
$$3p^2c^2 = m_0^{\,2}c^4$$
$$p = m_0c/\sqrt{3}$$

(iv)

$$p = \gamma m_0 v$$
$$p^2 = \gamma^2 v^2 m_0{}^2$$
$$\frac{m_0{}^2 c^2}{3} = \frac{v^2 m_0{}^2}{1-(v/c)^2}$$
$$v = c/2.$$

(b) Schaum's series Modern Physics, pg. 27, Q6.1.

The length of the meter stick as measured by you is improper length, given by

$$L = L_0\sqrt{1-(v/c)^2} = (1\text{m})\sqrt{1-(0.6)^2} = 0.8\text{m}$$

The time for the meter stick to pass you is then found from

Distance = velocity × time

0.8 m = $0.6c \times \Delta t$

$\Delta t = 4.44 \times 10^{-9}$ s.

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ZCT 104/3E Modern Physics
Semester II, Sessi 2006/07
Open Book Quiz I (22 Dec 2007)
Duration: 30 min

Name:

Matrics No:

INSTRUCTION: Answer both following questions. Note that question 2 is printed at the opposite page. Each question carries 10 marks.

1. Derive time dilation effect $\Delta\tau = \Delta t/\gamma$ by using the Lorentz transformation formula, where $\Delta\tau$ is the proper time interval, Δt the improper time interval, and γ is the Lorentz factor, $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$.

ANS

Lorentz transformation: $x' = \gamma(x - vt), t' = \gamma\left(t - \frac{v}{c^2}x\right)$.

Say two events are happening at the same point one after another in the primed frame, which is moving with a constant velocity v with respect to an unprimed frame. The proper time between these two events is $\Delta\tau = t_2' - t_1'$. By definition, these two events are happening in the same point in the primed frame, hence $x_2' - x_1' = 0$.

The temporal interval of these two events as observed in the unprimed frame, $\Delta t = t_2 - t_1$, according to LT, could be related to $\Delta\tau = t_2' - t_1'$ via LT as

$$\Delta\tau = t_2' - t_1' = \gamma\left(t_2 - \frac{v}{c^2}x_2\right) - \gamma\left(t_1 - \frac{v}{c^2}x_1\right) = \gamma(t_2 - t_1) - \frac{\gamma v}{c^2}(x_2 - x_1) = \gamma\Delta t - \frac{\gamma v}{c^2}(x_2 - x_1),$$

where x_2 and x_1 are the event sites as observed in the unprimed frame. Within the temporal interval of Δt, the primed frame has moved through a distance of $v\Delta t$ (as observed by an observer in the unprimed frame), which is equal to the displacement of the two event sites from the unprimed frame point of view: $(x_2 - x_1) = v\Delta t$.

Hence, $\Delta\tau = \gamma\Delta t - \frac{\gamma v}{c^2}(v\Delta t) = \gamma\Delta t - \frac{\gamma v^2}{c^2}\Delta t = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}\Delta t\left(1 - \frac{v^2}{c^2}\right) = \Delta t\sqrt{1 - \frac{v^2}{c^2}} = \Delta t/\gamma$.

Hence we recover time dilation formula: $\Delta\tau = \Delta t/\gamma$

2. An object of rest mass M decays into two daughter objects of rest mass m_1 and m_2 respectively. Calculate the kinetic energy for each of the daughter masses respectively in terms of M, m_1 and m_2.

ANS

By conservation of energy: total energy before decay = total energy after decay:

$$E = E_1 + E_2,$$

where

$E = Mc^2$ $E_1 = K_1 + m_1c^2$, $E_2 = K_2 + m_2c^2$

$\Rightarrow Mc^2 = (K_1 + K_2) + (m_1 + m_2)c^2$ Eq(1)

For daughter mass 1:

$E_1{}^2 = p_1{}^2c^2 + m_1{}^2c^4$. Eq. (2)

Likewise, for daughter mass 2:

$E_2{}^2 = p_2{}^2c^2 + m_2{}^2c^4$ Eq. (3)

Due to conservation of momentum: $|\vec{p}_2| \equiv p_2 = |\vec{p}_1| \equiv p_1 \equiv p$

Eq. (3) - Eq. (2):

$E_2{}^2 - E_1{}^2 = (m_2{}^2 - m_1{}^2)c^4$

$\Rightarrow (E_2 - E_1)(E_2 + E_1) = (m_2{}^2 - m_1{}^2)c^4$ Eq. (4)

Substitute $E_1 = K_1 + m_1c^2$, $E_2 = K_2 + m_2c^2$ and $E_1 + E_2 = E = Mc^2$ into Eq. (4),

$\Rightarrow [(K_2 - K_1) + (m_2 - m_1)c^2](Mc^2) = (m_2{}^2 - m_1{}^2)c^4$

$\Rightarrow (K_2 - K_1) = \left(\frac{m_2{}^2 - m_1{}^2}{M}\right)c^2 - (m_2 - m_1)c^2$ Eq. (5)

We can then solve for K_1 and K_2 from Eq. (5) and Eq. (1):

Eq. (5) + Eq. (6):

$$\Rightarrow 2K_2 = Mc^2 - (m_1 + m_2)c^2 + \left(\frac{m_2{}^2 - m_1{}^2}{M}\right)c^2 - (m_2 - m_1)c^2$$

$$\Rightarrow K_2 = \frac{1}{2}\left[M - m_2\left(2 - \frac{m_2}{M}\right) - \frac{m_1{}^2}{M}\right]c^2$$

Eq. (5) - Eq. (6):

$$\Rightarrow 2K_1 = Mc^2 - (m_1 + m_2)c^2 - \left(\frac{m_2{}^2 - m_1{}^2}{M}\right)c^2 + (m_2 - m_1)c^2$$

$$\Rightarrow K_1 = \frac{1}{2}\left[M - 2m_1 - \left(\frac{m_2{}^2 - m_1{}^2}{M}\right)\right]c^2 = \frac{1}{2}\left[M - m_1\left(2 - \frac{m_1{}^2}{M}\right) - \left(\frac{m_2{}^2}{M}\right)\right]c^2$$

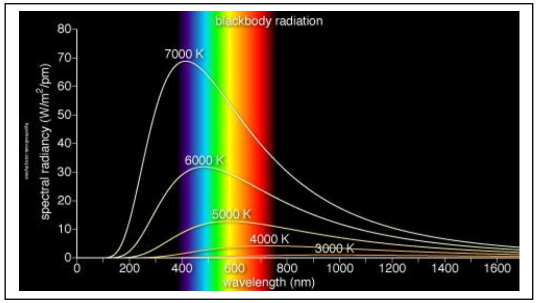
ZCT 104/3E Modern Physics
Semester II, Sessi 2006/07
Open Book Quiz 2 (5 Feb 2007)
Duration: 30 min

Name:

Matrics No:

INSTRUCTION: Answer the following question. Write your answer at the back of this question paper.
(5 + 5 = 10 marks.)

A typical spectral distribution of radiation energy of a blackbody for several temperatures is as shown.



The shift of the peak of the curve was found to obey the empirical relationship,

$\lambda_p T$ = constant , (*Wein's displacement law*)

where the symbol λ_p refers to the value of the wavelength corresponding to the peak of the curve. The *total power radiated per unit area* (i.e. its intensity) of a blackbody is found to be empirically related to its absolute temperature by

$I(T) = \sigma T^4$, (*the Stefan-Boltzman law*)

where σ = 5.6699 $\times 10^{-8}$ watts m^{-2} degree^{-4} (Stefan constant). The radiance, $R(\lambda,T)$ is the power radiated per unit area per unit wavelength interval at a given wavelength λ and a given temperature *T*. $I(T)$ and $R(\lambda,T)$ are related by the integral $I(T) = \int_0^\infty R(\lambda,T)d\lambda$. Wein proposed an empirical form for the radiance $R(\lambda,T)$ by constructing a mathematical function to fit the experimental blackbody curve, knows as the *Wein's law*:

$$R(\lambda,T) = \frac{ae^{-b/\lambda T}}{\lambda^5} \quad \text{(Wein's law)}$$

The quantities *a* and *b* are not derived but are simply curve-fitting parameters.

Question:
From Wien's law as given above,
(i) derive the constant in the displacement law, and (5 marks)
(ii) derive the Stefan-Boltzman constant (5 marks)
in terms of *a* and *b*.

Hint: You may need $\int_0^\infty \frac{e^{-\frac{1}{x}}}{x^5}dx = 6$ or $\int_0^\infty x^3 e^{-x} dx = 6$.

SESSI 06/07/Quiz 2

Solution

(i) $R(\lambda,T) = \frac{ae^{-b/\lambda T}}{\lambda^5}$

$$\frac{d}{d\lambda}R(\lambda,T) = a\left[\frac{b}{T}\left(\frac{1}{\lambda^2}\right)\lambda^5 e^{-b/\lambda T} - 5\lambda^4 e^{-b/\lambda T}\right] / \lambda^{10} \qquad \text{(Eq. 1)}$$

Minimize $R(\lambda,T)$ with respect to λ, we will get λ_p:

$$\left.\frac{d}{d\lambda}R(\lambda,T)\right|_{\lambda_p} = 0 \qquad \textit{(2 marks)}$$

Setting Eq. 1 to zero, we get

$$\frac{b}{T}\lambda_p^3 e^{-b/\lambda_p T} = 5\lambda_p^4 e^{-b/\lambda_p T} \qquad \textit{(show working, 2 marks)}$$

$$\Rightarrow \lambda_p T = b/5 \qquad \textit{(correct answer: 1 marks)}$$

(ii) Stafan-Boltzman law: $I(T) = \sigma T^4$

Substitute Wein's law, $R(\lambda,T) = \frac{ae^{-b/\lambda T}}{\lambda^5}$, into the definition of $I(T) = \int_0^\infty R(\lambda,T)d\lambda$, we get

$$I(T) = \int_0^\infty R(\lambda,T)d\lambda = \int_0^\infty \frac{ae^{-b/\lambda T}}{\lambda^5}d\lambda. \qquad \textit{(1 marks)}$$

Define $x = \frac{b}{\lambda T} \Rightarrow dx = -\frac{b}{T}\frac{1}{\lambda^2}d\lambda$

$$I(T) = a\left(\frac{T}{b}\right)^4 \int_0^\infty x^3 e^{-x}dx = 6a\left(\frac{T}{b}\right)^4 \qquad \textit{(show working, 3 marks)}$$

$$\Rightarrow I(T) = 6a\left(\frac{T}{b}\right)^4 \equiv \sigma T^4 \Rightarrow \sigma \equiv \frac{6a}{b^4} \qquad \textit{(correct answer, 1 mark)}$$

SESSI 06/07/Quiz 3

10/10

ZCT 104/3E Modern Physics
Semester II, Sessi 2006/07
Open Book Quiz III
Duration: 20 min

Name: CHONG HOOI MIN

Matrics No: 83806104

INSTRUCTION: Answer the following question. **[10 marks]**

Derive the Compton scattering formula between a photon and a free particle of mass m:

$$\Delta\lambda = \lambda' - \lambda = \lambda_e(1-\cos\theta)$$

where $\lambda_m = \dfrac{h}{mc}$ is the Compton wavelength of the target particle. Explain your steps clearly.

[10 mark]

mom conservation in y: $p'\sin\theta = p_e \sin\phi$ ✓
mom conservation in x: $p - p'\cos\theta = p_e\cos\phi$ ✓

} squaring and adding $p_e^2 = p^2 - 2pp'\cos\theta + p'^2$ — ① ✓

conservation of total relativistic energy:

$cp + m_e c^2 = cp' + E_e \Rightarrow E + m_e c^2 = E' + E_e$ — ② ✓

$(p_y)^2 + (p_x)^2$, substitute into $(RE)^2$ to eliminate ϕ, p_e and E_e (and using $E_e^2 = c^2 p_e^2 + m_e^2 c^4$):

~~squaring and adding → $p_e^2 = p^2 - 2pp'\cos\theta + p'^2$ — ①~~

Gantiran ① dan ② dlm ③

$E_e^2 = c^2 p_e^2 + m_e^2 c^4$ — ③ ✓

~~$(E + m_e c^2$~~

$(E + m_e c^2 - E')^2 = c^2(p^2 - 2pp'\cos\theta + p'^2) + m_e^2 c^4$ ✓

left: $(E + m_e c^2 - E')^2 = E^2 + 2E m_e c^2 - 2EE' - 2E' m_e c^2 + m_e^2 c^4 + E'^2$

right: $c^2(p^2 - 2pp'\cos\theta + p'^2) + m_e^2 c^4$

$= c^2 p^2 - 2c^2 pp'\cos\theta + c^2 p'^2 + m_e^2 c^4$

left = right

$E^2 + 2E m_e c^2 - 2EE' - 2E' m_e c^2 + m_e^2 c^4 + E'^2 = c^2 p^2 - 2c^2 pp'\cos\theta + c^2 p'^2 + m_e^2 c^4$

$E^2 + 2E m_e c^2 - 2EE' - 2E' m_e c^2 + m_e^2 c^4 + E'^2 = E^2 - 2EE'\cos\theta + E'^2 + m_e^2 c^4$

$2E m_e c^2 - 2EE' - 2E' m_e c^2 = -2EE'\cos\theta$ ✓

$E m_e c^2 - E' m_e c^2 = -EE'\cos\theta + EE'$

$m_e c^2 (E - E') = EE'(1-\cos\theta)$

$\dfrac{E - E'}{EE'} = \dfrac{(1-\cos\theta)}{m_e c^2}$

$\dfrac{1}{E'} - \dfrac{1}{E} = \dfrac{1}{m_e c^2}(1-\cos\theta)$ ✓

$\lambda_e = \dfrac{h}{m_e c}$

$E = \dfrac{hc}{\lambda}$

$\dfrac{\lambda'}{hc} - \dfrac{\lambda}{hc} = \dfrac{1}{m_e c^2}(1-\cos\theta)$ ✓

$\dfrac{1}{hc}(\lambda' - \lambda) = \dfrac{1}{m_e c^2}(1-\cos\theta)$

$\lambda' - \lambda = \dfrac{hc}{m_e c^2}(1-\cos\theta)$

$\lambda' - \lambda = \dfrac{h}{m_e c}(1-\cos\theta)$

$\Delta\lambda = \lambda' - \lambda = \lambda_e(1-\cos\theta)$ – terbukti ✓

ZCT 104/3E Modern Physics
Semester II, Sessi 2006/07
Open Book Quiz IV
Duration: 30 min

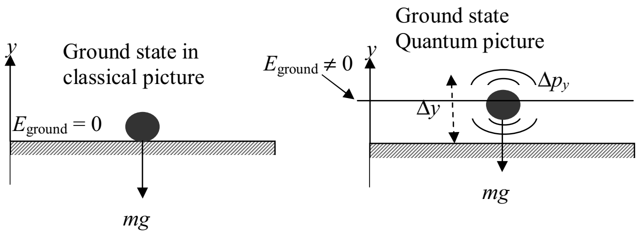
Name:

Matrics No:

INSTRUCTION: Answer the following question. **[10 marks]**

A particle under gravity

A particle falls under gravity towards an impenetrable floor.



According to classical mechanics, the ground state (the state of least energy) is one in which the particle is at rest on the floor. Let us measure the distance vertically from the floor and call it y. Thus, we know the position of the particle in its ground state ($y = 0$) and also its momentum ($p_y = 0$). This contradicts the uncertainty principle. In the quantum picture, we know that a particle cannot rest on the floor even under the pull of gravity. Even in the lowest energy state, the particle bounces up and down with a range Δy and Δp_y according to the Uncertainty principle. See the picture above.

(i) Write down the uncertainty relation that relates Δy and Δp_y.

[2 marks]

The potential energy of the particle is

$$V(y) = mgy \text{ if } y > 0,$$
$$= +\infty \text{ if } y < 0.$$

(ii) What is the approximate energy of the particle at the ground state? (*Hint: The ground state energy is the sum of the potential energy and the kinetic energy. You should express the energy estimate in terms of* Δy.)

[4 marks]

(iii) Estimate the order of Δy in terms of m (*Hint: To obtain the estimate of* Δy*, you simply minimise the answer obtained in (ii) with respect to* Δy)

[4 marks]

ZCT 104/3E Modern Physics
Semester II, Sessi 2006/07
Open Book Quiz IV
Duration: 30 min

Name:

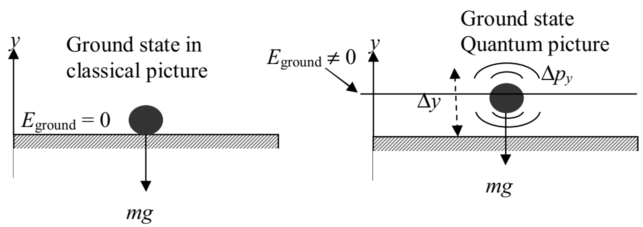
Matrics No:

INSTRUCTION: Answer the following question. **[10 marks]**

Particle under gravity

A particle under gravity

A particle falls under gravity towards an impenetrable floor.



According to classical mechanics, the ground state (the state of least energy) is one in which the particle is at rest on the floor. Let us measure the distance vertically from the floor and call it y. Thus, we know the position of the particle in its ground state ($y = 0$) and also its momentum ($p_y = 0$). This contradicts the uncertainty principle. In the quantum picture, we know that a particle cannot rest on the floor even under the pull of gravity. Even in the lowest energy state, the particle bounces up and down with a range Δy and Δp_y according to the Uncertainty principle. See the picture above.

(i) Write down the uncertainty relation that relates Δy and Δp_y. [2 marks]

ANS: The ground state will differ from the classical solution by having an uncertainty in position of Δy and momentum Δp_y where

$$\Delta p_y \sim \hbar / (2\Delta y).$$ **(2 marks)**

(Note: never mind if the factor 2 is missing since this is an estimate anyway)

(ii) Then the energy is approximately

$$E \sim \frac{(\Delta p_y)^2}{2m} + mg\Delta y = \frac{\hbar^2}{8m(\Delta y)^2} + mg\Delta y$$

[4 marks]

Note: Deduct half the marks if relativistic form of kinetic energy $K = pc$ is used instead of non-relativistic one (i.e. $K = \frac{p_y^2}{2m} \sim \frac{(\Delta p_y)^2}{2m}$). The question is obviously to be treated non-relativistically as we are talking about a 'rest' particle, of which motion is not expected to be fluctuating violently. (The violent the motion is the more relativistic it will be.)

(iii) Minimizing the energy with respect to Δy,

$$\frac{dE}{d(\Delta y)} = -\frac{\hbar^2}{8m}(\Delta y)^{-3} + mg = 0$$

$$\Rightarrow (\Delta y) = \left(\frac{\hbar^2}{8m^2 g}\right)^{1/3} = \frac{1}{2}\left(\frac{\hbar^2}{m^2 g}\right)^{1/3} \sim \left(\frac{\hbar^2}{m^2 g}\right)^{1/3} \sim 10^{-23}\left(\frac{kg}{m}\right)^{2/3} \text{ m}$$ [4 mark]

Note: IF the candidate uses relativistic expression for the energy in (ii), i.e. $E = p_y c + mg\Delta y \sim \frac{\hbar c}{2\Delta y} + mg\Delta y$, and minimise it as per

$$\frac{d}{d(\Delta y)}\left[\frac{\hbar c}{2\Delta y} + mg\Delta y\right] = -\frac{\hbar c}{2(\Delta y)^2} + mg = 0$$

to get

$$\frac{\hbar c}{2(\Delta y)^2} = mg \Rightarrow \Delta y = \left(\frac{\hbar c}{2mg}\right)^{1/2} \sim \left(\frac{\hbar c}{g}\right)^{1/2}\left(\frac{\text{kg}}{m}\right)^{1/2} \text{m} \sim 10^{-27}\left(\frac{\text{kg}}{m}\right)^{1/2} \text{m},$$

only half of 4 marks shall be given.

ZCT 104/3E Modern Physics
Semester II, Sessi 2006/07
Open Book Quiz V
Duration: 30 min

Name:

Matrics No:

INSTRUCTION: Answer the following question. **[12 marks]**

Four possible transitions for a hydrogen atom are listed here.

(i) $n_i = 2; n_f = 5$ (ii) $n_i = 5; n_f = 3$ (iii) $n_i = 7; n_f = 4$ (iv) $n_i = 4; n_f = 7$

(a) For which transitions does the atom emit photon? [2 marks]

(b) Which transition emits the shortest wavelength? Show your argument and steps of calculation clearly. [4 marks]

(c) For which transitions does the atom gain energy? [2 marks]

(d) For which transition does the atom gain most energy? Show your argument and steps of calculation clearly. [4 marks]

(Serway, M & M. Q11, pg. 145)

Solution

For atom emitting photon, $\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \Rightarrow \lambda = \frac{1}{R}\left(\frac{n_f^2 n_i^2}{n_i^2 - n_f^2}\right)$ with $n_f < n_i$;

For atom absorbing photon, $\frac{1}{\lambda} = R\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) \Rightarrow \lambda = \frac{1}{R}\left(\frac{n_f^2 n_i^2}{n_f^2 - n_i^2}\right)$ with $n_f > n_i$

(a) (ii), (iii) emit photon. [2 marks. 1 for each correct answer. No mark deduced for wrong answer.]

(b) Test the emitted photons' wavelength $\lambda(n_i, n_f)$ for (ii), (iii) in turn:

For (ii), $\lambda(n_i = 5, n_f = 3) = \frac{1}{R}\left(\frac{(3)^2(5)^2}{(5)^2 - (3)^2}\right) = \frac{1}{R}\left(\frac{225}{25-9}\right) = \frac{1}{R}\left(\frac{225}{16}\right) \approx \frac{14.06}{R}$

For (iii) $\lambda(n_i = 7, n_f = 4) = \frac{1}{R}\left(\frac{(4)^2(7)^2}{(7)^2 - (4)^2}\right) = \frac{1}{R}\left(\frac{784}{49-16}\right) = \frac{1}{R}\left(\frac{784}{33}\right) \approx \frac{23.8}{R}$.

Hence, (ii) emits the shortest wavelength.

[1 mark for showing the correct use of $\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \Rightarrow \lambda = \frac{1}{R}\left(\frac{n_f^2 n_i^2}{n_i^2 - n_f^2}\right)$ with $n_f < n_i$]

[2 marks for showing $\lambda(n_i = 5, n_f = 3) \approx \frac{14.06}{R}$ and $\lambda(n_i = 7, n_f = 4) \approx \frac{23.8}{R}$ correctly.]

[1 mark for stating the correct answer, "(ii) emits the shortest wavelength"]

(c) Atoms in (i), (iv) gain energy. [2 marks. 1 for each correct answer. No mark deduced for wrong answer.]

(d) Test the absorbed photons' wavelength $\lambda(n_i, n_f)$ for (i), (iv) in turn:

For (i), $\lambda(n_i = 2, n_f = 5) = \frac{1}{R}\left(\frac{(2)^2(5)^2}{(7)^2-(4)^2}\right) = \frac{1}{R}\left(\frac{100}{49-16}\right) = \frac{1}{R}\left(\frac{100}{33}\right) \approx \frac{3.03}{R}$

For (iv), $\lambda(n_i = 4, n_f = 7) = \frac{1}{R}\left(\frac{(4)^2(7)^2}{(7)^2-(4)^2}\right) = \frac{1}{R}\left(\frac{784}{49-16}\right) = \frac{1}{R}\left(\frac{784}{33}\right) \approx \frac{23.8}{R}$

Hence, atom in (i) gains most energy since the shorter the wavelength of a photon, the larger the energy it has.

[1 mark for showing the correct use of $\frac{1}{\lambda} = R\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) \Rightarrow \lambda = \frac{1}{R}\left(\frac{n_f^2 n_i^2}{n_f^2 - n_i^2}\right)$ with $n_f > n_i$.]

[2 marks for showing $\lambda(n_i = 2, n_f = 5) \approx \frac{3.03}{R}$ and $\lambda(n_i = 4, n_f = 7) \approx \frac{23.8}{R}$ correctly]

[1 mark for stating the correct answer, "(i) gains most energy"]

UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2006/2007

April 2007

ZCT 104E/3 – Physics IV (Modern Physics)
[Fizik IV (Fizik Moden]

Duration: 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains **XXX** pages before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **XXX** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]*

Instruction:
Answer ALL questions in Section A and Section B.

Please answer the objective questions from Section A in the objective answer sheet provided. Please submit the objective answer sheet and the answers to the structured questions separately.

Students are allowed to answer all questions in Bahasa Malaysia or in English.

*[**Arahan**: Jawab **SEMUA** soalan dalam Bahagian A dan Bahagian B.*

Sila jawab soalan-soalan objektif daripada bahagian A dalam kertas jawapan objektif yang dibekalkan. Sila serahkan kertas jawapan objektif dan jawapan kepada soalan-soalan struktur berasingan.

Pelajar dibenarkan untuk menjawab samada dalam bahasa Malaysia atau bahasa Inggeris.]

Data

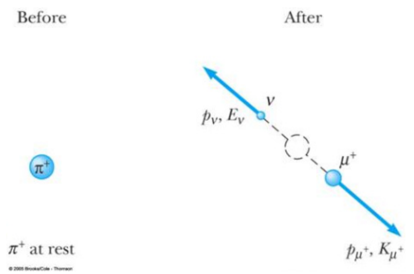
Speed of light in free space, $c = 3.00 \times 10^8$ m s^{-1}
Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
Permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
Elementary charge, $e = 1.60 \times 10^{-19}$ C
Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg
Molar gas constant, = 8.31 J K^{-1} mol^{-1}
Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}
Gravitational constant, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
Acceleration of free fall, $g = 9.81$ m s^{-2}

Section A: Objectives. [40 marks]
[Bahagian A: Soalan-soalan objektif]

Instruction: Answer all 40 objective questions in this Section.
[Arahan: Jawab kesemua 40 soalan objektif dalam Bahagian ini.]

Question 1 - 3 are based on the decay of a π meson into a muon and a massless neutrino shown in the figure below. The rest mass of the muon is m_μ, and the kinetic energy of the muon is measured to be K_μ. p_μ denotes the momentum of the muon. m_π denotes the rest mass of π meson.

[Soalan 1-3 adalah berdasarkan pereputan satu meson π kepada satu muon dan satu neutrino tanpa jisim, sepertimana ditunjukkan dalam gambarajah di bawah. Diketahui jisim rehat muon ialah m_μ, dan tenaga kinetik muon yang terukur ialah K_μ. p_μ menandakan momentum muon. m_π menandakan jisim rehat meson π.]



1. How is the energy of the muon E_μ related to the momentum of the muon?
[Bagaimanakah tenage muon E_μ dikaitkan dengan momentum muon?]

A. $E_\mu^2 = p_\mu^2 c^2 - m_\mu^2 c^4$ **B.** $E_\mu = p_\mu c + m_\mu c^2$
C. $E_\mu = p_\mu c$ **D.** $E_\mu^2 = p_\mu^2 c^2 + m_\mu^2 c^4$
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS:D

2. What is the kinetic energy of the π meson?
[Apakah tenaga kinetik meson π ?]

A. $K_\mu + m_\mu c^2$ **B.** 0 **C.** K_μ **D.** $m_\pi c^2$
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS:B.

3. What is the momentum of the neutrino?
[Apakah momentum neutrino?]

A. $p_\nu = \frac{1}{c}\sqrt{K_\mu\left(2m_\mu c^2 + K_\mu\right)}$ **B.** $p_\nu = \frac{1}{c}\sqrt{\left(2m_\mu^2 c^4 + K_\mu^2\right)}$
C. $p_\nu = K_\mu / c$ **D.** 0
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS:A.

4. Which of the following statements is (are) true regarding the spectrum of hydrogen atom, according to the Bohr model?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai spektrum atom hidrogen menurut model Bohr?]

I. The Lyman series emission spectrum of a hydrogen atom lies in the visible region of the electronmagnetic spectrum. (F)
[Spektrum pancaran siri Lyman atom hidrogen terletak dalam rantau nampak spektrum elektromagnetik.]

II. The Balmer series emission spectrum of a hydrogen atom lies in the ultraviolet region of the electronmagnetic spectrum. (F)
[Spektrum pancaran siri Balmer atom hidrogen terletak dalam rantau ultraungu spektrum elektromagnetik.]

III. The Paschen series emission spectrum of a hydrogen atom lies in the ultraviolet region of the electronmagnetic spectrum. (T)
[Spektrum pancaran siri Paschen atom hidrogen terletak dalam rantau ultra ungu spektrum elektromagnetik.]

IV. Not all of the emission spectrum of a hydrogen atom lies in the visible region of the electronmagnetic spectrum. (T)
[Bukan kesemua spektrum pancaran siri atom hidrogen terletak dalam rantau nampak spektrum elektromagnetik.]

A. I, II, III, IV **B.** I, II, III **C.** II, IV
D. III, IV
E. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANS: D (Only III, IV are true)

5. Which of the following statements is (are) true regarding the kinetic energy and momentum of an object?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tenaga kinetik dan momentum suatu objek?]

I. The kinetic energy of an object is the energy associated with the motion of the object. (T)
[Tenaga kinetik suatu objek adalah tenaga yang berkaitan dengan pergerakan objek.]

II. The kinetic energy of an object cannot be larger than its total energy. (T)
[Tenaga kinetik suatu objek tidak boleh melebihi jumlah tenaganya.]

III. The relativistic expression of momentum reduces to that of the classical theory of machanics in the limit $v << c$. (T)
[Ungkapan momentum keretatifan terturun kepada ungkapan mekanik teori klasik dalam limit $v<<c$.]

IV. The classical expression of kinetic energy has to be supplanted by that of the special theory of relativity when v approaches c from below. (T)
[Ungkapan tenaga kinetik klasik harus digantikan oleh ungkapan kerelatifan jika v menokok ke c dari bawah.]

A. I, II, III B. II, IV C. I, II, III, IV
D. I, III, IV
E. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANS: C [My own question.]

6. Consider a proton and an electron, both moving at a common momentum, p. Let K_p and K_e denote the proton and electron kinetic energies respectively. Which of the following statements is (are) true?
[Pertimbangkan suatu proton dan suatu elektron, kedua-duanya bergerak dengan momentum yang sama, p. Biar K_p dan K_e masing-masing menandakan tenaga kinetik proton dan elektron. Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. $K_p = K_e$ for $v < c$. *[$K_p = K_e$ untuk $v < c$.](F)*
II. $K_p \neq K_e$ in general. *[$K_p \neq K_e$ pada amnya.](T)*
III. $K_p > K_e$ for all values of $v < c$. *[$K_p > K_e$ untuk semua nilai $v < c$.](F)*
IV. $K_e > K_p$ for $v << c$. *[$K_e > K_p$ untuk $v << c$.](T)*

A. II only B. I, IV C. II, III
D. II, IV
E. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANS: D

Note: In the limit $v<<c$, $\frac{K_P}{K_e} = \frac{p^2/2m_P}{p^2/2m_e} \Rightarrow \frac{K_P}{K_e} = \frac{m_e}{m_P} \Rightarrow K_P = \frac{m_e}{m_P} K_e < K_e$

7. Which of the following statements is (are) true according to the special theory of relativity?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar menurut teori kerelatifan?]

I. A massless particle can travel at the speed lower than the speed of light. [F]
[Suatu zarah tanpa jisim mungkin bergerak dengan laju yang kurang daripada laju cahaya.]

II. A particle with non-zero mass does not necessarily travel at the speed smaller than that of light. [F]
[Suatu zarah dengan jisim bukan sifar tidak semestinya bergerak dengan laju yang kurang daripada laju cahaya.]

III. The rest mass of a moving object changes when it is moving. (F)
[Jisim rehat suatu objek berubah bila ia bergerak.]

IV. It requires an infinite amount of energy to accelerate a massive object to the speed of light. (T)
[Tenaga yang infinit diperlukan untuk memecutkan suatu zarah kepada laju cahaya..]

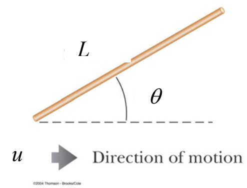
A. I, III, IV B. I, II, III, IV C. I, II, III
D. IV ONLY
E. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANS: D [My own question.]

8. When two particles collide relativistically, *[Bila dua zarah berlanggar secara kerelatifan,]*

I. the total momentum is conserved. *[jumlah momentum adalah terabadikan.](T)*
II. the total kinetic is conserved. *[jumlah tenaga kinetik adalah terabadikan.](F)*
III. the total kinetic energy is an invariant. *[jumlah tenaga kinetik adalah tak varian.](F)*
IV. the total rest mass is conserved. *[jumlah jisim rehat adalah terabadikan.](F)*

A. I , III B. I Only C. III, IV
D. I, II, III, IV
E. (None of A, B, C) *[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]*
ANS: D.

9. In its rest frame, a rod has a proper length of L and is orientated at an angle of $\theta = 45°$ with the x-axis. The rod then move at a speed of $u = c/2$ in the x-direction.
[Dalam rangka rehatnya, suatu rod dengan panjang lazim L diorientasikan pada suatu sudut $\theta = 45°$ merujuk kepada paksi-x. Ia kemudian bergerak pada laju $u = c/2$ dalam arah x.]



What is the length of the rod as observed in the improper frame?
[Apakah panjang rod tersebut dalam rangka tak lazim?]

A. L **B.** $\frac{\sqrt{7}}{4}L$ **C.** $\frac{3}{4}L$ **D.** $\sqrt{\frac{7}{8}}L$
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS:B

10. In Question 9, what is the inclination angle of the rod with respect to the x-axis as observed in the improper frame?
[Dalam solaan 9, apakah sudut di antara rod dengan paksi-x dalam rangka tak lazim?]

A. $\tan^{-1}\left(\frac{\sqrt{7}}{8}\right)$ **B.** $\tan^{-1}\left(\frac{\sqrt{3}}{2}\right)$ **C.** $\tan^{-1}(1)$
D. $\tan^{-1}\left(\frac{2}{\sqrt{3}}\right)$
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS:D

11. What measurement(s) do two observers in relative motion always agree on?
[Apakah ukuran(-ukuran) yang sentiasa disetujui oleh dua orang pemerhati yang berada dalam pergerakan relatif]

I The speed of an electron moving in medium water.
[Laju suatu elektron dalam medium air.](F)

II The time interval between two events. *[Selang masa antara dua kejadian.](F)*

III The number of particles. *[bilangan zarah.](T)*

IV The density of an object. *[Ketumpatan suatu objek](F)*

A. II, III **B. I, II, IV** **C. II, III, IV** **D. I, II**
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
Solution: only III is true

12. The units of the work function are those of:
[Unit bagi fungsi kerja adalah sama dengan unit bagi …]

A. energy **B.** power **C.** momentum **D.** angular momentum
E. frequency
Solution: A

13. The S.I. units of 1-D wavefunction are those of:
[Unit bagi fungsi gelombang 1D adalah sama dengan unit bagi …]

A. $1/\sqrt{\text{length}}$ **B.** $1/\sqrt{\text{energy}}$
C. $1/\sqrt{\text{momentum}}$ **D.** $1/\sqrt{\text{frequency}}$ **E.** $1/\sqrt{\text{mass}}$
Solution: A

14. The light intensity incident on a metallic surface produces photoelectrons with a maximum kinetic energy of 2 eV. The light intensity is doubled. Determine the maximum kinetic energy of the photoelectrons (in eV).

[*Keamatan cahaya yang menujui suatu permukaan logam menghasilkan fotoelektron dengan tenaga kinetik maksimum 2 eV. Keamatan cahaya digandaduakan. Tentukan tenaga kinetik maksimum fotoelektron terhasil (dalam eV).*]

A. 4 **B.**2 **C.** $\sqrt{2}$ **D.**3 **E.**16
Solution: B

15. Microscopes are inherently limited by the wavelength of the light used. How much smaller (in order of magnitude) can we "see" using an electron microscope whose electrons have been accelerated through a potential difference of 10 000 V than using red light (100 nm)?

[*Secara tabiinya mikroskop dihadkan oleh jarak gelombang cahaya yang digunakan. Berbanding dengan penggunaan cahaya merah (100 nm), betapa kecilkah (dalam magnitud tertib) yang boleh kita 'nampak' dengan menggunakan mikroskop elektron yang elektronnya dipecutkan melalui suatu beza keupayaan 10 000 V?*]

A. 3 B. 4 **C.** 5 **D.** 6 **E.** 14

Solution: B

$$eV = \frac{p^2}{2m} = \frac{(h/\lambda_e)^2}{2m}$$

$$\Rightarrow \lambda_e = \frac{h}{\sqrt{2m_e eV}} = \frac{hc}{\sqrt{2m_e c^2 eV}} = \frac{hc}{\sqrt{2m_e c^2 eV}} = \frac{1240\text{nm}\cdot\text{eV}}{\sqrt{1\text{MeV}\cdot e\cdot 10000\text{V}}} =$$

$$\frac{1240\text{nm}\cdot\text{eV}}{\sqrt{1\times10^{10}\text{eV}^2}} = \frac{1240\text{nm}}{\sqrt{10^{10}}} \sim \frac{10^3\text{nm}}{10^5} = 10^{-2}\text{nm}$$

$$\frac{\lambda_e}{\lambda} \sim \frac{10^{-2}\text{nm}}{10^2\text{nm}} = 10^{-4}$$

Hence, with λ_e we can see 4 orders smaller.

16. Which of the following statements is (are) true about photon?

[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai foton?]

I. A photon will either be absorbed or otherwise when interacts with matter. [*Suatu foton akan terserap atau tidak dalam interaksinya dengan jirim*]. *[T]*
II. Photons have mass. [*foton mempunyai jisim.*] [F]
III. Photons have electric charge. [*foton mempunyai cas electrik.*] [F]
IV. Photons can be accelerated via an electric field. [*foton boleh dipecutkan oleh suatu medan elektrik.*][F]

A. II, III **B.** I, II, IV **C.** II, III, IV **D.** I, II
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

Solution: E, Only I is true
Solution: Young and Freeman, pg. 1485, Q38

17. Which of the following statements is (are) true about the nature of light?

[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tabii cahaya?]

I. Effects due to the photon nature of light are generally more important at the low-frequency end of the electromagnetic spectrum (radio waves).
[*Kesan-kesan disebabkan oleh tabii foton dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi rendah spektrum elektromagnet (gelombang radio)*]. *[F]*

II. Effects due to the photon nature of light are generally more important at the high-frequency end of the electromagnetic spectrum (x-rays and gamma rays). [*Kesan-kesan disebabkan oleh tabii foton dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi tinggi spektrum elektromagnet (sinaran-X dan sinaran gamma).] [T]*

III. Effects due to the wave nature of light are generally more important at the low-frequency end of the electromagnetic spectrum (radio waves). [*Kesan-kesan disebabkan oleh tabii gelombang dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi rendah spektrum elektromagnet (gelombang radio)]. [T]*

IV. Effects due to the wave nature of light are generally more important at the high-frequency end of the electromagnetic spectrum (x-rays and gamma rays). [*Kesan-kesan disebabkan oleh tabii gelombang dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi tinggi spektrum elektromagnet (sinaran-X dan sinaran gamma).] [F]*

A. II, III **B.** I, IV **C.** I, III **D.** II, IV
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
Solution: A

18. The total energy (kinetic plus potential) of the hydrogen atom is negative. What significance does this have?

[*Jumlah tenaga (kinetik serta keupayaan) atom hidrogen adalah negatif. Apakah kepentingannya?*]

A. The hydrogen atom is ionized. [*Atom higrogen diionkan.*]
B. The angular momentum of the electron is quantized. [*Momentum sudut elektron terkuantumkan.*]
C. The electron is bonded by the hydrogen atom's electric field. [*Elektron adalah terikat oleh medan elektrik atom hidrogen.*]
D. The hydrogen atom is a free particle. [*Atom hidrogen adalah zarah bebas.*]
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

Solution: C

19. A double ionized lithium atom (Li^{++}) is one that has had two of its three electrons removed. The ground state energy of the Li^{++} is _____ times the ground state energy of the hydrogen atom.

[*Suatu atom lithium yang berganda terionkan ialah atom yang dua daripada tiga elektronnya disingkirkan. Keadaan dasar* Li^{++} *adalah ______kali tenaga dasar hidrogen.*]

A.2 **B.**4 **C.**8 **D.** 9
E.32

Solution: D. Note: $E_n = -\frac{Z^2}{n^2} E_0$

20. In photoelectric effect experiment, which of the following will increase the maximum kinetic energy of the photoelectron? [*Dalam eksperimen kesan fotoelektrik, yang manakah berikut akan menambahkan tenaga kinetik maksmum fotoelektron?*]

I. Use the light of greater intensity. [*Guna cahaya yang keamatannya lebih tinggi]. [F]*

II. Use the light of greater frequency. [*Guna cahaya yang frekuensinya lebih tinggi]. [T]*

III. Use the light of greater wavelength. [*Guna cahaya yang jarak gelombangnya lebih tinggi]. [F]*

IV. Use metal surface with a smaller work function. [*Guna permukaan logam yang fungsi kerjanya lebih rendah]. [T]*

A. II, III **B.** I, IV **C.** I, III **D.** II, IV
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
Solution: D

21. Which of the following associations with experiments is (are) true?

[Yang manakah perhubungan-perhubungan dengan eksperimen berikut adalah benar?]

I. The Davisson-Gremer experiment shows that electrons do behave like waves. [T] [*Eksperimen Davisson-Germer menunjukkan bahawa elektron berlagak seperti gelombang.*]

II. The Frank-Hertz experiment shows that atoms do behave like waves. [F] [*Eksperimen Frank-Hertz menunjukkan bahawa atom-atom berlagak seperti gelombang.*]

III. The Compton scattering experiment show that electrons behave like waves. [F] [*Eksperimen Compton menunjukkan bahawa elektron berlagak seperti gelombang.*]

IV. The Young double slit experiment using electron as the source shows that electrons do behave like waves. [T] [*Eksperimen dwi-celah Young yang menggunakan elektron sebagai punca menunjukkan bahawa elektron berlagak seperti gelombang.*]

A. II, III **B.** I, IV **C.** I, III **D.** II, IV
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: B

22. Say a beam of light has an intensity of I (i.e. the total energy per unit area per unit time) and frequency ν. What is the photon density, n (i.e. the number of photon per unit volume), of the light beam?

[Katakan keamatan satu alur cahaya ialah I (iaitu jumlah tenaga per unit permukaan per unit masa) dan frekuensinya ialah ν. Apakah ketumpatan foton n (iaitu bilangan foton per unit isipadu) dalam alur cahaya tersebut?]

A. $(hc\nu)^2/I^2$ **B.** $hc\nu/I$ **C.** $I/(hc\nu)$ **D.** $I^2/(hc\nu)^2$
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: C

23. A particle of mass m is confined to a one-dimensional box of width L and infinite height. The particle's wavelength at state n is given by

[*Suatu zarah yang terperangkap dalam suatu kotak satu dimensi dengan lebar L dan ketinggian infiniti. Jarak gelombang zarah tersebut pada keadaan n ialah*]

A. $2L/n$ **B.** $n/2L$ **C.** $2L/n\hbar$ **D.** $n\hbar/2L$
E. None of the above
ANS: A

24. The kinetic energy of the particle in Question 23 is given by

[*Tenaga kinetik zarah dalam Soalan 23 ialah*]

A. $n^2\frac{\hbar^2}{8m\pi L^2}$ **B.** $n^2\frac{h^2}{8mL^2}$ **C.** $n^2\frac{\pi^2 h^2}{2mL^2}$
D. $n^2\frac{\hbar^2}{2mL^2}$
E. None of the above
ANS: B

25. If the infinitely high potential box in Question 23 is replaced by one with a finite height, how would the wavelength of the particle at a given state n be modified as compared to the answer in Question 23?

[*Jika keupayaan kotak yang infinit dalam Soalan 23 digantikan dengan kotak yang tinggi keupayaannya finit, bagaimanakah jarak gelombang zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 23?*]

A. The wavelength would be longer than that in Question 23.
[*Jarak gelombang akan menjadi lebih panjang daripada jarak gelombang dalam Soalan 23.*]

B. The wavelength would be shorter than that in Question 23.
[*Jarak gelombang akan menjadi lebih pendek daripada jarak gelombang dalam Soalan 23.*]

C. The wavelength would be the same as that in Question 23.
[*Jarak gelombang adalah sama seperti jarak gelombang dalam Soalan 23.*]

D. The wavelength could be longer or shorter than that in Question 23, depending on the state *n.*
[*Jarak gelombang akan menjadi lebih panjang atau lebih pendek daripada jarak gelombang dalam Soalan 23, bergantung kepada keadaan n.*]

E. None of the above.
ANS: A

26. Following Question 25, how would the kinetic energy of the particle at a given state n be modified as compared to the answer in Question 24?

[*Menurut Soalan 25, bagaimanakah tenaga kinetik zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 24?*]

A. The kinetic energy would be larger than that in Question 24.
B. The kinetic energy would be smaller than that in Question 24.
C. The kinetic energy would be the same as that in Question 24.
D. The kinetic energy could be larger or smaller than that in Question 24, depending on the state *n.*
E. None of the above
ANS: B

27. If the finite potential box in Question 25 is in turn replaced by one with a width larger than L, how would the wavelength of the particle at a given state n be modified as compared to the answer in Question 25?

[*Jika kotak yang berkeupayaan finit dalam Soalan 25 digantikan dengan kotak yang lebarnya lebih besar daripada L, bagaimanakah jarak gelombang zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 25?*]

A. The wavelength would be longer than that in Question 25.
B. The wavelength would be shorter than that in Question 25.
C. The wavelength would be the same as that in Question 25.
D. The wavelength could be longer or shorter than that in Question 25, depending on the state *n.*
E. None of the above
ANS: A

28. Following Question 27, how would the kinetic energy of the particle at a given state n be modified as compared to the answer in Question 26?

[*Menurut Soalan 27, bagaimanakah tenaga kinetik zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 26?*]

A. The kinetic energy would be larger than that in Question 26.
B. The kinetic energy would be smaller than that in Question 26.
C. The kinetic energy would be the same as that in Question 26.
D. The kinetic energy could be larger or smaller than that in Question 26, depending on the state *n.*
E. None of the above
ANS: B

29. What are the features of a X-rays curve as produced from a X-ray tube?

I. The spectrum is continuous.

II. The existence of a minimum wavelength for a given accelerating potential *V*, below which no x-ray is observed.

III. Increasing *V* decreases the minimum wavelength.

IV. There exists an upper limit in the wavelength of the X-ray produced.

A. II, III **B.** I, IV **C.** I, II, III **D.** I, II, III, IV
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS: C

30. Which of the following statements is (are) true?

[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. In photoelectricity the whole photon is directly absorbed by the free electron in the metal surface.
[*Dalam kesan fotoelektrik keseluruh foton diserap secera terus oleh elektron bebas dalam permukaan logam.*] *[F]*

II**.** In photoelectricity the whole photon is first absorbed by the atom in the metal surface.
[*Dalam kesan fotoelektrik keseluruh foton terdahulunya diserap oleh atom dalam permukaan logam.*] [T]

III. In X-ray production by electron bombardment on a metal target, the kinetic energy of the bombarding electron is converted to the X-ray photon energy via Bremsstrahlung.
[*Dalam penghasilan sinar-X oleh penghentaman elektron ke atas sasaran logam, tenaga kinetik elektron yang menghentam ditukarkan kepada tenaga foton sinar-X melalui Bremsstrahlung.*] [T]

IV. In the X-ray production using the X-ray tube, the energy of the X-ray photon is converted to the kinetic energy of the electron via Bremsstrahlung.
[*Dalam penghasilan sinar-X dalam tiub sinar-X, tenaga foton ditukarkan kepada tenaga kinetik elektron melalui Bremsstrahlung.*] [F]

A. II, IV **B.** I, IV **C.** II, III **D.** I, III
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS: C

31. Which of the following statements is (are) true?

[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. A photon can materialize into an electron plus a positron in the absence of any electric field.
[*Suatu foton boleh bertukar menjadi jirim satu elektron serta satu positron dalam ketidakhadiran medan elektrik.*] *[F]*

II. A photon can materialize into either a single electron OR a single positron in the presence of a strong electric field.
[*Suatu foton boleh bertukar menjadi jirim satu elektron tunggal atau satu positron tunggal dalam kehadiran medan elektrik kuat.*] *[F]*

III**.** An electron-positron pair can annihilate into a single photon.
[*Suatu pasangan elektron-positron boleh menghabisbinasa menjadi satu foton tunggal.*] [F]

IV**.** An electron-positron pair can annihilate into two photons.
[*Suatu pasangan elektron-positron boleh menghabisbinasa menjadi dua foton.*] [T]

A. II, IV **B**. I, IV **C.** II, III **D.** I, III
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS: E (Only IV is true)

32. Which of the following statements is (are) true regarding the interactions between photons with matter?

[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai interaksi foton dengan jirim?]

I. The probability (cross section) of a photon undergoes a given channel of interaction with matter depends on the photon energy.
[*Kebarangkalian (keratan rentas) suatu foton menjalani mana-mana saluran interaksi dengan jirim bergantung kepada tenaga foton.*] *[T]*

II. The probability (cross section) of a photon undergoes a given channel of interaction with matter depends on the atomic number of the absorbing material.
[*Kebarangkalian (keratan rentas) suatu foton menjalani mana-mana saluran interaksi dengan jirim bergantung kepada nombor atom bahan penyerap.*] *[T]*

III For a fixed atomic number, the photon-material interactions at low energy are dominated by photoelectric effect.
[*Pada suatu nombor atom yang tertentu, interaksi di antara foton dengan jirim pada tenaga rendah dikuasai oleh kesan fotoelektrik.*] [T]

IV. Pair production begins to show up when the photon energy approaches, but not yet exceed, the value of 1.02 MeV.
[*Penghasilan pasangan mula muncul semasa tenaga foton menhampiri, tapi belum melebihi, nilai 1.02 MeV.*] [F]

A. I, III, IV **B.** I, II, IV **C.** II, III **D.** I, II, III
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*

ANS: D

33. A relativistic electron has a de Broglie wavelength of λ. Find its kinetic energy.

[*Jarak gelombang de Broglie suatu elektron kerelatifan ialah λ. Dapatkan tenaga kinetiknya.*]

A. $K = ((hc/\lambda)^2 - m_e^2c^4)^{½} + m_ec^2$.
B. $K = ((hc/\lambda)^2 + m_e^2c^4)^{½} + m_ec^2$.
C. $K = ((\lambda/hc)^2 + m_e^2c^4)^{½} - m_ec^2$.
D. $K = ((hc/\lambda)^2 + m_e^2c^4)^{½} - m_ec^2$.
E. None of the above
ANS: D

34. In the Davisson-Gremer experiment, the electron is accelerated via an electric potential of V. The wavelength of the electron, λ, in terms of V is given by the expression

[*Dalam eksperimen Davisson-Gremer, elektron dipecutkan oleh keupayaan elektrik V. Jarak gelombang elektron,λ, dalam ungkapan V, adalah diberikan oleh*]

A. $\lambda = (2eVm_e)^{1/2}/h$
B. $\lambda = h^{1/2}/(2eVm_e)$
C. $\lambda = h/(2eVm_e)$
D. $\lambda = h/(2eVm_e)^{1/2}$
E. None of the above
ANS: D

Questions 35 - 37 are based on Figure 1. [*Soalan 35 -37 adalah berdasarkan gambarajah 1.*]

35. Figure 1 shows three group waves. Which of the group waves has the largest spatial spread, Δx?

[*Gambarajah 1 menunjukkan 3 gelombang kumpulan. Yang mana satukah mempunyai sebaran ruagan Δx yang terbesar*?] (ANS: C)

36. Which of the group waves has the largest spread in wavelength, $\Delta\lambda$?

[*Yang mana satukah mempunyai sebaran jarak gelombang Δλ yang terbesar*?] (ANS: A)

37. Which of the group waves has the largest spread in wave number, Δk?

[*Yang mana satukah mempunyai sebaran nombor gelombang Δk yang terbesar*?] (ANS: A)

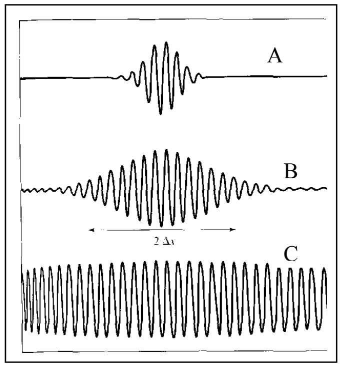


Figure 1

38. Assume that the uncertainty in the position of a particle is equal to two times its de Broglie wavelength. What is the minimal uncertainty in its velocity?*[Anggap bahawa ketidakpastian dalam kedudukan suatu zarah adalah bersamaan 2 kali jarak gelombang de Broglienya. Apakah ketidakpastian mimimum dalam halajunya?*]

A. $v_x/4\pi$ B. $v_x/2\pi$ C. $v_x/8\pi$ D. v_x/π
E. $v_x/16\pi$
ANS: C

$$\lambda = \frac{h}{p_x}$$

$$\Delta x = 2\lambda = \frac{2h}{p_x}$$

$$\Delta x \Delta p_x \geq \frac{\hbar}{2} \Rightarrow \frac{2h}{p_x}\Delta p_x \geq \frac{\hbar}{2} \Rightarrow \frac{\Delta p_x}{p_x} \geq \frac{\hbar}{4h} = \frac{1}{8\pi}$$

$$\frac{\Delta p_x}{p_x} = \frac{m\Delta v_x}{mv_x} \geq \frac{1}{8\pi} \Rightarrow \Delta v_x \geq \frac{v_x}{8\pi}$$

39. Which of the following statements is (are) true?

[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. The length scale characterizing atomic physics is ~ Å.
[*Skala panjang yang mencirikan fizik atom ialah* ~ Å.] *[T]*

II. The velocity scale characterizing special relativistic effect is ~ c.
[*Skala halaju yang mencirikan kesan kerelatifan khas ialah ~ c*] *[T]*

III. The length scale characterizing Compton scattering is ~ pm.
[*Skala panjang yang mencirikan serakan Compton ialah* ~ pm] *[T]*

IV. The energy scale characterizing pair creation is ~ MeV.
[*Skala tenaga yang mencirikan penghasilan pasangan ialah* ~ MeV] *[T]*

A. I, III, IV **B.** I, II, III **C.** I, IV **D.** I, II, III, V
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS: D

40. Which of the following statements is (are) true regarding Bohr's hydrogen model?

[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai model hidrogen Bohr?]

I. The velocity of the electron in the lower orbits is relativistic.
[*Halaju elektron dalam orbit rendah adalah kerelatifan.*] *[F]*

II. The kinetic energy of the electron in the lower orbits is relativistic.
[*Tenaga kinetik elektron dalam orbit rendah adalah kerelatifan.*] *[F]*

III. The model does not take into account the effect of Heisenberg uncertainty principle.
[*Model tersebut tidak mengambil kira kesan prinsip ketidakpastian Heisenberg*] *[T]*

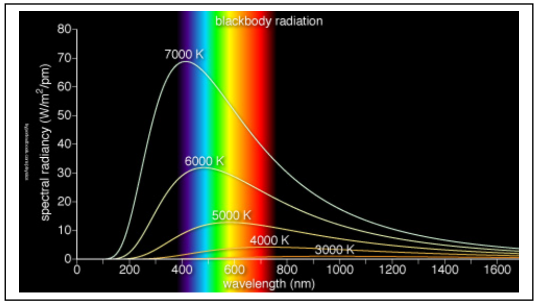
IV. The energy scale characterizing the transition is ~ keV.
[*Skala tenaga yang mencirikan peralihan ialah ~ keV*] *[F]*

A. III Only **B.** I, II, IV **C.** I, II **D.** III, V
E. None of A, B, C, D *[Jawapan tiada dalam A, B, C, D]*
ANS: A

Section B: Structural questions.
[*Bahagian B: Soalan-soalan strutur.***]**

Instruction: [*Arahan:***]**
Answer ALL questions. Each question carries 20 marks.
[*Jawab semua soalan. Setiap soalan membawa 20 markah.*]

1. (a) A typical spectral distribution of radiation energy of a black body for several temperatures is as shown. [*Terpapar adalah suatu taburan spektrum yang tipikal bagi tenaga pancaran suatu jasad hitam untuk beberapa suhu.*]



The shift of the peak of the curve was found to obey the empirical Wein's displacement law,

$$\lambda_p T = \text{constant},$$

where the symbol λ_p refers to the value of the wavelength corresponding to the peak of the curve.

The *total power radiated per unit area* of a blackbody is found to be empirically related to its absolute temperature by the *the Stefan-Boltzman law*

$$I(T) = \sigma T^4,$$

where σ is the Stefan constant. The radiance, $R(\lambda,T)$ and $I(T)$ are related by the integral

$$I(T) = \int_0^\infty R(\lambda,T)\,d\lambda .$$

Wein proposed an empirical form for the radiance $R(\lambda,T)$ by constructing a mathematical function to fit the experimental blackbody curve, known as the *Wein's law*:

$$R(\lambda,T) = \frac{ae^{-b/\lambda T}}{\lambda^5} \quad \text{(Wein's law)}$$

The quantities *a* and *b* are not derived but are simply curve-fitting parameters.

On the theoretically front, Planck derives his famous blackbody radiation law by assuming that the energies emitted from the oscillators are quantized. In his theory, the radiance is given by the theoretical expression

$$R(\lambda,T) = \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT} - 1\right)} \quad \text{(Planck's law)}$$

[*Anjakan puncak lengkungan didapati mematuhi hukum sesaran Wein,* $\lambda_p T = \text{pemalar}$*, dengan* λ_p *mewakili nilai jarak gelombang pada puncak lengkungan.*

Jumlah kuasa pancaran per unit permukaan suatu jasad hitam didapati berkait secara empirikal kepada suhu mutlak oleh hukum Stefan-Boltzman, $I(T) = \sigma T^4$*, dengan* σ *pemalar Stefan. Radians,* $R(\lambda,T)$ *dikaitkan dengan* $I(T)$ *oleh kamiran* $I(T) = \int_0^\infty R(\lambda,T)\,d\lambda$.

Wein menyarankan suatu bentuk empirikal bagi $R(\lambda,T)$ *dengan membinakan suatu fungsi matematik untuk memadankan lengkungan eksperimen jasad hitam. Ia dikenali sebagai hukum Wein:* $R(\lambda,T) = \frac{ae^{-b/\lambda T}}{\lambda^5}$. *Kuantiti a dan b bukannya diterbitkan tapi sekadar merupakan parameter-parameter untuk memadankan lengkungan.*

Dalam garis depan teori, Planck menerbitkan hukum jasad hitamnya yang masyur dengan anggapan bahawa tenaga terpancar daripada pengayun adalah terkuantumkan. Dalam teorinya, radians diberikan oleh

$$R(\lambda,T) = \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT} - 1\right)}.$$

]

Using Planck's law as given above, [*Dengan menggunakan hukum Planck,*]

(i) show that it reduces to Wein's law in the short wavelength limit.
[*tunjukkan bahawa ia terturun kepada hukum Wein dalam limit jarak gelombang pendek.*]

(ii) Evaluate *a* and *b* in terms of the natural constants (i.e. *k*, *c*, *h*, π).
[*Nilaikan a dan b dalam sebutan pamalar semulajadi, iaitu k, c, h,* π)]

(iii) Evaluate the Stefan constant.
[*Nilaikan pemalar Stefan.*]

[2+(2+2)+4=10]

(b) If the photocurrent of a photocell is cut off by a retarding potential of 0.92 V for monochromatic radiation of 2500 Å , what is the work function of the material? [*Jika fotoarus suatu fotosel dipengal oleh keupayaan rencatan 0.92 V untuk pancaran monokromatik 2500 Å , apakan funsi kerja bahan tersebut?*]

[4]

(c)

(i) What is the frequency of a X-rays photon with momentum 1.1×10^{-23} kg·m/s [*Apakah frekuensi suatu foton sinar-X dengan momentum* 1.1×10^{-23} kg·m/s ?]

(ii) What is the momentum of (c)(*i*) in unit of eV/*c*? [*Apakah memomtum di* (c)(*i*) *dalam unit eV/c?*]

[3 + 3 = 6]

2. (a) Derive the Compton scattering formula $\lambda' - \lambda = \frac{h}{mc}(1-\cos\theta)$, where λ and λ' are the wavelengths of the incident and scattered photon respectively, θ the scattered angle of the photon, *m* the mass of target particle.
[*Terbitkan formula serakan Compton* $\lambda' - \lambda = \frac{h}{mc}(1-\cos\theta)$.]

[10]

(b) Determine the wavelength of a photon that is emitted when a atom hydrogen makes a transition from state *n* = 10 to the ground state.
[Tebtukan jarak gelombang foton yang dipancarkan apabila suatu atom hydrogen beralih dari keadaan n = 10 ke keadaan asas.]

[5]

(c) Given the wave function of a particle in an infinite box $\psi_n(x) = \sqrt{\frac{2}{L}}\sin\frac{n\pi x}{L}$, where *L* is the width of the box. Find the probability that the particle can be found between *x* = 0 and *x* = *L/n* when it is in the *n*th state. [*Diberikan fungsi gelombang zarah dalam kotak infini* $\psi_n(x) = \sqrt{\frac{2}{L}}\sin\frac{n\pi x}{L}$, *di mana L ialah lebar kotak tersebut. Carikan kebarangkalian untuk mencarikan zarah di antara x=0 dan x=L/n bila ia berada dalam keadaan n.*]

[5]

3. (a) Consider three inertial frames that are moving along a common direction. The relative velocity of S′ with respect to S is $\beta_1 c$, whereas the relative velocity of S′′ with respect to S′ is $\beta_2 c$. Find the velocity of S′′ with respect to S, βc, in terms of $\beta_1 c$, and $\beta_2 c$.
[*Pertimbangkan tiga rangka inersia yang bergerak sepanjang arah yang sama. Halaju relatif S' terhadap S ialah* $\beta_1 c$, *manakala halaju relatif S'' terhadap S' ialah* $\beta_2 c$. *Carikan halaju S'' terhadap S,* βc, *dalam sebutan* $\beta_1 c$ *dan* $\beta_2 c$.]

[10]

(b) The kinetic energy, *K*, of a fast-moving alpha particle (with rest mass M_α) is measured in the laboratory. [*Tenaka kinetik, K, bagi suatu zarah alfa (dengan jisim rehat* M_α*) diukurkan dalam makmal.*]

(i) What is its total energy *E*? [*Apakah jumlah tenaganya?*]

(ii) What is its momentum *p*? [*Apakah momentumnya?*]

(iii) What's the increase in its mass (as compared to its mass when at rest), ΔM_α? [*Apakah pertambahan dalam jisimnya (berbanding dengan jisimnya semasa ia berehat)?*]

(iv) Based on the answer of (*ii*) above, show that the expression of the kinetic energy *K* reduces to the classical one in the limit $v \to c$, where *v* is the velocity of the alpha particle.
[*Berdasarkan jawapan dalam (ii) di atas, tunjukkan bahawa sebutan tenaga kinetik K terturun kepada sebutan tenaga kinetik klasikal dalam limit v→c, dengan v halaju zarah alfa.*]

[2+3+2+3]

1(A) ANS
Elmer Anderson, pg49, problem 2-6.

(i) For short wavelength, the exponential term in Planck's law, $e^{hc/\lambda kT}$, becomes very large compared to the value 1, $e^{hc/\lambda kT} >> 1$, hence the term in the bracket in the denominator of the Planck's law reduces to $e^{hc/\lambda kT}$, i.e.

$$\lim_{\lambda\to 0}\frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT}-1\right)} = \frac{2\pi hc^2}{\lambda^5}e^{-hc/\lambda kT} . \qquad \text{Eq. (1)}$$

Comparing Eq. (1) and the Wein's law, we find that both have the same form of λ–dependence,

$$\frac{2\pi hc^2}{\lambda^5}e^{-hc/\lambda kT} \equiv \frac{ae^{-b/\lambda T}}{\lambda^5} .$$

[*satisfactory argument:* 2 MARKS]

(ii) Comparing both equation, we identify the constants *a* and *b* to be
$a \equiv 2\pi hc^2$ **[2 MARKS]**
$b \equiv hc/k$ **[2 MARKS]**

(iii) Stafan-Boltzman law: $I(T) = \sigma T^4$

Substitute Planck's law, $R(\lambda,T)=\frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}$, into the definition of

$I(T)=\int_0^\infty R(\lambda,T)\mathrm{d}\lambda$, we get

$$I(T)=\int_0^\infty R(\lambda,T)\mathrm{d}\lambda=\int_0^\infty \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}\mathrm{d}\lambda=2\pi hc^2\int_0^\infty \frac{1}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}\mathrm{d}\lambda .$$

Define $x=\frac{hc}{\lambda kT}\Rightarrow \mathrm{d}x=-\frac{hc}{kT}\frac{1}{\lambda^2}\mathrm{d}\lambda$

$$I(T)=2\pi hc^2\int_0^\infty \frac{1}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}\mathrm{d}\lambda=2\pi hc^2\int_0^\infty \frac{1}{\lambda^3\left(e^{x}-1\right)}\frac{\mathrm{d}\lambda}{\lambda^2}$$

$$=-\frac{2\pi k^4T^4}{h^3c^2}\int_\infty^0 \frac{x^3}{e^x-1}\mathrm{d}x=\frac{2\pi k^4T^4}{h^3c^2}\int_0^\infty \frac{x^3}{e^x-1}\mathrm{d}x=\frac{2\pi k^4T^4}{h^3c^2}\frac{\pi^4}{15}=\frac{2\pi^5k^4T^4}{15h^3c^2}$$

Hence, the Stefan constant is $\sigma=\frac{2\pi^5k^4T^4}{15h^3c^2}$. **[4 marks]**

1(B) ANS: 4.08 eV
E. Anderson, pg. 57, Problem 2-16. **[4 marks]**

1(C)(i) ANS: 5×10^{18} Hz **[3 marks]**
1(C)(ii)ANS: xx eV/c **[3 marks]**

2(A) ANS Elmer E. Anderson, pg. 66 (BM version). **[10 marks]**

2(B) ANS: (Beiser, BM version, pg 161, Soalan 3) [5 marks]

2(C) ANS (Beiser, Ex. 19, pg. 198)

The probability density is given by $p_n(x)=\psi_n(x)\psi_n^*(x)$, where the wave function of a particle in a box is $\psi_n(x)=\sqrt{\frac{2}{L}}\sin\frac{n\pi x}{L}$; The probability to find the particle between x_2 and x_1 within the box is

$P_n(x_2,x_1)=\int_{x_1}^{x_2}\psi_n(x)\psi_n^*(x)dx=\frac{2}{L}\int_{x_1}^{x_2}\sin^2\frac{n\pi x}{L}dx=\left(\frac{x}{L}-\frac{x}{2n\pi}\sin\frac{2\pi nx}{L}\right)\Big|_{x_1}^{x_2}$. Here, set $x_2 = L/n$, $x_1 = 0$,

$$P(L/n,0)=\left(\frac{x}{L}-\frac{x}{2\pi}\sin\frac{2\pi x}{L}\right)\Big|_0^{L/n}=\left(\frac{1}{n}-\frac{L}{2\pi n}\sin 2\pi n\right)-(0-0)=\frac{1}{n}$$

[5 marks]

3(A) ANS
Elmer E. Anderson, pg. 19 (BM version), problem 1-10.

Take S′ to be the 'rest frame'. S′′ is moving with respect to S′ with a velocity of $u_x=\beta_2 c$. Take S as the "moving frame", moving at a velocity of $v = -\beta_1 c$ with respect to the frame S′. Hence, the velocity of S′′ with respect to S, u'_x, is related to both u_x and v via the formula

$$u'_x=\frac{u_x-v}{1-\frac{u_xv}{c^2}}=\frac{\beta_2c-(-\beta_1c)}{1-\frac{(\beta_2c)(-\beta_1c)}{c^2}}=\frac{(\beta_2+\beta_1)c}{1+\beta_2\beta_1}$$

Note: one can check the correctness of the above result by considering two limiting cases:

i. When $\beta_2\to0$, S′′ becomes S′, hence, we should recover $u'_x\to\beta_1c$.
ii. When $\beta_1\to0$, S becomes S′, hence, we should recover $u'_x\to\beta_2c$.

[10 marks]

3(B) ANS (My own question)

(i) Total energy $E = K + M_\alpha c^2$ **[2 marks]**

(ii) $E = K + M_\alpha c^2 \Rightarrow E^2 = (K + M_\alpha c^2)^2$
Energy-momentum invariance: $E^2 = p^2c^2 + M_\alpha^2c^4$
Eliminating E in the above equations, $p = \sqrt{(K^2/c^2 + 2KM_\alpha)}$. **[3 marks]**

(iii) Let M be the relativistic mass of the alpha particle. Its total energy is then related to this mass as per $E = Mc^2$. But $E = K + M_\alpha c^2$, hence, the increase in mass $\times c^2$,
$\Delta M_\alpha c^2 = Mc^2 - M_\alpha c^2 = (K + M_\alpha c^2) - M_\alpha c = K$
$\Rightarrow \Delta M_\alpha c^2 = K$ **[2 marks]**

(iv) In the limit of $v\to c$, the relativistic expression for the momentum reduces to classical one, i.e. $p_{SR} = \gamma M_\alpha v \to p_{Classical} = M_\alpha v$. Hence, from (*ii*), as $v\to c$, $\sqrt{(K^2/c^2 + 2KM_\alpha)} = M_\alpha v$.
Squaring, $K^2/c^2 + 2KM_\alpha = M_\alpha^2v^2$. Solving the quadratic equation in K:
$K^2 + 2KM_\alpha c^2 - M_\alpha^2v^2c^2 = 0$
The positive root is given by
$K= [-2M_\alpha c^2 + \sqrt{(4M_\alpha^2c^4 + 4M_\alpha^2v^2c^2)}]/2 = -M_\alpha c^2 + \sqrt{(M_\alpha^2c^4 + M_\alpha^2v^2c^2)}$
$= -M_\alpha c^2 + M_\alpha c^2 (1 + v^2/c^2)^{1/2} = -M_\alpha c^2 + M_\alpha c^2 (1 + v^2/2c^2 + \ldots)$ (Binomial expansion)
$= M_\alpha v^2/2$ (retaining the term up to order of v^2/c^2) **[3 marks]**

5. **ANS:D**
6. **ANS:B.**
7. **ANS:A.**
8. ANS: D (Only III, IV are true)
9. **ANS: C [My own question.]**
10. ANS: D
11. ANS: D [My own question.] Note: In the limit *v<<c,*

$$\frac{K_P}{K_e}=\frac{p^2/2m_P}{p^2/2m_e}\Rightarrow\frac{K_P}{K_e}=\frac{m_e}{m_P}\Rightarrow K_P=\frac{m_e}{m_P}K_e<K_e$$

12. ANS: D.
13. ANS:B
14. ANS:D
15. Solution: E. only III is true
16. Solution: A
17. Solution: A
18. Solution: B
19. Solution: B

$$eV=\frac{p^2}{2m}=\frac{(h/\lambda_e)^2}{2m}$$

$$\Rightarrow\lambda_e=\frac{h}{\sqrt{2m_e eV}}=\frac{hc}{\sqrt{2m_e c^2 eV}}=\frac{hc}{\sqrt{2m_e c^2 eV}}=\frac{1240\text{nm}\cdot\text{eV}}{\sqrt{1\text{MeV}\cdot e\cdot 10000\text{V}}}=$$

$$\frac{1240\text{nm}\cdot\text{eV}}{\sqrt{1\times10^{10}\text{eV}^2}}=\frac{1240\text{nm}}{\sqrt{10^{10}}}\sim\frac{10^3\text{nm}}{10^5}=10^{-2}\text{nm}$$

$$\frac{\lambda_e}{\lambda}\sim\frac{10^{-2}\text{nm}}{10^2\text{nm}}=10^{-4}$$

Hence, with λ_e we can see 4 orders smaller.
20. Solution: E, Only I is true. Young and Freeman, pg. 1485, Q38
21. Solution: A
22. Solution: C
23. Solution: D. Note: $E_n=-\frac{Z^2}{n^2}E_0$
24. Solution: D
25. ANS: B
26. ANS: C
27. ANS: A
28. ANS: B
29. ANS: A
30. ANS: B
31. ANS: A
32. ANS: B
33. ANS: C
34. ANS: C
35. ANS: E (Only IV is true)
36. ANS: D
37. ANS: D
38. ANS: D

39. (ANS: C)
40. (ANS: A)
41. (ANS: A)
42. ANS: C

$$\lambda=\frac{h}{p_x}$$

$$\Delta x=2\lambda=\frac{2h}{p_x}$$

$$\Delta x\Delta p_x\geq\frac{\hbar}{2}\Rightarrow\frac{2h}{p_x}\Delta p_x\geq\frac{\hbar}{2}\Rightarrow\frac{\Delta p_x}{p_x}\geq\frac{\hbar}{4h}=\frac{1}{8\pi}$$

$$\frac{\Delta p_x}{p_x}=\frac{m\Delta v_x}{mv_x}\geq\frac{1}{8\pi}\Rightarrow\Delta v_x\geq\frac{v_x}{8\pi}$$

43. ANS: D
44. ANS: A

Section B: Structural questions.
[*Bahagian B: Soalan-soalan strutur.***]**

1(A) ANS
Elmer Anderson, pg49, problem 2-6.

(iv) For short wavelength, the exponential term in Planck's law, $e^{hc/\lambda kT}$, becomes very large compared to the value 1, $e^{hc/\lambda kT}>>1$, hence the term in the bracket in the denominator of the Planck's law reduces to $e^{hc/\lambda kT}$, i.e.

$$\lim_{\lambda\to0}\frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}=\frac{2\pi hc^2}{\lambda^5}e^{-hc/\lambda kT}. \qquad \text{Eq. (1)}$$

Comparing Eq. (1) and the Wein's law, we find that both have the same form of λ–dependence,

$$\frac{2\pi hc^2}{\lambda^5}e^{-hc/\lambda kT}\equiv\frac{ae^{-b/\lambda T}}{\lambda^5}.$$

[*satisfactory argument:* 2 MARKS]

(v) Comparing both equation, we identify the constants *a* and *b* to be

$a\equiv 2\pi hc^2$ **[2 MARKS]**
$b\equiv hc/k$ **[2 MARKS]**

(vi) Stafan-Boltzman law: $I(T)=\sigma T^4$

Substitute Planck's law, $R(\lambda,T)=\frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}$, into the definition of

$I(T)=\int_0^\infty R(\lambda,T)\mathrm{d}\lambda$, we get

$$I(T)=\int_0^\infty R(\lambda,T)\mathrm{d}\lambda=\int_0^\infty \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}\mathrm{d}\lambda=2\pi hc^2\int_0^\infty \frac{1}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}\mathrm{d}\lambda .$$

Define $x=\dfrac{hc}{\lambda kT}\Rightarrow \mathrm{d}x=-\dfrac{hc}{kT}\dfrac{1}{\lambda^2}\mathrm{d}\lambda$

$$I(T)=2\pi hc^2\int_0^\infty \frac{1}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}\mathrm{d}\lambda=2\pi hc^2\int_0^\infty \frac{1}{\lambda^3\left(e^{x}-1\right)}\frac{\mathrm{d}\lambda}{\lambda^2}$$

$$=-\frac{2\pi k^4T^4}{h^3c^2}\int_\infty^0 \frac{x^3}{e^x-1}\mathrm{d}x=\frac{2\pi k^4T^4}{h^3c^2}\int_0^\infty \frac{x^3}{e^x-1}\mathrm{d}x=\frac{2\pi k^4T^4}{h^3c^2}\frac{\pi^4}{15}=\frac{2\pi^5k^4T^4}{15h^3c^2}$$

Hence, the Stefan constant is $\sigma=\dfrac{2\pi^5k^4T^4}{15h^3c^2}$.**[4 marks]**

1(B) ANS: 4.08 eV
E. Anderson, pg. 57, Problem 2-16. **[4 marks]**

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2(C) ANS (Beiser, Ex. 19, pg. 198)

The probability density is given by $p_n(x)=\psi_n(x)\psi_n^*(x)$, where the wave function of a particle in a box is $\psi_n(x)=\sqrt{\dfrac{2}{L}}\sin\dfrac{n\pi x}{L}$; The probability to find the particle between x_2 and x_1 within the box is

$$P_n(x_2,x_1)=\int_{x_1}^{x_2}\psi_n(x)\psi_n^*(x)dx=\frac{2}{L}\int_{x_1}^{x_2}\sin^2\frac{n\pi x}{L}dx=\left(\frac{x}{L}-\frac{x}{2n\pi}\sin\frac{2\pi nx}{L}\right)\Bigg|_{x_1}^{x_2}$$. Here, set $x_2 = L/n$, $x_1 = 0$,

$$P(L/n,0)=\left(\frac{x}{L}-\frac{x}{2\pi}\sin\frac{2\pi x}{L}\right)\Bigg|_0^{L/n}=\left(\frac{1}{n}-\frac{L}{2\pi n}\sin 2\pi n\right)-(0-0)=\frac{1}{n}$$

[5 marks]

3(A) ANS
Elmer E. Anderson, pg. 19 (BM version), problem 1-10.

Take S′ to be the ‘rest frame’. S′′ is moving with respect to S′ with a velocity of $u_x=\beta_2c$. Take S as the “moving frame”, moving at a velocity of $v = -\beta_1c$ with respect to the frame S′. Hence, the velocity of S′′ with respect to S, u'_x, is related to both u_x and v via the formula

$$u'_x=\frac{u_x-v}{1-\frac{u_xv}{c^2}}=\frac{\beta_2c-(-\beta_1c)}{1-\frac{(\beta_2c)(-\beta_1c)}{c^2}}=\frac{(\beta_2+\beta_1)c}{1+\beta_2\beta_1}$$

Note: one can check the correctness of the above result by considering two limiting cases:
iii. When $\beta_2\to0$, S′′ becomes S′, hence, we should recover $u'_x\to\beta_1c$.
iv. When $\beta_1\to0$, S becomes S′, hence, we should recover $u'_x\to\beta_2c$.

[10 marks]

3(B) ANS (My own question)

(v) Total energy $E = K + M_\alpha c^2$ **[2 marks]**

(vi) $E = K + M_\alpha c^2 \Rightarrow E^2 = (K + M_\alpha c^2)^2$
Energy-momentum invariance: $E^2 = p^2c^2 + M_\alpha^2c^4$
Eliminating E in the above equations, $p = \sqrt{(K^2/c^2 + 2KM_\alpha)}$. **[3 marks]**

(vii) Let M be the relativistic mass of the alpha particle. Its total energy is then related to this mass as per $E = Mc^2$. But $E = K + M_\alpha c^2$, hence, the increase in mass $\times c^2$,
$\Delta M_\alpha c^2 = Mc^2 - M_\alpha c^2 = (K + M_\alpha c^2) - M_\alpha c = K$
$\Rightarrow \Delta M_\alpha c^2 = K$ **[2 marks]**

(viii) In the limit of $v << c$, the relativistic expression for the momentum reduces to classical one, i.e. $p_{SR} = \gamma M_\alpha v \to p_{Classical} = M_\alpha v$. Hence, from (*ii*), as $v<<c$, $p = M_\alpha v=\sqrt{(K^2/c^2 + 2KM_\alpha)}$.
Squaring, $K^2/c^2 + 2KM_\alpha = M_\alpha^2v^2$. Solving the quadratic equation in K:
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The positive root is given by
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$= -M_\alpha c^2 + M_\alpha c^2\,(1 + v^2/c^2)^{1/2} = -M_\alpha c^2 + M_\alpha c^2\,(1 + v^2/2c^2 + \ldots)$ (Binomial expansion)
$= M_\alpha v^2/2$ (retaining the term up to order of v^2/c^2) **[3 marks]**

Sessi 06/07 KSCP

UNIVERSITI SAINS MALAYSIA

Kursus Semasa Cuti Panjang
Sessi 2006/2007

Jun 2007

ZCT 104/3 - Physics IV (Modern Physics)
[Fizik IV (Fizik Moden)]

Duration: 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains **XXX** pages before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **XXX** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]*

Instruction: Answer only **FIVE** questions out of six questions given.

Students are allowed to answer all questions in Bahasa Malaysia or in English.

*[**Arahan**: Jawab **LIMA** soalan daripada enam solaan yang disediakan.*

Sila jawab soalan-soalan objektif daripada bahagian A dalam kertas jawapan objektif yang dibekalkan. Sila serahkan kertas jawapan objektif dan jawapan kepada soalan-soalan struktur berasingan.

Pelajar dibenarkan untuk menjawab samada dalam bahasa Malaysia atau bahasa Inggeris.]

Data

Speed of light in free space, $c = 3.00 \times 10^8$ m s^{-1}
Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
Permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
Elementary charge, $e = 1.60 \times 10^{-19}$ C
Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg
Molar gas constant, = 8.31 J K^{-1} mol^{-1}
Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}
Gravitational constant, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
Acceleration of free fall, $g = 9.81$ m s^{-2}

Instruction: Answer only 5 out of six questions prepared. Each question carries 20 marks.
[Arahan: Jawab hanya 5 soalan daripada 6 soalan yang disediakan. Setiap soalan membawa 20 markah.]

1. (a) What is the de Broglie wavelength of an alpha particle ($q = +2e$, $M_\alpha = 6.64\times10^{-27}$ kg) accelerated from rest through a potential drop of 125 V?
[*Apakah jarak gelombang de Broglie zarah alfa ($q = +2e$, $M_\alpha = 6.64\times10^{-27}$ kg) yang dipecutkan daripada keadaan rehat melalui suatu kejatuhan keupayaan 125 V?*]
[5 marks]

(b) What is the energy of a photon that has wavelength 0.10 μm? Give your answer in unit of eV. [*Apakah tenaga foton yang ber jarak gelombang 0.10 μm?Nyatakan jawapan anda dalam unit eV*]
[3 marks]

(c) Show that the wavelength λ of an *relativistic* electron of kinetic energy K and rest mass m is $\lambda = \dfrac{hc}{\sqrt{K\left(K+2mc^2\right)}}$.
[*Tunjukkan bahawa jarak gelombang λ suatu elektron kerelatifan yang tenaga kinetik K dan berjisim rehat m diberikan oleh* $\lambda = \dfrac{hc}{\sqrt{K\left(K+2mc^2\right)}}$.]
[8 marks]

(d) A block is attached to a massless spring. The spring is stretched from its equilibrium position and released, and the block is set into a simple harmonic motion with a total energy of 2.0 J with a frequency of oscillation 0.56 Hz. Assuming that the energy is quantised, find the quantum number n for the system.
[*Suatu blok diikat kepada suatu spring yang jisimnya boleh dibaikan. Spring tersebut ditarik daripada kedudukan keseimbangannya dan dilepaskan. Blok tersebut melakukan gerakan harmonik mudah dengan jumlah tenaga 2.0 J dan frekuensi ayunan 0.56 Hz. Andaikan tenaga adalah terkuantumkan, cari nombor quantum n bagi sistem tersebut.*]
[4 marks]

Sessi 06/07 KSCP

2. (a) (*i*) The x-coordinate of an electron is measured with an uncertainty of 0.20 mm. What is the x-component of the electron's velocity, v_x, if the minimum percentage uncertainty in a simultaneous measurement of v_x is 1.0 %?
[*Koordinat-x suatu elektron diukurkan dengan ketidakpastian 0.20 mm. Apakah komponen-x bagi halaju elektron, v_x, jika peratusan minimum ketidakpastian dalam ukuran v_x yang serentak ialah 1.0 %?*]

[3 marks]

(*ii*) Repeat part a(*i*) for a proton.
[*Ulangi bahagian a(i) bagi kes proton*]

[2 marks]

(b) The unstable W^+ particle has a rest energy of 80.41 GeV (1 GeV = 10^9 eV) and an uncertainty in rest energy of 2.06 GeV. Estimate the lifetime of the W^+ particle.
[*Zarah W^+ yang tidak stabil mempunyai tenaga rehat 80.41 GeV dan ketidakpastian dalam tenaga rehat 2.06 GeV. Anggarkan jangka hayat zarah W^+*]

[5 marks]

(c) The kinetic energy of a nonrelativistic particle in terms of its momentum can be writen as $K = p^2/2m$. Use the Heisenberg uncertainty principle to estimate the minimum kinetic energy of a proton confined within a nucleus having a diameter of 1 fm (1 fm = 10^{-15}m)
[*Tenaga kinetik suatu zarah tidak kerelatifan dalam sebutan momentumnya boleh dinyatakan sebagai $K = p^2/2m$. Gunakan prinsip ketidakpastian Heisenberg untuk menganggarkan tenaga kinetik minimum suatu proton yang terperangkap dalam suatu nukleus yang berdiameter 1 fm.*]

[10 marks]

3. (a) Electrons are ejected from a metallic surface with speeds ranging up to 4.6×10^5 m/s when light with a wavelength of 625 nm is used in a photoelectric effect experiment.
[*Elektron dipancarkan daripada suatu permukaan logam dengan laju sehingga 4.6×10^5 m/s bila cahaya berjarak gelombang 625 nm digunakan dalam suatu eksperiment kesan fotoelektrik.*]

(*i*) What is the work function of the surface in unit of eV?
[*Apakah fungsi kerja bagi permukaan tersebut dalam unit eV?*]

[4 marks]

(*ii*) What is the cutoff frequency for this surface?
[*Apakah frekuensi penggal bagi permukaan tersebut?*]

[4 marks]

(b) Show that a photon cannot transfer all of its energy to a free electron. (*Hint:* Note that the system energy and momentum transfer must be conserved).
[*Tunjukkan banawa suatu foton tidak boleh pindahkan kesemua tenaganya kepada suatu elektron bebas (Petunjuk: Dimaklumkan bahawa tenaga sistem dan momentum terpindahkan mest diabadikan.)*]

[12 marks]

4. (a) A particle of mass m is confined to an impenetrable one-dimensional box between $x = 0$ and $x = L$. The wave function of the particle is $\psi(x) = A\sin\left(\frac{n\pi x}{L}\right)$.
[*Suatu zarah berjisim m diperangkapkan dalam suatu kotak satu dimensi yang tidak boleh ditembusi di antara x = 0 and x = L. Fungsi gelombang zarah tersebut ialah* $\psi(x) = A\sin\left(\frac{n\pi x}{L}\right)$.]

(*i*) Use the normalization condition on ψ to obtain the normalization constant A.
[*Dengan menggunakan syarat normalisasi pada ψ, dapatkan pemalar normalisasi A.*]

[3 marks]

(*ii*) Find the expectation value of the position x of the particle in the ground state.
[*Dapatkan nilai jangkaan bagi kedudukan x zarah dalam keadaan dasar.*]

[6 marks]

(*iii*) Calculate the probability of finding the electron between x=0 and $x = L/4$ in the ground state.
[*Hitungkan kebarangkalian menjumpai elektron di antara x=0 dan x=L/4 dalam keadaan dasar.*]

[5 marks]

(b) Why is it impossible for the lowest-energy state of a harmonic oscillator to be zero?
[*Mengapakah keadaan pengayun harmonik pada tenaga paling rendah tidak boleh menjadi sifar?*]

[6 marks]

5. (a) A particle has mass 5.52×10^{-27} kg. Compute the rest energy of the particle in MeV.
[*Suatu zarah berjisim 5.52×10^{-27} kg. Hitungkan tenaga rehat zarah tersebut dalam unit MeV.*]

[5 marks]

(b) A cube of metal with sides of length a sits at rest in a frame S with one edge parallel to the x-axis. Therefore in S the cube has volume a^3. Frame S' moves along the x-axis with a speed u. As measured by an observer in frame S', what is the volume of the metal cube?
[*Suatu kuib logam dengan sisinya a berada dalam keadaan rehat dalam rangka S. Salah satu sisi kuib adalah selari dengan paski-x rangka S. Jadi dalam rangka S isipadu kuib adalah a^3. Rangka S' bergerak sepanjang paksi-x dengan laju u. Apakah isipadu kuib logam sebagaimana diukurkan oleh pemerhati dalam rangka S'?*]

[5 marks]

(c) High-speed electrons are used to probe the interior structure of the atomic nucleus. For such electrons the expression $\lambda = h/p$ still holds, but we must use the relativistic expression for momentum $p = \frac{mv}{\sqrt{1-v^2/c^2}}$. Show that the speed of an electron that has de Broglie wavelength λ is $v = \frac{c}{\sqrt{1+\left(\frac{mc\lambda}{h}\right)^2}}$

Sessi 06/07 KSCP

[Elektron berlaju tinggi biasanya digunakan untuk mempelapori struktur dalaman nukleus atom. Bagi elektron tersebut, kenyataan $\lambda = h/p$ *masih benar tapi kita mesti menyatakan momentumnya dalam bentuk kerelatifan,* $p = \frac{mv}{\sqrt{1-v^2/c^2}}$. *Tunjukkan bahawa bagi elektron yang jarak gelombang de Broglie-nya* λ, *lajunya diberikan oleh*

$$v = \frac{c}{\sqrt{1+\left(\frac{mc\lambda}{h}\right)^2}}$$]

[10 marks]

6. (a) How much energy is required to ionise hydrogen?
[Berapa banyakkah tenaga yang diperlukan untuk mengionkan hidrogen]

(*i*) in the ground state? [*dalam keadaan dasar?*]

[2 marks]

(*ii*) when it is in the state for which n=3? [*bila ia berada pada keadaan n=3?*]

[2 marks]

(b) Two hydrogen atoms collide head-on and end up with zero kinetic energy. Each atom then emits light with a wavelength of 121.6 nm (n= 2 to n= 1 transition). At what speed were the atoms moving before collision?
[*Dua atom hidrogen berlanggar secara muka-sama-muka dan berakhiran dengan tenaga kinetik sifar. Setiap satu atom kemudian memancarkan cahaya berjarak gelombang 121.6 nm (perlihan n=2 kepada n=1). Apakah laju atom sebelum mereka berlanggar?*]

[4 marks]

(c) Based on the Bohr model, derive the expression for the Bohr radius for hydrogen atom from scratch. Express you answer in unit of Å.

[*Berdasarkan model Bohr, terbitkan ungkapan radius Bohr bagi atom hidrogen. Nyatakan jawapan anda dalam unit* Å.]

[10 marks]

SOLUTION

1. (a) What is the de Broglie wavelength of an alpha particle ($q = +2e$, $M_\alpha = 6.64\times10^{-27}$ kg) accelerated from rest through a potential drop of 125 V?

Solution
Young and Freedman, Chap 39, pg. 1516, Q39.43 (b)

Recall $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mq\Delta V}}$. For an alpha particle:

$$\lambda = \frac{6.63\times10^{-34}\,\text{J}\cdot\text{s}}{\sqrt{2(6.64\times10^{-27}\,\text{kg})2(1.60\times10^{-19}\,\text{C})(125\,\text{V})}} = 9.10\times10^{-13}\,\text{m}.$$

(b) What is the energy of a photon that has wavelength 0.10 μm? Give your answer in unit of eV.

Solution
Young and Freedman, Chap 39, pg. 1515, Q39.37 (a)

$$E = hc/\lambda = 12.4\text{eV}$$

(c) Show that the wavelength λ of an *relativistic* electron of kinetic energy K and rest mass m is $\lambda = \frac{hc}{\sqrt{K(K+2mc^2)}}$.

Young and Freedman, Chap 39, pg. 1516, Q39.44 (a)

$E^2 = p^2c^2 + m^2c^4$ and $E = K + mc^2 \Rightarrow (K+mc^2)^2 = p^2c^2 + m^2c^4$

$$\Rightarrow p = \frac{[(K+mc^2)^2 - m^2c^4]^{1/2}}{c} = \frac{[K^2 + 2Kmc^2 + m^2c^4 - m^2c^4]^{1/2}}{c}$$

$$= \frac{[K(K+2mc^2)]^{1/2}}{c}$$

$$\Rightarrow \lambda = \frac{h}{p} = \frac{hc}{[K(K+2mc^2)]^{1/2}}.$$

(d) A block is attached to a massless spring. The spring is stretched from its equilibrium position and released, and the block is set into a simple harmonic motion with a total energy of 2.0J with a frequency of oscillation 0.56 Hz. Assuming that the energy is quantised, find the quantum number n for the system.

Serway and Jewett, Chap 40, pg. 1291, Example 40.2

$$E_n = nhf = n(6.63\times10^{-34}\,\text{J}\cdot\text{s})(0.56\text{Hz}) = 2.0\text{J}$$

$$n = 5.4\times10^{33}$$

2. (a) (i) The x-coordinate of an electron is measured with an uncertainty of 0.20 mm. What is the x-component of the electron's velocity, v_x, if the minimum percentage uncertainty in a simultaneous measurement of v_x is 1.0 %?

Young and Freedman, Chap 39, pg. 1514, Q39.20 (a)

$(\Delta x)(m\Delta v_x) \geq h/4\pi$, and setting $\Delta v_x = (0.010)v_x$ and the product of the uncertainties equal to $h/4\pi$ (for the minimum uncertainty) gives
$v_x = h/(4\pi m(0.010)\Delta x) = (57.9/2)\text{ m/s} = (29.0)\text{ m/s}$.

(ii) Repeat part a(i) for a proton.

Repeating with the proton mass gives 15.8 mm/s.

$$v_x \propto \frac{1}{m} \Rightarrow \frac{v_{x,(ii)}}{v_{x,(i)}} = \frac{m_{(i)}}{m_{(ii)}} \Rightarrow v_{x,(ii)} = v_{x,(i)}\frac{m_{(i)}}{m_{(ii)}} = v_{x,(i)}\frac{m_e}{m_P} = \left(5.5\times10^{-4}\right)\frac{9.1\times10^{-31}}{1.67\times10^{-27}} = 15.8\text{ mm/s.}$$

(b) The unstable W^+ particle has a rest energy of 80.41 GeV (1 GeV = 10^9 eV) and an uncertainty in rest energy of 2.06 GeV. Estimate the lifetime of the W^+ particle.

Young and Freedman, Chap 39, pg. 1515, Q39.22

$$\Delta E\Delta t = \frac{h}{4\pi} \quad \Delta E = \Delta mc^2 \quad \Delta mc^2 = 2.06\times10^9\text{ eV} = 3.30\times10^{-10}\text{ J}$$

$$\Delta t = \frac{h}{4\pi\Delta mc^2} = \frac{6.63\times10^{-34}\text{ J}\cdot\text{s}}{4\pi(3.3\times10^{-10}\text{ J})} = 1.6\times10^{-25}\text{ s.}$$

(c) The kinetic energy of a nonrelativistic particle in terms of its momentum can be written as $K = p^2/2m$. Estimate the minimum kinetic energy of a proton confined within a nucleus having a diameter of 1 fm (1 fm = 10^{-15}m)

Serway and Jewett, Chap 40, pg. 1317, Q52.

To find the minimum kinetic energy, think of the minimum momentum uncertainty, and maximum position uncertainty of $10^{-15}\text{ m} = \Delta x$. We model the proton as moving along a straight line with $\Delta p\Delta x = \frac{\hbar}{2}$, $\Delta p = \frac{\hbar}{2\Delta x}$. The average momentum is zero. The average squared momentum is equal to the squared uncertainty:

$$K = \frac{p^2}{2m} = \frac{(\Delta p)^2}{2m} = \frac{\hbar^2}{4(\Delta x)^2 2m} = \frac{h^2}{32\pi^2(\Delta x)^2 m} = \frac{\left(6.63\times10^{-34}\text{ J}\cdot\text{s}\right)^2}{32\pi^2\left(10^{-15}\text{ m}\right)^2 1.67\times10^{-27}\text{ kg}} = 8.33\times10^{-13}\text{ J}$$

$$= \boxed{5.21\text{ MeV}}$$

3. (a) Electrons are ejected from a metallic surface with speeds ranging up to 4.6×10^5 m/s when light with a wavelength of 625 nm is used in a photoelectric effect experiment.

(i) What is the work function of the surface?
(ii) What is the cutoff frequency for this surface?

Serway and Jewett, Chap 40, pg. 1315, Problem 14

$$K_{max} = \frac{1}{2}mv_{max}^2 = \frac{1}{2}\left(9.11\times10^{-31}\right)\left(4.60\times10^5\right)^2 = 9.64\times10^{-20}\text{ J} = 0.602\text{ eV}$$

(a) $$\phi = E - K_{max} = \frac{1\,240\text{ eV}\cdot\text{nm}}{625\text{ nm}} - 0.602\text{ nm} = \boxed{1.38\text{ eV}}$$

(b) $$f_c = \frac{\phi}{h} = \frac{1.38\text{ eV}}{6.626\times10^{-34}\text{ J}\cdot\text{s}}\left(\frac{1.60\times10^{-19}\text{ J}}{1\text{ eV}}\right) = \boxed{3.34\times10^{14}\text{ Hz}}$$

(b) Show that a photon cannot transfer all of its energy to a free electron. (*Hint:* Note that the system energy and momentum transfer must be conserved).

Serway and Jewett, Chap 40, pg. 1318, Q59.

Show that if all of the energy of a photon is transmitted to an electron, momentum will not be conserved.

Energy: $\frac{hc}{\lambda_0} = \frac{hc}{\lambda'} + K_e = m_ec^2(\gamma - 1)$ if $\frac{hc}{\lambda'} = 0$ Eq. (1)

Momentum: $\frac{h}{\lambda_0} = \frac{h}{\lambda'} + \gamma m_ev = \gamma m_ev$ if $\lambda' = \infty$ Eq. (2)

From (1), $\gamma = \frac{h}{\lambda_0 m_ec} + 1$ Eq. (3)

$v = c\sqrt{1 - \left(\frac{\lambda_0 m_ec}{h + \lambda_0 m_ec}\right)^2}$ Eq. (4)

Substitute (3) and (4) into (2) and show the inconsistency:

$$\frac{h}{\lambda_0} = \left(1 + \frac{h}{\lambda_0 m_ec}\right)m_ec\sqrt{1 - \left(\frac{\lambda_0 m_ec}{h + \lambda_0 m_ec}\right)^2} = \frac{\lambda_0 m_ec + h}{\lambda_0}\sqrt{\frac{h(h + 2\lambda_0 m_ec)}{(h + \lambda_0 m_ec)^2}} = \frac{h}{\lambda_0}\sqrt{\frac{h + 2\lambda_0 m_ec}{h}}.$$

This is impossible, so all of the energy of a photon cannot be transmitted to an electron.

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Alternatively, we can prove this as followed:
Assume that a photon can give all of its energy to a free electron initially at rest. The photon's momentum is $\vec{p}_\gamma \neq 0$. The proton's momentum after absorption $\vec{p}' \neq 0$.

Before absorption After absorption

Total energy conservation requires that

$$\left|c\vec{p}_\gamma\right| + m_P c^2 = E'_P. \qquad \text{Eq. (1)}$$

Einstein's energy-momentum conservation formula relates the total energy of the proton after absorption, E'_P, to the proton's momentum after photon absorption, $\vec{p}'$ via

$$E'^2_P = \left|\vec{p}'\right|^2 c^2 + m_P{}^2 c^4. \qquad \text{Eq. (2)}$$

Squaring Eq. (1), we could relate $\vec{p}'$ to $\vec{p}_\gamma$ by virtue of Eq. (2):

$$c^2\left|\vec{p}_\gamma\right|^2 + m_P{}^2c^4 + 2\left|\vec{p}_\gamma\right| m_P c^3 = E'^2_P = \left|\vec{p}'\right|^2 c^2 + m_P{}^2 c^4$$

$$\Rightarrow \left|\vec{p}_\gamma\right|^2 + 2\left|\vec{p}_\gamma\right| m_P c = \left|\vec{p}'\right|^2 \qquad \text{Eq.(3)}$$

Independently, we also require the process to observe total momentum conservation,

$$\vec{p}_\gamma = \vec{p}' \Rightarrow \left|\vec{p}_\gamma\right| = \left|\vec{p}'\right| \qquad \text{Eq. (4)}$$

Obviously, Eq. (3) and Eq. (4) are not consistent, hence, we conclude that both momentum and energy conservation does not hold simultaneously if a photon delivers all of its energy to a free electron.

4. (a) A particle of mass m is confined to an impenetrable one-dimensional box between $x = 0$ and $x = L$. The wave function of the particle is $\psi(x) = A\sin\left(\frac{n\pi x}{L}\right)$.

(*i*) Use the normalization condition on ψ to obtain the normalization constant A.
(*ii*) Find the expectation value of the position x of the particle in the ground state.
(*iii*) Calculate the probability of finding the electron between x=0 and x = L/4 in the ground state.

Serway and Jewett, Chap 41, pg. 1346, Problem 17, 18.

(i) Normalization requires

$$\int_{\text{all space}} |\psi|^2\,dx = 1 \quad \text{or} \quad \int_0^L A^2\sin^2\left(\frac{n\pi x}{L}\right)dx = 1$$

$$\int_0^L A^2\sin^2\left(\frac{n\pi x}{L}\right)dx = A^2\left(\frac{L}{2}\right) = 1 \quad \text{or} \quad \boxed{A = \sqrt{\frac{2}{L}}}.$$

(ii)

$$\langle x\rangle = \int_0^L x\frac{2}{L}\sin^2\left(\frac{\pi x}{L}\right)dx = \frac{2}{L}\int_0^L x\left(\frac{1}{2} - \frac{1}{2}\cos\frac{2\pi x}{L}\right)dx = \frac{1}{L}\frac{x^2}{2}\bigg|_0^L - \frac{1}{L}\frac{L^2}{16\pi^2}\left[\frac{4\pi x}{L}\sin\frac{4\pi x}{L} + \cos\frac{4\pi x}{L}\right]_0^L = \boxed{\frac{L}{2}}$$

(iii) The desired probability is

$$P = \int_0^{L/4}|\psi|^2\,dx = \frac{2}{L}\int_0^{L/4}\sin^2\left(\frac{\pi x}{L}\right)dx = \frac{2}{L}\left(\frac{x}{2} - \frac{1}{4\pi}\sin\frac{2\pi x}{L}\right)\bigg|_0^{L/4} = \frac{2}{L}\left(\frac{L}{8} - 0 - 0 + 0\right) = \boxed{0.250}$$

(b) Why is it impossible for the lowest-energy state of a harmonic oscillator to be zero?

Serway and Jewett, Chap 41, pg. 1345, Question 8.

Quantum mechanically, the lowest kinetic energy possible for any bound particle is greater than zero. The following is a proof: If its minimum energy were zero, then the particle could have zero momentum and zero uncertainty in its momentum. At the same time, the uncertainty in its position would not be infinite, but equal to the width of the region in which it is restricted to stay. In such a case, the uncertainty product $\Delta x \Delta p_x$ would be zero, violating the uncertainty principle. This contradiction proves that the minimum energy of the particle is not zero. Any harmonic oscillator can be modeled as a particle or collection of particles in motion; thus it cannot have zero energy.

Sessi 06/07 KSCP

5. (a) A ψ particle has mass 5.52×10^{-27} kg. Compute the rest energy of the particle in MeV.

Young and Freedman, Chap 37, pg. 1440, Q37.42
$(5.52\times10^{-27}\ \text{kg})(3.00\times10^{8}\ \text{m/s})^2 = 4.97\times10^{-10}\ \text{J} = 3105\ \text{MeV}$.

(b) A cube of metal with sides of length a sits at rest in a frame S with one edge parallel to the x-axis. Therefore in S the cube has volume a^3. Frame S' moves along the x-axis with a speed u. As measured by an observer in frame S', what is the volume of the metal cube?

Young and Freedman, Chap 37, pg. 1441, Q37.50
One dimension of the cube appears contracted by a factor of $\frac{1}{\gamma}$, so the volume in S' is
$a^3/\gamma = a^3\sqrt{1-(u/c)^2}$.

(c) High-speed electrons are used to probe the interior structure of the atomic nucleus. For such electrons the expression $\lambda = h/p$ still holds, but we must use the relativistic expression for momentum $p=\dfrac{mv}{\sqrt{1-v^2/c^2}}$. Show that the speed of an electron that has de Broglie wavelength λ is $v=\dfrac{c}{\sqrt{1+\left(\dfrac{mc\lambda}{h}\right)^2}}$

Young and Freedman, Chap 39, pg. 1516, Q39.42

$$\lambda = \frac{h}{p} = \frac{h\left(1-\frac{v^2}{c^2}\right)^{1/2}}{mv}$$

$$\Rightarrow \lambda^2 m^2 v^2 = h^2\left(1-\frac{v^2}{c^2}\right) = h^2 - \frac{h^2v^2}{c^2}$$

$$\Rightarrow \lambda^2 m^2 v^2 + h^2\frac{v^2}{c^2} = h^2$$

$$\Rightarrow v^2 = \frac{h^2}{\left(\lambda^2 m^2 + \frac{h^2}{c^2}\right)} = \frac{c^2}{\left(\frac{\lambda^2 m^2 c^2}{h^2}+1\right)}$$

$$\Rightarrow v = \frac{c}{\left(1+\left(\frac{mc\lambda}{h}\right)^2\right)^{1/2}}.$$

6. (a) How much energy is required to ionize hydrogen?
(*i*) in the ground state?

(*ii*) when it is in the state for which n=3?

Serway and Jewett, Chap 42, pg. 1392, Problem 8.

(a) We use $E_n = \dfrac{-13.6\ \text{eV}}{n^2}$.

To ionize the atom when the electron is in the n^{th} level, it is necessary to add an amount of energy given by $E=-E_n=\dfrac{13.6\ \text{eV}}{n^2}$.

(i) Thus, in the ground state where $n=1$, we have $\boxed{E=13.6\ \text{eV}}$.

(ii) In the $n=3$ level, $E=\dfrac{13.6\ \text{eV}}{9}=\boxed{1.51\ \text{eV}}$.

(b) Two hydrogen atoms collide head-on and end up with zero kinetic energy. Each atom then emits light with a wavelength of 121.6 nm (n= 2 to n= 1 transition). At what speed were the atoms moving before collision?

Serway and Jewett, Chap 42, pg. 1392, Problem 11.

Each atom gives up its kinetic energy in emitting a photon,

so $\frac{1}{2}mv^2 = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34}\ \text{J}\cdot\text{s})(3.00\times10^{8}\ \text{m/s})}{(1.216\times10^{-7}\ \text{m})} = 1.63\times10^{-18}\ \text{J}$

$v=\boxed{4.42\times10^{4}\ \text{m/s}}$. Note: the mass of a hydrogen is taken to be the same as the mass of a proton, $1.67\times10^{-27}\text{kg}=938\text{MeV}$

(c) Based on the Bohr model, derive the expression for the Bohr radius for hydrogen atom from scratch. Express you answer in unit of Å.

Serway and Jewett, Chap 42, pg. 1392, Problem 11.

Quantisation of angular momentum:

$L=mvr=n\hbar \Rightarrow v=\dfrac{n\hbar}{mr}$ Eq. (1)

Mechanical stability:

$\dfrac{mv^2}{r}=\dfrac{Ze^2}{4\pi\varepsilon_0 r^2}$ Eq. (2)

Substitute v from Eq. (1) into Eq. (2), we have $\dfrac{m\left(\frac{n\hbar}{mr}\right)^2}{r}=\dfrac{Ze^2}{4\varepsilon_0\pi r^2}\Rightarrow r=\dfrac{n^2}{Z}\dfrac{4\pi\varepsilon_0\hbar^2}{me^2}\equiv\dfrac{n^2}{Z}a_0$

$a_0=\dfrac{4\pi\varepsilon_0\hbar^2}{me^2}$=0.53 Å

SESSI 07/08/TEST1

ZCT 104/3E Modern Physics
Semester I, Sessi 2007/08
1. Test I (26 Jan 2008)

Name:____

Matrix Number:____________________________________

Class A / Class B

Instruction: Do all questions in Section A and Section B.

Duration : 1 Hour

Section A (Objective questions)

1. In the following, which statement(s) is (are) correct regarding two events, A and B, at the space-time coordinates (x_A,t_A) and (x_B,t_B)? Assume $x_A > x_B$, $t_B > t_A$.

   I. If $x_B - x_A > c(t_B - t_A)$, events A and B can never be causally related.
   II. If $x_B - x_A < c(t_B - t_A)$, events A and B could be causally related.
   III. If $x_B - x_A = c(t_B - t_A)$, events A and B must be causally related.
   IV. If $x_B - x_A = c(t_B - t_A)$, events A and B could be causally related.

A. I, II B. II, IV C. I, II, III D. I, II, IV E. None of A, B, C, D

ANS: D (I, II, IV true).

2. Referring to Question 1 above, the space-time interval of the events A and B, $c^2(t_B - t_A)^2 - (x_B - x_A)^2$, is

   A. always the same in all inertial frames of reference.
   B. unpredictable when measured in other frame of reference.
   C. always positive
   D. always negative
   E. None of A, B, C, D.

ANS: A

3. O' is running at a velocity of v towards O. O' throws out a ball towards O. The velocity of the ball as measured by O is u. What is the velocity of the ball as measured by O'? Assume the velocities are non-relativisitic.

   A. $u + v$ B. $u - v$ C. $v - u$ D. $\sqrt{|u^2 - v^2|}$

   E. (None of **A**, **B**, **C**)

   ANS: B

4. Reconsider Question 3 above. Which of the following statement(s) is (are) true?

   I. Galilean transformation of velocities can be used to calculate the correct relative velocities in Question 3.
   II. Lorentz transformation of velocities can be used to calculate the correct relative velocities in Question 3.
   III. Either Galilean or Lorentz transformation of velocities can be used to calculate the correct relative velocities in Question 3.
   IV. Only one of the Galillean or Lorentz transformations of velocities, BUT not both, can be used to calculate the correct relative velocities in Question 3.

Test 2 sessi 0708

FIZIK IV (MODERN PHYSICS)
ZCT 104
TEST 2
15 March 2008

Instruction: Answer both questions on blank paper. Explain your steps as clearly as possible.

1. In Compton scattering experiment, X-ray photons with frequency f are incident on a target. After collision with electrons which initially at rest, the scattered photons with frequency of f' are observed at angle θ while the recoiled electrons are observed at angle φ.
   (a) What is the kinetic energy of the recoiling electron in terms of the f and f'?
   (b) Show that the kinetic energy of the recoiling electron in the Compton scattering is give by the general formula:

$$KE_{recoil\ electron} = \frac{2\left(\frac{h}{m_e c}\right)\sin^2\left(\frac{\theta}{2}\right)}{\frac{c}{f} + 2\left(\frac{h}{m_e c}\right)\sin^2\left(\frac{\theta}{2}\right)} hf$$

   Where m_e = rest mass of electron
   h = Planck's constant
   c = speed of light
   θ = angle of the scattered-photon
   f = frequency of the incident photon

   [*Hint:* $\cos\theta = 1 - 2\sin^2\left(\frac{\theta}{2}\right)$.]

   (c) Show that the maximum kinetic energy of the recoiling electron in this Compton scattering experiment is given by

$$KE_{max}(recoiling\ electron) = hf \frac{\frac{2hf}{m_e c^2}}{1 + \frac{2hf}{m_e c^2}}$$

   (i) At what angles θ and ϕ does this occur?
   (ii) If we detect a scattered electron at ϕ = 0° of 100 keV, what energy photon was scattered?

[25 marks]

2. Being not prohibited by the uncertainty principle, a particle of mass m can be created spontaneously in vacuum, exists for a short period of lifetime, Δt, and then annihilate into vacuum again. **[25 marks]**

   (i) How long will this particle exist (i.e, what is Δt in terms of m)?

   (ii) If the particle travels at approximately the speed of light, approximately how far will it travel during its short existence?
   (iii) If such a spontaneous creation-annihilation happens within the nucleus, of a typical size of r ~ fm, estimate the mass of m in unit of MeV.

(iv) Estimate the lifetime of *m* of the mass as calculated in (iii), in unit of seconds.

Solution:

1.

(a) $KE_{recoil\ electron} = hf - hf'$ (1a)

(b) From the Compton scattering formula, we have

$$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta) \quad (1b)$$

By substituting

$$\lambda' = \frac{c}{f'} \quad \text{and} \quad \lambda = \frac{c}{f}$$

into Equation (1b) and after a bit of algebra, we find

$$f' = \frac{f m_e c}{hf(1-\cos\theta) + m_e c} \quad (1c)$$

By substituting Equation (1c) into 1(a) and after a bit algebra, the kinetic energy of the recoiling electrons given by

$$KE_{recoil\ electron} = \frac{2\left(\frac{h}{m_e c}\right)\sin^2\left(\frac{\theta}{2}\right)}{\frac{c}{f} + 2\left(\frac{h}{m_e c}\right)\sin^2\left(\frac{\theta}{2}\right)} hf \quad (1d)$$

(c) From Equation (1d), the kinetic energy of the recoiling electron become maximum when $\sin^2\left(\frac{\theta}{2}\right)$ = 1. Consequently,

$$KE_{max}(recoiling\ electron) = \frac{2\left(\frac{h}{m_e c}\right)}{\frac{c}{f} + 2\left(\frac{h}{m_e c}\right)} hf \quad (1e)$$

After a bit algebra, the maximum kinetic energy of the recoiling electron is

$$KE_{max}(recoiling\ electron) = hf \frac{\frac{2hf}{m_e c^2}}{1 + \frac{2hf}{m_e c^2}} \quad (1f)$$

(c) (i)

From (c), the kinetic energy of the recoiling electron become maximum when

$\sin^2\left(\frac{\theta}{2}\right) = 1$ or θ = 0°, 180° and 360°

Therefore, the kinetic energy of the recoiling electron become maximum when

θ = 180° (head-on collision) because the shift in wavelength is zero at 0°.

and ϕ = 0°.

(c) (ii)

Here, $\phi = 0°$, θ = 180°, and KE_{max} (*recoiling electron*) = 100 keV.

By substituting these values into Equation 1(d) and solving the equation for *hf*, we obtain

hf = 0.2173 MeV

[*Hint*: In order to get this answer, you need to get the quadratic equation and then solves the equation by using:

$$x = \frac{-b \pm \sqrt{b^2 + 4ac}}{2a}.$$]

Finally, replace the *hf* = 0.2173 MeV and KE_{max} (*recoiling electron*) = 100 keV into Equation (1a), we obtain

$$\text{Energy of scattered photon} = hf'$$
$$= hf - KE_{recoil\ electron}$$
$$¿(0.2173 - 0.1)\ \text{MeV}$$
$$¿0.173\ \text{MeV}$$

2. (i) $\Delta t \sim \frac{\hbar}{2\Delta E} = \frac{\hbar}{2mc^2}$

(ii) $x = c\,\Delta t \sim \frac{\hbar}{2mc}$

(iii) take $x = r$,

$$r \sim \frac{\hbar}{2mc} \Rightarrow mc^2 \sim \frac{\hbar c}{2r} = \frac{hc}{4\pi r} = \frac{1240\ \text{eV}\cdot 10^{-9} m}{4\pi \times 10^{-15} m} = \frac{1240\ \text{eV}\cdot 10^{-9} m}{4\pi \times 10^{-15} m} = 98.7\text{MeV} \sim 100\,\text{MeV}$$

(iv)

$$\Delta t \sim \frac{\hbar}{2\Delta E} = \frac{\hbar c}{2cmc^2} = \frac{hc}{4\pi cmc^2} = \frac{1240\ \text{eV}\cdot 10^{-9} m}{4\pi \times (3\times 10^8 \text{m/s})100\,\text{MeV}} = \frac{1240\ \text{eV}\cdot 10^{-9}}{4\pi \times (3\times 10^8)(100\times 10^6)\text{eV}} s$$

$$¿\frac{1240\,10^{-9}}{4\pi \times (3\times 10^8)(100\times 10^6)} s \sim 10^{-24} s$$

A. I,II B. IV only C. I,II,IV D. I, IV E. None of A,B,C,D
ANS: E (I,II, III are true.)

5. Reconsider the similar scenario as in Question 3 above but with both *u*, *v relativistic*. Which of the following statements is true?

A. the speed of the ball as measured by O' would be smaller than that in Question 3.
B. the speed of the ball as measured by O' would be larger than that in Question 3.
C. the speed of the ball as measured by O' would be equal to that in Question 3.
D. the speed of the ball as measured by O' could be larger or smaller than that in Question 3.
E. None of A, B,C,D.
ANS: B

ANS: Let *u* be the velocity of the ball observed by O. O' is moving with a velocity *v* with respect to O. The Lorentz transformation for *u*,*v* and *u*', the velocity of the ball as measured by O', is simply

$u' = \frac{u-v}{1-\frac{uv}{c^2}}$. Since *u*,*v* has the same direction, $1-\frac{uv}{c^2}<1, \therefore |u'| = \left|\frac{u-v}{1-\frac{uv}{c^2}}\right| > |u-v|$

6. Given a species of fly has an average lifespan of τ. Let say you put many of them in a box and send them to a destination at some remote destination in deep space using a rocket that travel at speed *v*. The destination is located at a distance of *L* from Earth. Considering only special relativistic effect and assuming that none of the flies die of any cause other than aging, which of the following statements is (are) correct? (Lorentz factor is defined as $\gamma = [1-(v/c)^2]^{-1/2}$).

I. To the Earth observer, the time taken by the rocket to arrive at its destination is L/v.
II. To the flies, the time taken by the rocket to arrive at its destination is $(1/\gamma)(L/v)$.
III. Most of the flies would survive if $(1/\gamma)(L/v) < \tau$
IV. Most of the flies would survive if $(L/v) < \tau$

A. I,II B. I,II,III C. I,II,IV D. I, II,III,IV
E. None of A,B,C,D

ANS: D (ALL are true.)

7. Consider an object moving in a straight line with constant speed. Say in frame O, the momentum of the object is measured to be *P*. In a frame O′ moving with a non-zero relative constant velocity with respect to O, the momentum of the same object is measured to be P'. Which of the following statements are (is) true regarding *P* and P'?

I. In non-relativistic regime, *P* and P' have a same numerical value.
II. In relativistic regime, *P* and P' have a same numerical value.
III. *P* and P' have a same numerical value in the relativistic regime but not in the non-relativistic one.
IV. *P* and P' have a same numerical value in the non-relativistic regime but not in the relativisitic one.

A. I,II B. II,III C. I, IV D. III,IV
E. None of A, B, C,D

ANS: E (*P*,*P*' in general are different in different frames of reference, since momentum is not an invariant.)

8. Consider an object moving in a straight line with constant speed. Say in frame O, the kinetic energy of the object is measured to be *K*. In a frame O′ moving with a non-zero relative constant velocity with respect to O,

the kinetic energy of the same object is measured to be K'. Which of the following statements are (is) true regarding *K* and K'?

I. In non-relativistic regime, *K* and K' have a same numerical value.
II. In relativistic regime, *K* and K' have a same numerical value.
III. *K* and K' have a same numerical value in the relativistic regime but not in the non-relativistic one.
IV. *K* and K' have a same numerical value in the non-relativistic regime but not in the relativisitic one.

A. I,II B. II,III C. I, IV D. III,IV
E. None of A, B, C,D

ANS: E (*K*,*K*' in general are different in different frames of reference, since kinetic energy is not an invariant.)

9. A subatomic particle of rest mass of *M*, initially at rest, decays into two daughter subatomic particles with rest masses m_1 and m_2 respectively. Which statements in the following is (are) true?

I. $M = m_1 + m_2$
II. $(M - m_1 - m_2)c^2$ equals the sum of kinetic energy of the daughter subatomic particles.
III. The kinetic energy of the daughter subatomic particle with rest mass m_1 equals the kinetic energy of the daughter subatomic particle with rest mass m_2.
IV. The momentum of the daughter subatomic particle with rest mass m_1 equals the momentum of the daughter subatomic particle with rest mass m_2.

A. I,IV B. II,III, IV C. III, IV D. II,IV
E. None of A,B,C,D

ANS: D

10. A clock moving with a finite speed *v* is observed to run slow. If the speed of light were to be halved, you would observe the clock to be

A. Even slower.
B. Still slow but not as much
C. As slow as it was
D. To start to actually run fast.
E. None of A, B, C,D

ANS: A. The gamma-factor would be modified. The time dilation effect will be greater if *c* becomes *c*/2.

$$\gamma(c) \rightarrow \gamma(c/2) \equiv \gamma'(c)$$

$$\Rightarrow (\gamma')^2 = \frac{1}{1-\left(\frac{v}{c/2}\right)^2} = \frac{1}{1-4\left(\frac{v}{c}\right)^2} > \gamma^2 = \frac{1}{1-\left(\frac{v}{c}\right)^2}$$

Alternatively, in an ordinary world with speed of light *c*, the asymptote of the Lorentz factor γ is at *v*=*c*, whereas in a world with speed of light *c*'=*c*/2, the asymptote for γ' occurs at *v* = *c*/2. This intuitive argument leads to the conclusion that γ' is generally larger than γ at the same *v*.

Section B (Structured questions)

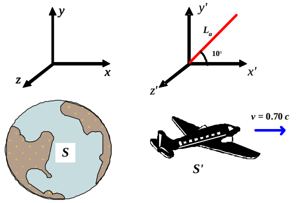
1. A spacecraft antenna is at an angle of 10° relative to the axis of the spacecraft. If the spacecraft moves away from the earth at a speed of 0.70*c*, what is the angle of the antenna as seen from the earth? (biser, p.50) [Ans. 14°]

2. At what velocity does the KE of a particle equal its rest energy? [Ans. 2.6×10^{8} m s^{-1}] (Chand, p.25)

SESSI 07/08/TEST1

Solutions:

1. Let say the length of the antenna as measured by an observer on the spacecraft (system S') is L_a.



According to system S':

The projection of the antenna onto the spacecraft,

$$L_{a,x'} = L_a \cos(10°).$$

The projection of the antenna onto an axis perpendicular to the spacecraft's axis,

$$L_{a,y'} = L_a \sin(10°).$$

To an observer on the earth (system S):

The length in the direction of the spacecraft's axis will be contracted:

$$L_{a,x} = \frac{1}{\gamma} L'_{a,x'} = L'_{a,x'}\sqrt{1-\frac{v^2}{c^2}}$$

$$\therefore \quad L_{a,x} = L_a \cos(10°)\sqrt{1-\left(\frac{0.70c}{c}\right)^2}. \qquad (1)$$

The length perpendicular to the spacecraft's motion will appear unchanged:

$$L_{a,y} = L_{a,y'} = L_a \sin(10°). \qquad (2)$$

The angle as seen from the earth will then be [Eq. (2) / Eq. (1)]:

$$\tan\theta = \frac{L_{a,y}}{L_{a,x}}$$

$$= \frac{L_a \sin(10°)}{L_a \cos(10°)\sqrt{1-\left(\frac{0.70c}{c}\right)^2}}$$

$$= \frac{\tan(10°)}{\sqrt{1-\left(\frac{0.70c}{c}\right)^2}}$$

$$\therefore \quad \theta = \arctan\left[\frac{\tan(10°)}{\sqrt{1-\left(\frac{0.70c}{c}\right)^2}}\right]$$

$$= 14°$$

2. If the kinetic energy KE = $E_0 = m_0c^2$, then the total energy will become

$$E = E_0 + KE = m_0c^2 + m_0c^2 = 2m_0c^2 \qquad (1)$$

Since,

$$E = mc^2 = \gamma m_0c^2 = \frac{1}{\sqrt{1-v^2/c^2}} m_0c^2 \qquad (2)$$

Therefore, Eq. (1) = Eq. (2)

$$\frac{1}{\sqrt{1-v^2/c^2}} m_0c^2 = 2m_0c^2$$

$$\therefore \quad \frac{1}{\sqrt{1-v^2/c^2}} = 2$$

Solving for v,

$$v = \frac{\sqrt{3}}{2}c = 2.60\times10^8 \text{ m s}^{-1}$$

FIZIK IV (MODERN PHYSICS)
ZCT 104
TEST
24 March 2008

Instruction: Two questions are prepared. Please answer both of them in this question sheet. Use extra blank paper if you need more space. Explain your steps as clearly as possible.

1. In Compton scattering experiment, X-ray photons with wavelength λ are incident on a target. After collision with electrons which initially at rest, the scattered photons are observed at angle θ while the recoiled electrons are observed at angle ϕ.

(a) Show that the angle between the directions of the recoil electron and the incident photon is given by

$$\tan\phi = \frac{\sin\theta}{(1+\cos\theta)\left[\frac{h}{m_ec\lambda}+1\right]}.$$

Here
- h = Planck constant
- λ = wavelength of incident photons
- m_e = rest mass of electron
- c = speed of light

(b) If the wavelength of the X-rays is 1.5406Å and the scattered photons are observed at 120°, find
- (i) the wavelength of the scattered photons,
- (ii) the angle of the recoil electron, and
- (iii) the kinetic energy of the recoil electron (in keV).

[25 marks]

2. (a) Derive a non-relativistic formula that gives the de Broglie wavelength of a particle, of charge q and mass m, in terms of the potential difference V through which it has been accelerated.

(b) Derive the relativistic version for the de Broglie wavelength in (a).

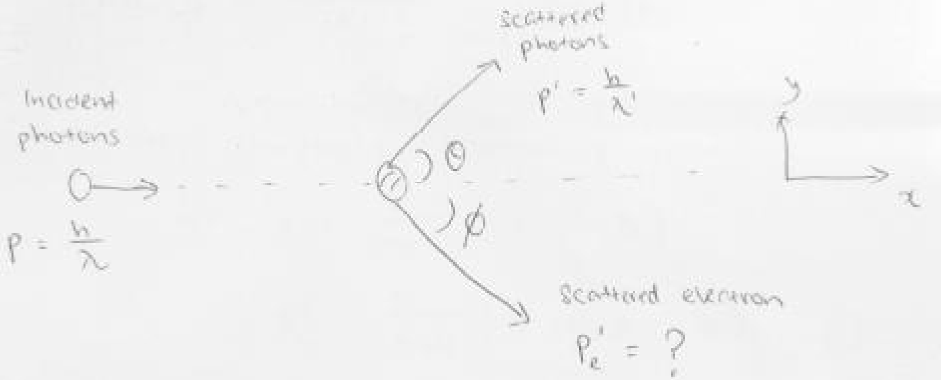
(c) Show that your formula in (b) reduces to that of (a) in the limit of $qV << mc^2$.

[25 marks]

Solution:

make-up test 0708

a) Let consider the conservation of momentum in 2-D



⇒ Based on the principle of conservation of momentum

initial momentum = final momentum.

⇒ In x-direction:

$$p + 0 = p'\cos\theta + p_e'\cos\phi$$

$$p_e'\cos\phi = p - p'\cos\theta \quad (1)$$

⇒ In y-direction

$$0 + 0 = p'\sin\theta - p_e'\sin\phi$$

$$\therefore \quad p_e'\sin\phi = p'\sin\theta \quad (2)$$

$$\Rightarrow \frac{(2)}{(1)} \quad \tan\phi = \frac{p'\sin\theta}{p - p'\cos\theta}$$

$$= \frac{\sin\theta}{p/p' - \cos\theta} \quad (3)$$

Since $p = \frac{h}{\lambda}$ & $p' = \frac{h}{\lambda'}$, we have

$$\tan\phi = \frac{\sin\theta}{\lambda'/\lambda - \cos\theta} \quad (4)$$

⇒ From the compton's scattering formula:

$$\lambda' - \lambda = \frac{h}{m_e c}(1-\cos\theta)$$

$$\lambda' = \frac{h}{m_e c}(1-\cos\theta) + \lambda \quad (5)$$

⇒ ~~Replace (5)~~ By substituting (5) into (4)

$$\therefore \tan\phi = \frac{\sin\theta}{\frac{\left[\frac{h}{m_e c}(1-\cos\theta)+\lambda\right]}{\lambda} - \cos\theta}$$

$$= \frac{\sin\theta}{\left(\frac{h}{m_e c\lambda}(1-\cos\theta)+1\right) - \cos\theta}$$

$$= \frac{\sin\theta}{(1-\cos\theta)\left[\frac{h}{m_e c\lambda}+1\right]} \quad (6)$$

(shown)

b) here $\lambda = 1.5406\times10^{-10}$ m, $\theta = 120°$

i) $\lambda' - \lambda = \frac{h}{m_e c}(1-\cos\theta)$

$$\lambda = \frac{h}{m_e c}(1-\cos\theta) + \lambda$$

$$= 2.43\times10^{-12}(1-\cos120) + 1.5406\times10^{-10}\text{ m}$$

$$= 1.5771\times10^{-10}\text{ m}$$

$$= 1.5771\ \text{Å}$$

ii) From Equation (6)

$$\tan\phi = \frac{\sin 120}{(1-\cos120)\left[\frac{2.43\times10^{-12}}{1.5406\times10^{-10}}+1\right]}$$

$$= \frac{0.866}{(1.5)(1.0158)}$$

$$= 0.5684$$

$$\phi = 29.61°$$

iii) The kinetic energy of the recoil electron:

$$KE(\text{recoil electron}) = \frac{hc}{\lambda} - \frac{hc}{\lambda'}$$

$$= \frac{1240\text{ eV·nm}}{0.15406\text{ nm}} - \frac{1240\text{ eV·nm}}{0.15771\text{ nm}}$$

$$= 8.049\text{ keV} - 7.817\text{ keV}$$

∴ KE (recoil electron)

= 0.186 keV

Solution:

Q2. Beiser, Ex. 12, pg 117.

(a) Non-relativistic scenario:

If the electron is non-relativistic, $K = p^2/2m$;

According to de Broglie's postulate, $p = h/\lambda$;

$K = qV$;

Hence,

$K = qV = p^2/2m = (h/\lambda)^2/2m$

$\Rightarrow qV = h^2/2m\lambda^2$

$\Rightarrow \lambda = h/\sqrt{(2mqV)}$.

(b) $K = qV$;

K is related to momentum p via $E^2 = (K + mc^2)^2 = p^2c^2 + m^2c^4 \Rightarrow K^2 + 2Kmc^2 = p^2c^2$

$$\Rightarrow K = \frac{-2mc^2 \pm \sqrt{4m^2c^4 + 4p^2c^2}}{2} = -mc^2 \pm c^2\sqrt{m^2 + p^2/c^2}$$

$$\Rightarrow K = c^2\left(\sqrt{m^2 + p^2/c^2} - m\right) = qV$$

$$p^2 = \left(\frac{qV}{c^2} + m\right)^2 c^2 - m^2c^2 = \frac{q^2V^2}{c^2} + 2mqV = \frac{h^2}{\lambda^2}$$

$$\Rightarrow \lambda = \frac{hc}{\sqrt{q^2V^2 + 2mc^2qV}}$$

(c) λ In non-relativistic limit:

$$\lambda = \frac{hc}{\sqrt{2qVmc^2}\sqrt{\frac{qV}{2mc^2} + 1}} = \frac{hc}{\sqrt{2qVmc^2}}\left(1 + \frac{qV}{2mc^2}\right)^{-1/2} = \frac{hc}{\sqrt{2qVmc^2}}\left(1 - \frac{qV}{4mc^2} + \ldots\right)$$

$$\Rightarrow \lim_{qV \ll mc^2} \lambda = \frac{hc}{\sqrt{2qVmc^2}} = \frac{h}{\sqrt{2qVm}}$$

Data

Speed of light in free space, $c = 3.00 \times 10^8$ m s^{-1}
Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
Permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
Elementary charge, $e = 1.60 \times 10^{-19}$ C
Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg
Molar gas constant, = 8.31 J K^{-1} mol^{-1}
Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}
Gravitational constant, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
Acceleration of free fall, $g = 9.81$ m s^{-2}

Section A: Objectives. [20 marks]
[Bahagian A: Soalan-soalan objektif]

Instruction: Answer all 20 objective questions in this Section.
[Arahan: Jawab kesemua 20 soalan objektif dalam Bahagian ini.]

1. How fast must a spacecraft travel relative to the earth for each day on the spacecraft to correspond to 2 day on the earth?
[Apakah kelajuan suatu kapal angkasa relatif kepada bumi supuya setiap hari dalam kapal angkasa setara dengan dua hari di bumi?]

A. $\sqrt{3}/2c$ B. $\sqrt{2}/3c$. C. $2/\sqrt{3}c$. D. $1/\sqrt{3}c$ E. c

2. Which of the following statement is true?
[Yang manakah kenyataan-kenyataan berikut adalah benar?]

A. It is possible for the electron beam in a television picture tube to move across the screen at a speed faster than the speed of light. This does not contradict special relativity.
[Adalah mungkin bagi bim elektron dalam tiub televisyen untuk bergerak merentasi skrin dengan laju yang lebih cepat daripada laju cahaya. Ini tidak bercanggah dengan kerelatifan khas.]

B. It is possible for the electron beam in a television picture tube to move across the screen at a speed faster than the speed of light despite this contradicts special relativity.
[Adalah mungkin bagi bim elektron dalam tiub televisyen untuk bergerak merentasi skrin dengan laju yang lebih cepat daripada laju cahaya walaupun ini bercanggah dengan kerelatifan khas.]

C. It is NOT possible for the electron beam in a television picture tube to move across the screen at a speed faster than the speed of light because this contradicts special relativity.
[Adalah TIDAK mungkin bagi bim elektron dalam tiub televisyen untuk bergerak merentasi skrin dengan laju yang lebih cepat daripada laju cahaya kerana ini bercanggah dengan kerelatifan khas.]

D. It is NOT possible for the electron beam in a television picture tube to move across the screen at a speed faster than the speed of light despite this does not contradict special relativity.
[Adalah TIDAK mungkin bagi bim elektron dalam tiub televisyen untuk bergerak merentasi skrin dengan laju yang lebih cepat daripada laju cahaya walaupun ini tidak bercanggah dengan kerelatifan khas.]

E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A,B,C,D]

3. A massless neutrino is measured to have a relativistic energy of 1 MeV. What is the order of magnitude of its momentum, in SI unit?
[Tenaga kerelatifan suatu neutrino yang berjisim sifar diukurkan dan bernilai 1 MeV. Apakah tertib magnitud momentumnya dalam unit SI?]

A. -19 B. -20 C. -21 D. -22 E. -23

4. Which of the following statements is (are) true?
[Yang manakah kenyataan-kenyataan berikut adalah benar?]

I. Heisenberg uncertainty principle is closely related to the particle attribute of things.
[Prinsip ketidakpastian Heisenberg adalah berkait rapat dengan tabii zarah jasad.]

II. Heisenberg uncertainty principle is closely related to the wave-particle duality of things.
[Prinsip ketidakpastian Heisenberg adalah berkait rapat dengan dualiti gelombang-zarah jasad.]

III. The ultimate accuracy of a simultaneous measurement on the position and linear momentum of a microscopic particle moving in one-dimension is constrained by the Heisenberg uncertainty principle.
[Kejituan muktamat ukuran serentak ke atas kedudukan dan momentum linear bagi zarah mikroskopik yang bergerak dalam satu dimensi adalah dikekang oleh prinsip ketidakpastian Heisenberg .]

IV. The ultimate accuracy of a simultaneous measurement on the *x*-coordinate and *y*-coordinate of a microscopic particle moving in two-dimension is constrained by the Heisenberg uncertainty principle.
[Kejituan muktamat ukuran serentak ke atas koordinat-x dan koordinat-y bagi zarah mikroscopik yang bergerak dalam dua dimensi adalah dikekang oleh prinsip ketidakpastian Heisenberg .]

A. I, III, IV
B. II, III
C. II, IV
D. I, II, IV
E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A,B,C,D]

5. Which of the following statements is (are) true regarding the spectrum of hydrogen atom, according to the Bohr model?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai spektrum atom hidrogen menurut model Bohr?]

I. The spectral line of the shortest wavelength in the Lyman series in the emission spectrum of a hydrogen atom is more energetic than the spectral line of the shortest wavelength in the Balmer series.
[Garis spektrum yang berjarak gelombang paling pendek dalam siri Lyman dalam spektrum pancaran suatu atom hidrogen adalah lebih bertenaga daripada garis spektrum yang berjarak gelombang paling pendek dalam siri Balmer.]

II. The spectral line of the longest wavelength in the Lyman series in the emission spectrum of a hydrogen atom is more energetic than the spectral line of the shortest wavelength in the Balmer series.
[Garis spektrum yang berjarak gelombang paling panjang dalam siri Lyman dalam spektrum pancaran suatu atom hidrogen adalah lebih bertenaga daripada garis spektrum yang berjarak gelombang paling pendek dalam siri Balmer.]

III. The spectral line of the shortest wavelength in the Lyman series in the emission spectrum of a hydrogen atom is more energetic than the spectral line of the longest wavelength in the Balmer series.
[Garis spektram yang berjarak gelombang paling pendek dalam siri Lyman dalam spektrum pancaran suatu atom hidrogen adalah lebih bertenaga daripada garis spektram yang berjarak gelombang paling panjang dalam siri Balmer.]

IV. The spectral line of the longest wavelength in the Lyman series in the emission spectrum of a hydrogen atom is more energetic than the spectral line of the longest wavelength in the Balmer series.
[Garis spektrum yang berjarak gelombang paling panjang dalam siri Lyman dalam spektrum pancaran suatu atom hidrogen adalah lebih bertenaga daripada garis spektrum yang berjarak gelombang paling panjang dalam siri Balmer.]

A. I, II, III, IV
B. I, II, III
C. II, IV
D. III, IV
E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A,B,C,D]

6. Which of the following statements is (are) true regarding the kinetic energy of an object?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tenaga kinetik suatu objek?]

I. The upper limit of the kinetic energy of an object is infinity.
[Limit atas tenaga kinetik suatu objek adalah infinit.]

II. The lower limit of the kinetic energy of an object is negative infinity.
[Limit bawah tenaga kinetik suatu objek adalah infiniti negatif.]

…6/-

III. The kinetic energy of an object is equal to the increase in its relativistic mass times c^2.
[Tenaga kinetik suatu objek adalah bersamaan dengan pertambahan dalam jisim kerelatifannya darab c^2.]

IV. The decrease in the kinetic energy of an object is equal to the decrease in its relativistic mass times c^2.
[Pengurangan dalam tenaga kinetik suatu objek adalah bersamaan dengan pengurangan dalam jisim kerelatifannya darab c^2.]

A. I, II, III
B. II, IV
C. I, II, III, IV
D. I, III, IV
E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C,D]

7. Which of the following statements is (are) true regarding a blackbody?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai suatu jasad hitam?]

I. A perfect blackbody does not radiate electromagnetic radiation.
[Jasad hitam sempurna tidak memancarkan pancaran elektromagnet.]

II. A perfect blackbody radiates the whole spectrum of electromagnetic radiation.
[Jasad hitam sempurna tidak memancarkan pancaran elektromagnet.]

III. An approximate blackbody does not radiate electromagnetic radiation.
[Jasad hitam hampiran tidak memancarkan pancaran elektromagnet.]

IV. An approximate blackbody radiates electromagnetic radiation.
[Jasad hitam hampiran memancarkan pancaran elektromagnet.]

A. I, III
B. II,IV
C. I, IV
D. II,III
E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C,D]

…7/-

8. The unit of Compton shift is that of:
[Unit bagi anjakan Compton adalah sama dengan unit bagi:]

A. energy *[tenaga]*
B. time *[masa]*
C. momentum *[momentum]*
D. length *[panjang]*
E. frequency *[frekuensi]*

9. In the Planck theory of blackbody radiation,
[Dalam teori Planck untuk pancaran jasad hitam,]

I. The smallest amount of energy carried by a single mode of oscillation in the electromagnetic radiation is proportional to the frequency of that mode.
[Jumlah tenaga yang paling kecil yang terbawa oleh suatu mod ayunan tertentu dalam pancaran elektromagnetik adalah berkadar terus dengan frekuensi mod tersebut.]

II. The smallest amount of energy carried by a single mode of oscillation of non-zero frequency in the electromagnetic radiation is non-zero.
[Jumlah tenaga yang paling kecil yang terbawa oleh suatu mod ayunan bukan sifar tertentu dalam pancaran elektromagnetik adalah bukan sifar.]

III. The smallest amount of energy carried by a single mode of oscillation in the electromagnetic radiation is proportional to the amplitude squared of the electromagnetic field of that mode.
[Jumlah tenaga yang paling kecil yang terbawa oleh suatu mod ayunan tertentu dalam pancaran elektromagnetik adalah berkadar terus dengan kuasadua amplitud medan elektromagnetik mod tersebut.]

IV. The smallest amount of energy carried by a single mode of oscillation in the electromagnetic radiation is zero.
[Jumlah tenaga yang paling kecil yang terbawa oleh suatu mod ayunan tertentu dalam pancaran elektromagnetik adalah sifar.]

A. II, III
B. I, II
C. I,II, III
D. I, III,IV
E. None of A, B, C, D [*Jawapan tiada dalam A, B, C, D*]

…8/-

10. The light intensity incident on a metallic surface produces photoelectrons which could be stopped by a stopping potential of V_s. If the wavelength is halved, a stopping potential of V' is required to stop the photoelectrons. Which statement in the following correctly relates V_s to V' ?
[Keamatan cahaya yang menuju suatu permukaan logam menghasilkan fotoelektron yang dapat diberhentikan dengan keupayaan penghenti V_s. Jika jarak gelombang disetengahkan, keupayaan penghenti V' diperlukan untuk memberhentikan fotoelektron yang terhasil. Kenyataan berikut yang manakah dengan betulnya menghubungkaitkan V_s dengan V' ?]

A. $V' > 2V_s$
B. $V' < 2V_s$
C. $V' = 2V_s$
D. $V' < V_s$
E. V' could be larger or smaller than V_s
[V' mungkin lebih besar atau kecil daripada V_s]

11. Which of the following statements is (are) true about photon?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai foton?]

I. It is mandatory for photon in vacuum to travel at the speed of light *c*.
[Adalah mandatori bagi foton dalam vakum untuk bergerak dengan laju cahaya c.]

II. Photon does not gravitate since it has no mass.
[Foton tidak mengraviti kerana ia tidak berjisim.]

III. Photon gravitates since it has energy.
[Foton mengraviti kerana ia mempunyai tenaga.]

IV. Photon interacts with atoms.
[Foton berinteraksi dengan atom-atom.]

A. II, IV
B. I, II
C. I, III, IV
D. III, IV
E. None of A, B, C, D
[Jawapan tiada dalam A,B,C,D]

…9/-

12. Which of the following statements is (are) true about the nature of X-ray?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tabii sinar X?]

I. X-ray is made up of neutral particles of non-zero mass.
[Sinar-X adalah terdiri daripada zarah-zarah bercas yang berjisim bukan sifar.]

II. X-ray is made up of charged particles.
[Sinar-X adalah terdiri daripada zarah-zarah bercas.]

III. X-ray can be produced by bombarding metal targets with electron at the energy of ~ eV.
[Sinar-X boleh dihasilkan dengan menghentum sasaran logam dengan elektron bertenaga ~eV.]

IV. A proton-antiproton pair will annihilates into a pair of X-ray photons.
[Pasangan proton-antiproton akan saling membinasa kepada pasangan foton sinar-X.]

A. II, III
B. I, IV
C. I, III
D. II, IV
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

13. Which of the following statements is (are) true regarding the energies of a hydrogen atom according to the Bohr model?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tenaga atom hidrogen menurut model Bohr?]

I. The total mechanical energy of a hydrogen atom is negative.
[Jumlah tenaga mekanik suatu atom hidrogen adalah negatif.]

II. The kinetic energy of an electron in a hydrogen atom is negative.
[Tenaga kinetik bagi suatu elektron dalam atom hidrogen adalah negatif.]

III. The potential energy of a hydrogen atom is negative.
[Tenaga keupayaan bagi suatu atom hidrogen adalah negatif.]

IV. The total mechanical energy of an ionized hydrogen atom is 0.
[Jumlah tenaga mekanik bagi suatu atom hidrogen terionkan adalah sifar.]

A. I, II,IV
B. II,IV
C. I, III,IV
D. I, III
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

14. Which of the following statements is (are) true regarding photoelectric effect?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai kesan fotoelektrik?]

I. In a photoelectric effect experiment, the intensity of photoelectron detected will keep increasing when the incident wavelength keep decreasing, while other parameters are fixed.
[Dalam eksperimen kesan fotoelektrik, keamatan fotoelektron yang diukur akan terus meningkat bila jarak gelombang tuju terus berkurang, dengan parameter-parameter lain ditetapkan.]

II. Photoelectric effect can be explained in terms of classical electromagnetic theories.
[Kesan fotoelektrik boleh diterangkan dengan teori elektromagnetik klasik.]

III. The cutoff frequency in a photoelectric effect experiment is a measure of the maximal kinetic of the photoelectron.
[Frekuensi penggal dalam eksperimen fotoelektrik merupakan suatu ukuran bagi tenaga kinetik maksimum fotoelektron.]

IV. The stopping potential in a photoelectric effect experiment is a measure of the work function of the target material.
[Keupayaan penghenti dalam eksperimen fotoelektrik merupakan suatu ukuran bagi fungsi kerja bahan sasaran.]

A. I only
B. I, II, III, IV
C. I, II
D. III, IV
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

15. Which of the following statements is (are) true?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. Gamma rays will undergo spontaneous electron-positron pair production in vacuum.
[Sinar gamma boleh menjalani penghasilan pasangan elektron-positron secara spontan dalam vakum.]

II. The probability of a photon to undergo a Compton scattering with the free electron in a metallic target generally drops when the photon energy increases beyond ~ MeV.
[Kebarangkalian suatu foton menjalani serakan Compton dengan elektron bebas dalam suatu sasaran logam secara amnya akan berkurangan jika energy foton bertambah melebihi MeV.]

III. The larger the atomic number of the target material, the larger the probability of an incident X-ray photon to undergo Compton scattering in that target.
[Lebih besar nombor atom bahan sasaran, lebih besar kebarangkalian suatu foton sinar X tuju menjalani serakan Compton dalam sasaran tersebut.]

IV. The larger the atomic number of the target material, the larger the probability of an incident gamma-ray photon of energy $>2m_ec^2$ to undergo electron-positron pair-production in that sample.
[Lebih besar nombor atom bahan sasaran, lebih besar kebarangkalian suatu foton sinar gamma tuju bertenaga $>2m_ec^2$ menjalani penghasilan pasangan elektron-positron dalam sasaran tersebut.]

A. II, III
B. I, IV
C. I, III
D. II, IV
E. None of A, B, C, D [*Jawapan tiada dalam A,B,C,D*]

16. A relativistic electron has a de Broglie wavelength of λ. Find its total relativistic energy.
[Jarak gelombang de Broglie suatu elektron kerelatifan ialah λ. Hitungkan jumlah tenaga kerelatifannya.]

A. $c\sqrt{\frac{\lambda^2}{h^2}+m_e^2c^2}$
B. $c\sqrt{\frac{h^2}{\lambda^2}+m_e^2c^2}$
C. $\sqrt{\frac{h^2}{\lambda^2}+m_e^2c^2}$.
D $\frac{hc}{\lambda}+m_ec^2$
E. None of the above
[Jawapan tiada dalam A, B, C, D]

17. Consider the photoelectric effect experiment. According to classical electromagnetic theory,
[Pertimbangkan eksperimen kesan fotoelektrik. Menurut teori elektromagnet klasikal,]

I. the photoelectron is expected to be ejected from the atom immediately.
[fotoelektron dijangka akan ditendang keluar dari atom dengan serta-merta.]

II. some time interval is required for the atom to absorb enough energy from the electromagnetic radiation before the photoelectron can be ejected from the atom.
[suatu selang masa adalah diperlukan untuk atom menyerap cukup tenaga daripada pancaran electromagnet sebelum fotoelektron dapat ditendang keluar dari atom.]

III. the atom will never absorb any electromagnetic energy from the incident light.
[atom tidak akan menyerap apa-apa tenaga elektromagnetik daripada pancaran cahaya tuju.]

IV. the atom will absorb the electromagnetic energy from the incident light at a rate proportional to the intensity of the incident light.
[atom akan menyerap tenaga elektromagnetik daripada cahaya tuju pada kadar yang berkadaran dengan keamatan cahaya tuju.]

A. II, IV
B. I, IV
C. III only
D. I, II,IV
E. None of A, B, C, D
[Jawapan tiada dalam A,B,C,D]

18. Which of the following statements is (are) true?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. $\lambda_e = h/m_ec$ characterises the length scale of the Compton effect between the incident photon and free electron in a sample target.
[$\lambda_e = h/m_ec$ mencirikan skala panjang kesan Compton di antara foton tuju dan elektron bebas dalam suatu sampel sasaran.]

II. The velocity of electron in the ground state of hydrogen atom ~ αc, where α is the fine structure constant, $\alpha = \dfrac{e^2}{4\pi\varepsilon_0\hbar c}$.
[Halaju elektron dalam keadaan dasar atom hidrogen adalah ~ αc, di mana α pemalar struktur halus, $\alpha = \dfrac{e^2}{4\pi\varepsilon_0\hbar c}$.]

III. Planck's constant gives a measure of the scale at which quantum effects are observed.
[Pemalar Planck merupakan ukuran bagi skala di mana kesan kuantum dicerap.]

IV. The energy scale characterizing pair creation of proton-antiproton is ~ MeV.
[Skala tenaga yang mencirikan penghasilan pasangan proton-antiproton ialah ~ MeV]

A. I, III
B. I, II, III
C. II, III
D. I, II, III, V
E. None of A, B, C, D [*Jawapan tiada dalam A, B, C, D*]

…14/-

19. Which of the following statements is (are) true regarding Bohr's hydrogen model?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai model hidrogen Bohr?]

I. The kinetic energy of the electron in the higher orbits is much larger than m_ec^2.
[Tenaga kinetik elektron dalam orbit tinggi adalah jauh lebih besar daripada m_ec^2.]

II. The kinetic energy of the electron in the lower orbits is much less than m_ec^2.
[Tenaga kinetik elektron dalam orbit rendah adalah jauh lebih kecil daripada m_ec^2.]

III. The emission line spectrum of hydrogen atom is well explained by the Bohr model.
[Spektrum garisan pancaran atom hidrogen dapat dijelaskan oleh model Bohr.]

IV. The absorption line spectrum of hydrogen atom is well explained by the Bohr model.
[Spektrum garisan serapan atom hidrogen dapat dijelaskan oleh model Bohr.]

A. I, II
B. I, III, IV
C. II, III, IV
D. III, IV
E. None of A, B, C, D [*Jawapan tiada dalam A, B, C, D*]

20. Which of the following statements is (are) true regarding the duality of an electron?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai dualiti suatu elektron?]

I. Electron behaves like wave in a Young double-slit experiment.
[Elektron berlagak seperti gelombang dalam suatu eksperimen dwi-celah Young.]

II. Electron behaves like particle in the TV cathode-ray tube.
[Elektron berlagak seperti zarah dalam tiub sinar katod TV.]

…15/-

III. Electron behaves like wave in the Compton scattering effect experiment.
[Elektron berlagak seperti gelombang dalam eksperimen kesan Compton.]

IV. Electron behaves like particle in the photoelectric effect experiment.
[Elektron berlagak seperti zarah dalam eksperimen kesan fotoelektrik.]

A. I, II
B. I, III, IV
C. I, II, IV
D. III, IV
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

Section B: Structural questions.
[*Bahagian B: Soalan-soalan strutur.***]**

Instruction: Answer ALL questions. Each question carries 10 marks.
[Arahan: Jawab semua soalan. Setiap soalan membawa 10 markah.]

1. An observer in rocket *A* finds that rockets *C* and *B* are approaching him from opposite direction at speeds of 0.9*c* and 0.8*c*, respectively. Determine the speed of rocket *C* as measured by *B* using Galilean approach and special relativity approach. Please state clearly all the symbols used in your working.
[Seorang pemerhati di dalam roket A mendapati bahawa roket-roket C dan B sedang menuju kepadanya dari arah yang bertentangan dengan laju masing-masing 0.9c dan 0.8c. Tentukan laju roket C seperti yang diukur oleh B dengan menggunakan pendekatan Galileo dan pendekatan teori kerelatifan khas. Sila nyatakan dengan jelas simbol-simbol yang digunakan dalam kerja anda.]
[10 marks (*markah)*]

2. A certain metal has a threshold wavelength of 600 nm. Find the stopping potentials when the metal is irradiated with:
[Suatu logam tertentu mempunyai jarak gelombang ambang 600 nm. Cari keupayaan penghenti apabila logam itu disinari dengan]

(a) monochromatic light of wavelength 400 nm,
[cahaya monokromatik yang berjarak gelombang 400 nm]
[4 marks *(markah)*]

(b) light having twice the frequency of that in (a), and
[cahaya yang berfrekuensi dua kali ganda daripada cahaya dalam (a), dan]
[4 marks *(markah)*]

(c) light having three times the intensity of that in (a).
[cahaya yang berkeamatan tiga kali ganda daripada cahaya dalam (a).]
[2 marks *(markah)*]

3. X-ray photons of wavelength 0.0248 nm are incident on a target and the Compton scattered photons are observed at 90°.
[Foton-foton X-ray yang berjarak gelombang 0.0248 nm ditujukan ke atas satu sasaran dan foton-foton yang mengalami serakan Compton dapat diperhatikan pada sudut 90°.]

(a) What is the wavelength of the scattered photons?
[Apakah jarak gelombang bagi foton-foton yang terserak?]
[2 marks *(markah)*]

(b) What is the momentum of the incident and the scattered photons?
[Apakah momentum bagi foton tuju dan foton yang terserak?]
[4 marks *(markah)*]

(c) What is the momentum (magnitude and direction) of the scattered electrons?
[Apakah momentum (magnitud dan arah) bagi elektron-elektron yang terserak?]
[4 marks *(markah)*]

4. Suppose that the momentum of a certain particle can be measured to an accuracy of 0.1%. Determine the minimum uncertainty in the position of the particle if the particle is
[Andaikan bahawa momentum suatu zarah tertentu dapat diukur dengan kejituan 0.1%. Tentukan ketakpastian minimum bagi kedudukan zarah jika zarah itu ialah]

(a) a 46 gm golf ball moving with speed of 2 m s^{-1}, and
[sebiji bola golf yang berjisim 46 gm bergerak dengan laju 2 m s^{-1}, dan]
[5 marks *(markah)*]

(b) an electron moving with a speed of 2.4×10^{8} m s^{-1}.
[suatu elektron yang bergerak dengan laju 2.4×10^{8} m s^{-1}]
[5 marks *(markah)*]

5. (a) If the Rydberg constant is 1.097×10^7 m^{-1}, determine the longest and the shortest wavelengths of the Paschen series for hydrogen?
[Jika pemalar Rydberg ialah 1.097×10^7 m^{-1}, tentukan jarak gelombang yang paling panjang dan paling pendek dalam siri Paschen hidrogen?]
[5 marks *(markah)*]

(b) Find the value of initial energy state, n_i in the series that gives rise to the line in the hydrogen spectrum at 4861 Å (angstrom)? Given that the final energy state, n_f in this series transitions is $n_f = 2$.
[Cari nilai keadaan tenaga awal, n_i yang peralihannya mengakibatkan garis pada 4861 Å (angstrom) di dalam spectrum hidrogen? Diberi bahawa keadaan tenaga akhir, n_f bagi peralihan ini ialah $n_f = 2$.]
[5 marks *(markah)*]

6. (a) K^0, an unstable, neutral meson, is produced in high energy accelerators. It will decay into a pair of oppositely charged pions via $K^0 \rightarrow \pi^- \pi^+$. The rest masses of the charged pions, π^-, π^+ are 139.6 MeV/c^2. In an experiment, the momentum of the charged pions is measured to be 206.0 MeV/c, calculate the mass of K^0. Assume K^0 is at rest before the decay. Express you answer in terms of MeV/c^2.
[5 marks *(markah)*]

(b) Explain with sufficient clarity why is it not possible for a microscopic particle of rest mass M to decay into a photon with the same energy, Mc^2.
[Terangkan dengan jelasnya mengapa adalah tidak mungkin bagi suatu zarah mikroskopik berjisim rehat M mereput menjadi suatu foton yang tanaganya Mc^2.]
[5 marks *(markah)*]

7. A photon of energy E is scattered by a particle of rest energy E_0. Find the maximum kinetic energy of the recoiling particle in terms of E and E_0.
[Suatu foton bertenaga E diserakkan oleh suatu zarah yang bertenaga rehat E_0. Dapatkan tenaga kinetik maksimum zarah yang tersentak itu dalam sebutan E_0 dan E.]
[10 makrs *(markah)*]

8. By what percentage will a nonrelativistic calculation of the de Broglie wavelength of an electron with kinetic energy100 keV be in error?
[Apakah peratusan ralat suatu pengiraan tak-kerelatifan jarak gelombang de Broglie bagi elektron bertenaga kinetik 100 keV?]
[10 marks *(markah)*]

- ooo O ooo -

Solution

Section A (objective)

1. A (Beiser, pg 49, Ex. 7)
2. A (Beiser, pg 49, Ex. 2)
3. C
   Energy can be measured in terms of MeV. Momentum can be measured in terms of MeV/c. A particle with energy of 1 MeV has a momentum of 1 MeV/c. The SI equivalent of 1 MeV/c is simply
   $$\frac{10^6 \cdot 1.6 \times 10^{-19}\,\text{J}}{3 \times 10^8\,\text{m/s}} \sim 10^{-21}\,\text{Ns}.$$
   Hence, 1 MeV/c has an order of magnitude of -21 in SI unit.

4. B
5. A.
   32 = longest wavelength in Balmer series;
   3∞ = shortest wavelength in Balmer series;
   21 = longest wavelength in Lyman series;
   ∞1 = shortest wavelength in Lyman series;
   $E_{32} < E_{3\infty} < E_{21} < E_{\infty 1}$;
   All of the spectral lines in the Lyman series is more energetic than the lines in the Balmer series.

6. D. I, III, IV are true, according to $\Delta K = (\Delta m)c^2$.

7. B

8. D (trivial)

9. B (I,II are true)

10. A.
    $K_{max} = hc/\lambda - W_0 = eV_s$. If $\lambda \rightarrow \lambda/2$, $\Rightarrow 2hc/\lambda - W_0 = eV'$. Expressing V' in terms of V_s, we have $eV' = 2hc/\lambda - W_0 = 2(eV_s + W_0) = 2eV_s + 2W_0$.

11. C

12. E. None is true. IV is false since a pair of gamma-ray with energy ~ GeV is produced, not X-ray.

13. C

14. E, none is true.

15. D

16. B

17. A

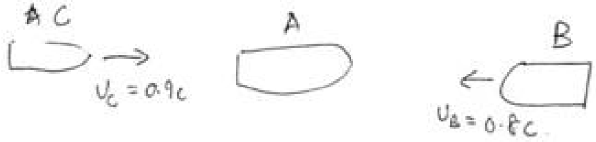
18. B

19. C

20. C

Sessi 07/08 Final Exam

(1)



→ Assume that the direction to the right-hand side is positif

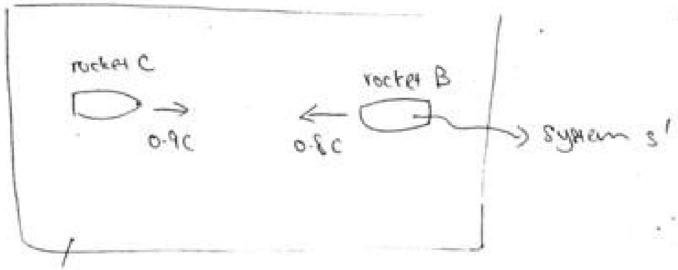
→ With respect to the rocket A,

→ the speed of rocket B, $V_B = -0.8C$

→ the speed of rocket C, $V_C = 0.9C$.

→ the speed of rocket C as measured by B:

→ Now, we may assume that the rocket B is a moving system (system S').



→ Here, $V = -0.8C$, $V_x (V_C) = 0.9C$ and we need to determine V_x' (speed of rocket C as measured by B)

① By Galileo approach.

$$V_x' = V_x - V$$

$$= 0.9c - (-0.8c) = 1.7c$$

By Special relativity approach:

$$V_x' = \frac{V_x - V}{1 - \left(\frac{V}{c^2}\right)V_x}$$

$$= \frac{0.9c - (-0.8c)}{1 - \left(\frac{-0.8c}{c^2}\right)(0.9c)}$$

$$= \frac{1.7c}{1 + 0.72}$$

$$= \frac{1.7c}{1.72}$$

$$= 0.9884c$$

Sessi 07/08 Final Exam

② Given that the threshold wavelength (or cut-off wavelength) of the metal is

$$\lambda_{cutoff} = 600 \text{ nm}.$$

→ The work function of this metal is given by

$$W_0 = \frac{hc}{\lambda_{cutoff}} \quad ①$$

or

$$W_0 = hf_{cutoff} \quad ②$$

where h = Planck constant

f_{cutoff} = Cut-off or threshold frequency = $\frac{c}{\lambda_{cutoff}}$

→ From ①, Hence.

$$W_0 = \frac{1240 \text{ eV.nm}}{600 \text{ nm}} = 2.067 \text{ eV}$$

→ The photoelectric (PE) formula is given by

$$eV_s = hf - W_0 \quad ③$$

or

$$eV_s = \frac{hc}{\lambda} - W_0 \quad ④$$

where e = charge of an electron

V_s = stopping potential

or $K_{max} = eV_s$

∴ $K_{max} = hf - W_0$.

2 (a) Given that $\lambda = 400 nm$.

→ ~~From~~ By using Eq. (3).

$$\therefore \quad eV_s = \frac{1240 \text{ eV. nm}}{400} - 2.067 \text{ eV}$$

$$= 3.100 \text{ eV} - 2.067 \text{ eV}$$

$$= 1.033 \text{ eV}$$

$$\therefore \quad V_s = 1.033 \text{ V}$$

2 b) Assume that the light frequency ~~of~~ in 2(a) is $f_1 = f = \frac{c}{\lambda}$

Now, the light frequency is, $f_2 = 2f = \frac{2c}{\lambda}$

→ By replacing $f_2 = \frac{2c}{\lambda}$ into Eq. (3), hence.

$$eV_s = \frac{2hc}{\lambda} - W_0$$

$$= 2\left(\frac{1240 \text{ eV. nm}}{400}\right) - 2.067 \text{ eV}$$

$$= 2(3.100 \text{ eV}) - 2.067 \text{ eV}$$

$$= 6.200 \text{ eV} - 2.067 \text{ eV}$$

$$= 4.133 \text{ eV}$$

$$\therefore \quad V_s = 4.133 \text{ V}$$

Sessi 07/08 Final Exam

2 (c) → the stopping potential V_s is independent of the ~~light~~ intensity of light.

→ Hence, the V_s remain the same as in 2(a)

$$\therefore \quad V_s = 1.033 \text{ V}$$

3.

→ The compton shift relationship is given by

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_o c}(1-\cos\theta) \quad (1)$$

or

$$\lambda' - \lambda = \lambda_e(1-\cos\theta)$$

where
- λ = wavelength of the incident photon
- λ' = wavelength of the scattered photon.
- m_o = rest mass of electron.
- θ = angle of the scattered photon.
- λ_e = Compton wavelength = 2.43×10^{-3} nm.

3 (a) Here, $\lambda = 0.0248$ nm, $\theta = 90°$, $\lambda' = ?$

→ From Eq. (1),

$$\lambda' - \lambda = \frac{h}{m_o c}(1-\cos\theta).$$

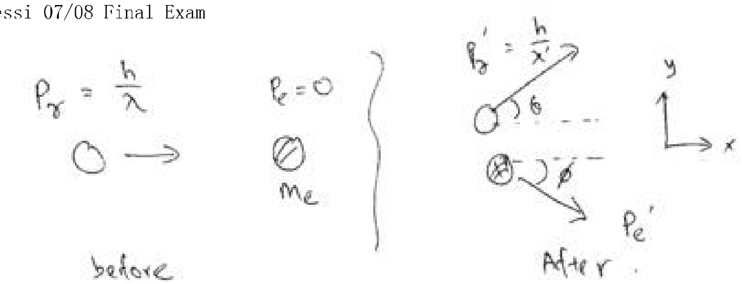
$$\lambda' = 2.43\times10^{-3}\left[1-\cos(90)\right] + \lambda$$

$$= 2.43\times10^{-3}\ \text{nm} + 0.0248\ \text{nm}$$

$$= 0.02723\ \text{nm}$$

$$= 2.723\times10^{-2}\ \text{nm}$$ #

3 b)



– Momentum of the incident photon

$$P_\gamma = \frac{h}{\lambda} = \frac{6.63\times10^{-34}\ \text{Js}}{0.0248\ \text{nm}}$$

$$= \frac{6.63\times10^{-34}\ \text{Js}}{2.48\times10^{-11}\ \text{m}}$$

$$= 2.673\times10^{-23}\ \text{kg m s}^{-1}$$ #

– momentum of the scattered photons.

$$P_\gamma' = \frac{h}{\lambda'}$$

$$= \frac{6.63\times10^{-34}\ \text{Js}}{2.723\times10^{-2}\ \text{nm}}$$

$$= \frac{6.63\times10^{-34}\ \text{Js}}{2.723\times10^{-11}\ \text{m}}$$

$$= 2.435\times10^{-23}\ \text{kg m s}^{-1}$$ #

(or)

$$|P_\gamma'| = \sqrt{(P_\gamma'\sin\theta)^2 + (P_\gamma'\cos\ldots}$$

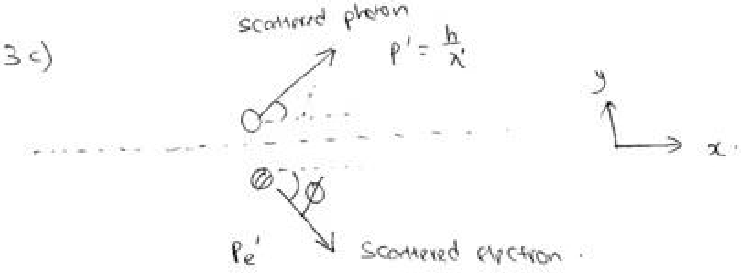
$$= \sqrt{P_\gamma'^2}$$

$$= P_\gamma'$$

$$= \frac{h}{\lambda'}$$

$$= 2.435\times10^{-23}\ \text{kg m s}^{-1}$$

3 c)



After collision

- Use the conservation of linear momentum in x- and y- directions.

Total momentum before = Total momentum after.

$$\therefore \quad P + P_e = P' + P_e' \quad (1)$$

→ In x- direction

$$P + 0 = P'\cos\theta + P_e'\cos\phi$$

$$\therefore \quad P_e'\cos\phi = P - P'\cos\theta \quad (2)$$

→ In y- direction

$$0 = P'\sin\theta - P_e'\sin\phi$$

$$\therefore \quad P_e'\sin\phi = P'\sin\theta \quad (3)$$

3 c) $\frac{(3)}{(2)}$

$$\frac{P_e'\sin\phi}{P_e'\cos\phi} = \frac{P'\sin\theta}{P - P'\cos\theta}$$

$$\therefore \quad \tan\phi = \frac{\sin\theta}{P/P' - \cos\theta} \quad (4)$$

- magnitude of the momentum of the scattered electron can be calculated using Eq. (1).

$$P = P' + P_e'$$

$$\therefore \quad P_e' = P - P'$$

$$= 2.673 \times 10^{-23}\ \text{kg m s}^{-1} - 2.435 \times 10^{-23}\ \text{kgms}^{-1}$$

$$= 0.238 \times 10^{-23}\ \text{kg m s}^{-1}$$

$$= 2.38 \times 10^{-24}\ \text{kg m s}^{-1}$$

→ the direction of the momentum of the scattered electron can be determined by using Eq. (4)

$$\therefore \quad \tan\phi = \frac{\sin\theta}{P/P' - \cos\theta}$$

$$= \frac{\sin(90^\circ)}{\left(\frac{2.673\times10^{-23}}{2.435\times10^{-23}}\right) - \cos(90^\circ)} = \frac{1}{1.0977} = 0.911$$

$$\phi = 42.33^\circ.$$

(4) a)

→ Heisenberg's uncertainty principle is given by

$$\Delta x \, \Delta p \geq \frac{\hbar}{2} \qquad \text{where } \hbar = \frac{h}{2\pi}$$

$$\therefore \Delta x \geq \frac{\hbar}{2} \cdot \frac{1}{\Delta p}$$

→ The minimum uncertainty in the position is then

$$\Delta x = \frac{\hbar}{2} \cdot \frac{1}{\Delta p} \qquad (1)$$

→ Given that $m = 46 \text{ gm} = 46 \times 10^{-3}$ kg.

$v = 2 \text{ ms}^{-1}$.

→ then, the momentum of the golf ball is

$$p_g = mv = (46 \times 10^{-3} \text{ kg}) \times (2 \text{ ms}^{-1})$$

$$= 9.2 \times 10^{-2} \text{ kg ms}^{-1} \; \#$$

→ Given that the accuracy of the momentum = 0.1%

$$\therefore \Delta p_g = 0.1\% \times p_g = \frac{0.1}{100} \times 9.2 \times 10^{-2} \text{ kgms}^{-1}$$

$$= 9.2 \times 10^{-5} \text{ kg m s}^{-1}$$

→ From Eq. (1), then

$$\Delta x = \frac{\hbar}{2} \cdot \frac{1}{\Delta p}$$

$$= \frac{6.63 \times 10^{-34}}{4\pi (9.2 \times 10^{-5})} = 5.735 \times 10^{-31} \text{ m} \; \#$$

Sessi 07/08 Final Exam

(4) a)

→ Heisenberg's uncertainty principle is given by

$$\Delta x \, \Delta p \geq \frac{\hbar}{2} \qquad \text{where } \hbar = \frac{h}{2\pi}$$

$$\therefore \Delta x \geq \frac{\hbar}{2} \cdot \frac{1}{\Delta p}$$

→ The minimum uncertainty in the position is then

$$\Delta x = \frac{\hbar}{2} \cdot \frac{1}{\Delta p} \qquad (1)$$

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$$= 9.2 \times 10^{-2} \text{ kg ms}^{-1} \; \#$$

→ Given that the accuracy of the momentum = 0.1%

$$\therefore \Delta p_g = 0.1\% \times p_g = \frac{0.1}{100} \times 9.2 \times 10^{-2} \text{ kgms}^{-1}$$

$$= 9.2 \times 10^{-5} \text{ kg m s}^{-1}$$

→ From Eq. (1), then

$$\Delta x = \frac{\hbar}{2} \cdot \frac{1}{\Delta p}$$

$$= \frac{6.63 \times 10^{-34}}{4\pi (9.2 \times 10^{-5})} = 5.735 \times 10^{-31} \text{ m} \; \#$$

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4 b) Here, $m_o = 9.1 \times 10^{-31}$ kg, $v = 2.4 \times 10^8$ ms^{-1}.

- In the case, we must treat the problem relativistically, namely,

$$P_e = \gamma m_o v$$

where $\gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}} = \frac{1}{\sqrt{1-\left(\frac{2.4\times10^8}{3.0\times10^8}\right)^2}} =$ 1.67

$\therefore P_e =$ 1.67 $(9.1\times10^{-31})(2.4\times10^8) =$ 3.64 $\times 10^{-22}$ $kgms^{-1}$

→ Given that the uncertainty of momentum = 0.1%

$\therefore \Delta P_e = 0.1\% \times P_e$

$= \frac{0.1}{100} \times$ 3.64 $\times10^{-22}$ = 3.64 $\times10^{-25}$ $kgms^{-1}$

→ From Eq (1), then

$$\Delta x = \frac{\hbar}{2} \cdot \frac{1}{\Delta P_e}$$

$= \frac{6.63\times10^{-34}}{4\pi\,(3.64\times10^{-25})}$

= 1.45 $\times 10^{-10}$ m.

(5) a)

→ The Paschen series for hydrogen is given by

$$\frac{1}{\lambda} = R_H\left[\frac{1}{3^2} - \frac{1}{n_i^2}\right] \quad (1)$$

where R_H = Rydberg constant $= 1.097\times10^7\ m^{-1}$

$n_i = 4, 5, 6, \ldots$

→ the shortest wavelength of the Paschen series for hydrogen corresponds to

$$n_i = \infty$$

$\therefore \frac{1}{\lambda} = R_H\left[\frac{1}{3^2} - \frac{1}{\infty^2}\right]$

$= 1.097\times10^7\left(\frac{1}{9} - 0\right)$

$= 1.2189\times10^6\ m^{-1}$

$\therefore \lambda = 8.204\times10^{-7}$ m ✗

5 b)

→ The longest wavelength of the Paschen series for hydrogen is corresponds to

$n_i = n_f + 1$

$= 3 + 1$

$= 4$

$\therefore \frac{1}{\lambda} = R_H \left[\frac{1}{3^2} - \frac{1}{4^2} \right]$

$= 1.097 \times 10^7 \left[\frac{1}{9} - \frac{1}{16} \right]$

$= 5.333 \times 10^5 \text{ m}^{-1}$

$\therefore \lambda = 1.875 \times 10^{-6} \text{ m}$ #

5 b)

→ The general formula of the spectral line series for hydrogen is given by

$$\frac{1}{\lambda} = R_H \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right]$$

→ Given that $\lambda = 4861 \text{ Å} = 4861 \times 10^{-10} \text{ m}$

and $n_f = 2$.

→ from 5(a), $R_H = 1.097 \times 10^7 \text{ m}^{-1}$.

$\therefore \frac{1}{4861 \times 10^{-10}} = 1.097 \times 10^7 \left[\frac{1}{2^2} - \frac{1}{n_i^2} \right]$

$\frac{1}{(4861 \times 10^{-10})(1.097 \times 10^7)} = \left(\frac{1}{4} - \frac{1}{n_i^2} \right)$

$0.1875 = 0.25 - \frac{1}{n_i^2}$

$\frac{1}{n_i^2} = 0.25 - 0.1875$

$\frac{1}{n_i^2} = 0.0625$

$n_i^2 = \frac{1}{0.0625}$

$n_i^2 = 16$

$n_i = 4$ #

Sessi 07/08 Final Exam

Section B (structured question)

6(a) ANS:
近代物理学，北京大学教材。Pg. 54.
Use conservation of energy and momentum:

$$E_K^2 = (E_{\pi^+} + E_{\pi^-})^2 = 4E_\pi^2 \qquad \because E_{\pi^+} = E_{\pi^-} = E_\pi, |p_{\pi^-}| = |p_{\pi^+}|.$$

$$m_K^2 c^4 = 4\left(c^2 p_\pi^2 + m_\pi^2 c^4\right) = 4\left(206^2\,\mathrm{MeV}^2 + 139^2\,\mathrm{MeV}^2\right) = 247028\,\mathrm{MeV}^2$$

$$\Rightarrow m_K = 497.0\,\mathrm{MeV}/c^2$$

(b)
In the rest frame of the particle ***M***, the total momentum before any decay is zero. If ***M*** decays into a single photon, which must necessarily has a non-zero momentum in all frames of reference due to the invariance of the speed of light, it is impossible to keep the conservation of momentum in the rest frame of ***M***. Hence, such a single photon decay mode is forbidden to preserve conservation of momentum.

7 **ANS: Beiser, Exercise 38, pg 91.**

Denote the corresponding Compton wavelength of the scattering (recoiling) particle as $\lambda_C^* = hc/E_0$. The recoil particle will have the maximum kinetic energy when the scattering angle is 180°, and so $\lambda' = \lambda + 2\lambda_C^*$, and the maximum kinetic energy will be

$$K_{\max} = E - \frac{hc}{\lambda'} = E - \frac{hc}{(hc/E) + 2\lambda_C^*} = E\left(1 - \frac{E_0}{E_0 + 2E}\right) = E\left(\frac{E_0}{2E} + 1\right)^{-1}$$

ANS: 8 Beiser, Exercise 5, pg 117.

3-5: Because the de Broglie wavelength depends only on the electron's momentum, the percentage error in the wavelength will be the same as the percentage error in the reciprocal of the momentum, with the nonrelativistic calculation giving the higher wavelength due to a lower calculated momentum. The nonrelativistic momentum is

$$p_{nr} = \sqrt{2m\,\mathrm{KE}} = \sqrt{2\,(9.1095 \times 10^{-31}\,\mathrm{kg})\,(100 \times 10^{3}\,\mathrm{eV})\,(1.602 \times 10^{-19}\,\mathrm{J/eV})}$$
$$= 1.708 \times 10^{-22}\,\mathrm{kg \cdot m/s},$$

and the relativistic momentum is

$$p_r = \frac{1}{c}\sqrt{(\mathrm{KE} + mc^2)^2 - (mc^2)^2} = \sqrt{(0.100 + 0.511)^2 - (0.511)^2}\,\mathrm{MeV}/c$$
$$= 1.790 \times 10^{-22}\,\mathrm{kg \cdot m/s},$$

keeping extra figures in the intermediate calculations. The percentage error in the computed de Broglie wavelength is then

$$\frac{(h/p_{nr}) - (h/p_r)}{(h/p_r)} = \frac{p_r - p_{nr}}{p_{nr}} = \frac{1.790 - 1.708}{1.708} = 4.8\%.$$

UNIVERSITI SAINS MALAYSIA

Kursus Semasa Cuti Panjang
Sessi 2007/2008

Jun 2008

ZCT 104/3 - Physics IV (Modern Physics)
[Fizik IV (Fizik Moden)]

Duration: 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains **SIX** printed pages before you begin the examination.
*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **ENAM** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]*

Instruction: Answer only **FIVE** questions out of six questions given.

Students are allowed to answer all questions in Bahasa Malaysia or in English.

*[**Arahan**: Jawab **LIMA** soalan daripada enam soalan yang disediakan.*

Pelajar dibenarkan untuk menjawab samada dalam bahasa Malaysia atau bahasa Inggeris.]

Data

Speed of light in free space, $c = 3.00 \times 10^{8}$ m s^{-1}
Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
Permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
Elementary charge, $e = 1.60 \times 10^{-19}$ C
Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg
Molar gas constant, = 8.31 J K^{-1} mol^{-1}
Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}
Gravitational constant, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
Acceleration of free fall, $g = 9.81$ m s^{-2}

Instruction: Answer only 5 out of six questions prepared. Each question carries 20 marks.
[Arahan: Jawab hanya 5 soalan daripada 6 soalan yang disediakan. Setiap soalan membawa 20 markah.]

1. (a) As measured by *O*, a lamp emits a light flash in $x = 100$ km, $y = 10$ km, $z = 1$ km at $t = 5\times10^{-4}$ *s.* What is the coordinat *x*', *y*', *z*', and *t*' of this event as measured by a second observer, *O*', who is moving relative to *O* with a velocity of -0.8*c* along their common axis *z – z*'?
[Seperti yang disukat oleh O, sebuah lampu mengeluarkan suatu cahaya kilat di x = 100 km, y = 10 km, z = 1 km pada t = 5×10^{-4} s. Apakah koordinat x', y', z', dan t' bagi peristiwa ini seperti ditentukan oleh seorang permerhati kedua, O' yang bergerak relative kepada O dengan halaju -0.8c sepanjang paksi sepunya z – z'?]
[8 marks]

   (b) If the proper length of each edge of a cube is l_0, find its volume when it is moving with a velocity *v* along one of its edges.
[Jika panjang wajar bagi setiap sisi suatu kubus ialah l_0, cari isipadunya apabila ia bergerak dengan suatu halaju v sepanjang salah satu sisinya.]
[6 marks]

(c) An electron is accelerated from rest to a velocity *v* through a potential difference of 40 kV. Find
[Suatu elektron dipecutkan daripada keadaan rehat ke suatu halaju v melalui suatu beza keupayaan 40 keV. Cari]

(i) its total energy in MeV, *[jumlah tenaganya dalam MeV,]*

(ii) its mass, and *[jisimnya, dan]*

(iii) its momentum. *[momentumnya.]*

[6 marks]

2. (a) The stopping potential of a certain metal is 3.91 V when it is irradiated with monochromatic light of wavelength 150 nm. What is the stopping potential if the metal is irradiated with monochromatic light of wavelength 300 nm.
[Keupayaan penghenti bagi suatu logam tertentu ialah 3.91 V apabila ia disinari dengan cahaya monokromatik yang berjarak gelombang 150 nm. Apakah keupayaan penghenti jika logam itu disinari dengan cahaya monokromatik yang berjarak gelombang 300 nm.]

[5 marks]

(b) Why X-rays are more penetrative than visible light?
[Mengapa Sinar-X adalah lebih menusuk berbanding cahaya nampak?]

[2 marks]

(c) X-ray photons are produced from an X-ray machine whose accelerating potential is 50 keV. The X-ray photons with shortest wavelength then incident on a target and undergo Compton scattering.
[Foton sinar-X dihasilkan daripada suatu mesin sinar-X yang mana keupayaan pecutannya ialah 50 keV. Foton sinar-X yang berjarak gelombang terpendek kemudian ditujukan ke atas suatu sasaran dan melalui serakan Compton.]

(i) Find the angle between the directions of the scattered photons and the incident photons at which the scattered photons have energy of 90% of the incident photons.
[Cari sudut di antara arah foton terserak dengan arah foton tuju yang mana foton terserak itu mempunyai 90% tenaga daripada foton tuju.]

[8 marks]

(ii) The scattered photons then incident on a crystal with unknown interatomic spacing *d*. If the second-order Bragg peak is observed at an angle of 12.82°. What is the interatomic spacing *d* for this crystal?
[Foton yang terserak kemudian ditujukan ke atas suatu hablur yang jarak antara atom d tidak diketahui. Jika puncak Bragg tertib kedua diperhatikan pada suatu sudut 12.82°. Apakah jarak antara atom d bagi hablur ini?]

[5 marks]

…4/-

3. (a) Show that the de Broglie wavelength for a particle of rest mass m_0 and charge q, accelerated from rest through a potential difference of V volts relativistically is given by
[Tunujukkan bahawa jarak gelombang de Broglie bagi suatu zarah yang berjisim rehat m_0 dan bercas q, dipecutkan daripada keadaan rehat melalui suatu beza keupayaan V volt secara kerelatifan diberi sebagai]

$$\lambda = \frac{h}{\sqrt{2m_0qV\left(1+\frac{qV}{2m_0c^2}\right)}}$$

where *h* and *c* are the Planck's constant and speed of light, respectively.
[di mana h dan c masing-masing ialah pemalar Planck dan halaju cahaya.]

[10 marks]

(b) A beam of electrons is incident on a slit of variable width. If it is possible to resolve a 1% difference in momentum, what slit width would be necessary to resolve the interference pattern of the electrons if their kinetic energy is 100 MeV?
[Suatu alur elektron ditujukan ke atas suatu celah yang lebarnya boleh berubah. Jika perbezaan dalam momentum yang mungkin dapat dileraikan ialah 1%, apakah lebar celah yang bakal perlu untuk meleraikan corak interferens bagi elektron jika tenaga kinetiknya ialah 100 MeV?]

[10 marks]

4. (a) The wavelength of the second line of the Balmer series in the hydrogen spectrum is 4861 Å (angstrom). Calculate the wavelength of the first line.
[Jarak gelombang garis kedua bagi siri Balmer di dalam spektrum hidrogen ialah 4861 Å (angstrom). Hitungkan jarak gelombang bagi garis pertama.]

[5 marks]

(b) An electron of energy 12.5 eV collides with a hydrogen atom in its ground state. Find the maximum amount of energy the incident electron can lose inelastically in this collision? Find the remaining energy of the electron?
[Suatu elektron yang bertenaga 12.5 eV berlanggar dengan suatu atom hidrogen yang berada di keadaan dasar. Cari jumlah tenaga maximum yang elektron tuju itu dapat hilang dalam perlanggaran tak kenyal ini? Cari baki tenaga bagi elektron itu?]

[5 marks]

…5/-

(c) Consider a X-ray of wavelength 0.050 nm scatters from a gold atom target.
[Pertimbangkan sinar-x yang berjarak gelombang 0.050 nm, terserak oleh suatu sasaran atom emas.]

(i) Can the X-ray be Compton-scattered from an electron bound by as much as 62,000 eV? Explain your answer.
[*Bolehkah sinar-x menjalani serakan Compton oleh suatu elektron yang terikat dengan tenaga sebesar 62,000 eV?*]

(ii) What is the largest wavelength of scattered photon that can be observed?
[*Apakah jarak gelombang foton terserak yang paling panjang yang mungkin dicerap?*]

(iii) What is the kinetic energy of the most energetic recoil electron and what angle does it occur?
[*Apakah tenaga kinetik elektron tersentak yang paling bertenaga, dan pada sudut apakah keadaan ini berlaku?*]

[10 marks]

5. (a) In an experiment conducted in the teaching lab in the School of Physics, USM, an electron originated from upper atmosphere is observed to move at the speed of $v = 0.998c$.
[*Dalam suatu eksperimen yang dijalankan dalam makmal mengajar di Pusat Pengajian Sains Fizik, USM, suatu elektron yang bergerak dengan laju 0.998c yang berasal daripada atmosfera atas telah dicerap.*]

(i) What is the magnitude of its momentum in unit of MeV/c?
[*Apakah magnitud momentumnya dalam unit MeV/c?*]

(ii) What is the total relativistic energy of the electron in unit of MeV?
[*Apakah tenaga jumlah kerelatifan elektron tersebut dalam unit MeV?*]

(iii) What is the kinetic energy of the electron in unit of MeV?
[*Apakah tenaga kinetik elektron tersebut dalam unit MeV?*]

(b) What is the kinetic energy of the electron at the $n = 4$ state in the Bohr's model of hydrogen atom in unit of eV? Explain clearly the steps of your working leading to your answer.
[*Apakah tenaga kinetik elektron yang berada pada keadaan n=4 dalam atom hidrogen model Bohr dalam unit eV? Terangkan dengan jelas langkah-langkah yang membawa kepada jawapan anda.*]

[20 marks]

…6/-

6. (a) Describe an experiment in which the value of the Planck constant can be measured.
[*Perihalkan suatu eksperimen di mana nilai pemalar Planck boleh diukur.*]

(b) Consider an electron and a proton, both moving at the speeds of $c\beta_e$ and $c\beta_P$ respectively.
[*Pertimbankan suatu elektron dan suatu proton, masing-masing bergerak pada laju* $c\beta_e$ *dan* $c\beta_P$.]

(i) What is the ratio of their de Broglie wavelengths, λ_e/λ_P? [Hint: You have to consider the most general scenario, i.e. relativistic scenario.]
[*Apakah nisbah jarak gelombang de Broglie mereka,* λ_e/λ_P? (*Petunjuk: Anda harus mempertimbangkan sinario paling am, iaitu sinario kerelatifan.*)]

(ii) What is the limit of λ_e/λ_P in the case where both are moving with ultra-relativistic speeds?
[*Apakah limit* λ_e/λ_P *dalam kes di mana kedua-dua zarah bergerak dengan laju ultra-kerelatifan?*]

(iii) What is the limit of λ_e/λ_P in the case where both are moving with non-relativistic speeds?
[*Apakah limit* λ_e/λ_P *dalam kes di mana kedua-dua zarah bergerak dengan laju tak-kerelatifan?*]

Your answer should be expressed in term of m_e, m_P, β_e, β_P and c.
[*Jawapan anda harus dinyatakan dalam sebutan* m_e, m_P, β_e, β_P *dan* c.]

[20 marks]

- ooo O ooo -

Q5(b). (Alternatively).

Expect the candidate to derive the expression for the K.E of the electron in the ~~the~~ n-th orbit of the hydrogen atom:

$$L = mvr = n\hbar \quad (1) \qquad ; \qquad \frac{Ze^2}{4\pi\epsilon_0 r^2} = \frac{mv^2}{r} \quad (2)$$

Substitute $r = \frac{n\hbar}{mv}$ from eq ① into eq ② to obtain expression of v in terms of the fundamental constants:

$$\frac{Ze^2}{4\pi\epsilon_0}\frac{1}{r} = mv^2$$

$$\Rightarrow v^2 = \frac{Ze^2}{4\pi\epsilon_0}\frac{1}{m}\frac{mv}{n\hbar}$$

$$\Rightarrow v = \frac{Ze^2}{4\pi\epsilon_0 n\hbar}$$

$$K.E,\ K = \frac{1}{2}mv^2 = \frac{1}{2}\cdot m \cdot \frac{Z^2e^4}{16\pi^2\epsilon_0^2\hbar^2 n^2}$$

$$= \frac{Z^2me^4}{32\pi^2\epsilon_0^2\hbar^2}\frac{1}{n^2} \quad ; Z = 1 \text{ for hydrogen}$$

$$\therefore K(n=4) = \frac{me^4}{32\pi^2\epsilon_0^2\hbar^2}\frac{1}{16} \quad (\text{in Joule})$$

$$= \frac{me^3 \cdot 4\pi^2}{512\pi^2\epsilon_0^2 h^2} \quad (\text{in eV})$$

$$= \frac{me^3}{128\epsilon_0^2 h^2} \ (\text{in eV}) = 0.85\ \text{eV}$$

(10 marks)

Solution

ZCT104 KSCP 07/08

Q 4(c). Reference, Thornton & Rex, third edition, 2006, pg 117, e.g. 3.16. (total 10 marks)

(a)(i) $E_{x\text{-}ray} = \frac{hc}{\lambda} = 24.8\ \text{keV}$.

The x-ray does not have enough energy to dislodge the inner electron which is bounded by 62 keV.

(2 marks) Argument - 1, final answer - 1

(ii) $\lambda' = \lambda + \Delta\lambda$. The longest wavelength $\lambda' = \lambda + \Delta\lambda$ occurs when $\Delta\lambda$ is a maximum ~~at~~ when $\theta = 180°$, i.e. $\Delta\lambda = \frac{2h}{m_e c} = 2(0.00243)$ nm

(4 marks)

$\lambda'_{max} = 0.050\text{nm} + 2(0.00243)\text{nm} = 0.055\text{nm}$

The energy of the scattered photon is then a minimum and has the value

$$E'_{x\text{-}ray} = \frac{hc}{\lambda'} = \frac{1240\ \text{keV}\cdot\text{nm}}{0.050\text{nm} + 2(0.00243)\text{nm}}$$

$$= \frac{hc}{\lambda + \Delta\lambda_{max}} = 22.5\ \text{keV}.$$

Difference in photon's energy, $E_{x\text{-}ray} - E'_{x\text{-}ray}$ is equal to the K.E of the electron (ignoring binding energy), i.e.

$$K.E_{elec} = E_{x\text{-}ray} - E'_{x\text{-}ray}$$

$$= 24.8\ \text{keV} - 22.5\ \text{keV}$$

$$= 2.3\ \text{keV}.$$

(3 marks)

(1 mark) Due to conservation of linear momentum, ϕ, the recoiled electron angle, is $\phi = 0°$ (in the forward direction).

Q5(a).

$v = 0.998c$.

a(i) momentum, $p = \gamma m v$; $\gamma = \frac{1}{\sqrt{1-0.998^2}} = 15.82$ (1 mark)

$= \gamma m (0.998c)$

$= 0.998 \gamma mc^2/c$

$= 15.79\ mc^2/c$

$= 15.79 \times 0.51\ MeV/c$

$= 8.05\ MeV/c$ # (3 marks)

a(ii) $E = \gamma m_0 c^2 = 15.82 \times 0.51\ MeV$

$= 8.07\ MeV$ (3 marks)

a(iii) $K = E - m_0 c^2$

$= \gamma m_0 c^2 - m_0 c^2 = (\gamma - 1) m_0 c^2$

$= (15.82 - 1)\ 0.51\ MeV$

$= 7.56\ MeV$ # (3 marks)

②

Q5(b). ~~Ex~~ Candidate is expected to derive ~~the~~ the expression of K.E of electron at the nth orbit in hydrogen atom explicitly, before using them:

From mechanical stability, | ~~Eq~~

$$\frac{Ze^2}{4\pi\epsilon_0 r^2} = \frac{mv^2}{r}$$

$$\Rightarrow \frac{Ze^2}{8\pi\epsilon_0 r} = \frac{mv^2}{2} \equiv K$$

potential energy, $V = \frac{-Ze^2}{4\pi\epsilon_0 r}$

By c.f V, K, $\rightarrow$ $V = -2K$.

Total energy, $E_n = K + V$

$= K - 2K = -K$.

$\therefore K_n = -E_n$

Know that $E_n = \frac{-13.6\,eV}{n^2}$

$\Rightarrow K_n = \frac{+13.6\,eV}{n^2}$

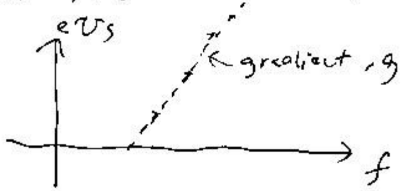
$n = 4$, $K_4 = \left(\frac{13.6}{16}\right) eV = 0.85\,eV$ #

(10 marks)

6(a). Photoelectricity effect experiment set-up is an typical example that can be used to measure h:

viz, $eV_s = hf - \phi$,

one measure V_s as a function of f, with fixed target material, then plot



The gradient of eV_s vs f gives the value of h. others experimental set-up also accepted if discussed clearly. (2 marks).

6(b)

(i)

$$\frac{\lambda_e}{\lambda_p} = \frac{p_p}{p_e} = \frac{\gamma_p m_p v_p}{\gamma_e m_e v_e} = \frac{\gamma_p m_p \beta_p}{\gamma_e m_e \beta_e}$$

$$\left(\frac{\lambda_e}{\lambda_p}\right)^2 = \left(\frac{\gamma_p m_p \beta_p}{\gamma_e m_e \beta_e}\right)^2 = \left(\frac{m_p}{m_e}\right)^2\left(\frac{\beta_p^2}{\beta_e^2}\right)\left(\frac{1-\beta_e^2}{1-\beta_p^2}\right) = \left(\frac{m_p}{m_e}\right)^2\left(\frac{1-\beta_e^2}{\beta_e^2}\right)\left(\frac{\beta_p^2}{1-\beta_p^2}\right)$$ (4 marks)

(ii) In the case where both are moving at ultra-relativistic speeds, i.e. $\beta_p^2,\ \beta_e^2 \to 1$. (3 marks)

$$\left(\frac{\lambda_e}{\lambda_p}\right)^2 = \left(\frac{m_p}{m_e}\right)^2\left(\frac{1-\beta_e^2}{\beta_e^2}\right)\left(\frac{\beta_p^2}{1-\beta_p^2}\right) \to \left(\frac{m_p}{m_e}\right)^2 \Rightarrow \frac{\lambda_e}{\lambda_p} \to \frac{m_p}{m_e}.$$

(iii) In the case where both are moving at non-relativistic speeds, i.e., $\beta_p^2 \ll 1$, $\beta_e^2 \ll 1$, but $\beta_p^2 \neq \beta_e^2$ in general,

$$\left(\frac{\lambda_e}{\lambda_p}\right)^2 = \left(\frac{m_p}{m_e}\right)^2\left(\frac{1-\beta_e^2}{\beta_e^2}\right)\left(\frac{\beta_p^2}{1-\beta_p^2}\right) \to \left(\frac{m_p}{m_e}\right)^2\left(\frac{\beta_p^2}{\beta_e^2}\right) \Rightarrow \frac{\lambda_e}{\lambda_p} \to \frac{m_p}{m_e}\frac{\beta_p}{\beta_e}.$$ (3 marks)

PAST YEAR TUTORIAL PROBLEM SET

(2003/04 – 2004/05)

Tutorial 1

Special Relativity

Conceptual Questions

1) What is the significance of the negative result of Michelson-Morley experiment?

ANS
The negative result of the MM experiment contradicts with the prediction of the absolute frame (the Ether frame) of reference, in which light is thought to propagate with a speed *c*. In the Ether postulate, the speed of light that is observed in other initial reference frame (such as the Earth that is moving at some constant speed relative to the Absolute frame), according to the Galilean transformation, would be different than that of the Ether frame. In other words, the MM negative result provides the first empirical evidence to the constancy of light postulate by Einstein.

2) Is it possible to have particles that travel at the speed of light?

ANS
Particle travelling at the speed of light would have an infinite mass, as per $m=\dfrac{m_0}{\sqrt{1-\left(\dfrac{v}{c}\right)^2}}$. Hence it is physically not possible to supply infinite amount of energy to boost a particle from rest to the speed of light.

postulate by Einstein.

3) A particle is moving at a speed less that *c*/2. If the speed of the particle is doubled, what happens to its momentum?

ANS

According to $\mathbf{p}=\gamma m\mathbf{u}$, doubling the speed *u* will make the momentum of an object increase by the factor $2\left[\dfrac{c^2-u^2}{c^2-4u^2}\right]^{1/2}$. Here's the working:

SESSI 04/05/ TUTORIAL 1

$$p=\gamma m_0 u \rightarrow p'=\gamma' m_0 u'$$

$$\left(\frac{p'}{p}\right)^2=\left(\frac{u'}{u}\right)^2\left(\frac{\gamma'}{\gamma}\right)^2=\left(\frac{u'}{u}\right)^2\left[\frac{1-\left(\dfrac{u}{c}\right)^2}{1-\left(\dfrac{u'}{c}\right)^2}\right]=\left(\frac{u'}{u}\right)^2\frac{c^2-u^2}{c^2-u'^2}\Rightarrow\frac{p'}{p}=\left(\frac{u'}{u}\right)\sqrt{\frac{c^2-u^2}{c^2-u'^2}}$$

$$\text{Let } u'=2u\Rightarrow\frac{p'}{p}=\left(\frac{2u}{u}\right)\sqrt{\frac{c^2-u^2}{c^2-(2u)^2}}=2\sqrt{\frac{c^2-u^2}{c^2-4u^2}}$$

4. The rest energy and total energy respectively, of three particles, expressed in terms of a basic amount *A* are (1) *A*, 2*A*; (2) *A*, 3*A*; (3) 3*A*, 4*A*. Without written calculation, rank the particles according to their (a) rest mass, (b) Lorentz factor, and (c) speed, greatest first.

ANS
Case 1: $\{m_0c^2, E\}=\{A,2A\}$; Case 2: $\{m_0c^2, E\}=\{A,3A\}$; Case 3: $\{m_0c^2, E\}=\{3A,4A\}$

(a) Rest mass = m_0. Hence for case 1: m_0 m_0c^2=A; Case 2:m_0c^2=A; Case 3: m_0c^2 =3A. Therefore, the answer is: mass in (3) > mass in (2) = mass in (1);

(b) Lorentz factor γ = E/m_0c^2. Hence for case 1: γ= 2A/A=2; case 2: γ= 3A/A=3; case 3: γ= 4A/3A=4/3 = 1.33. Therefore, the answer is: γ in (2) > γ in (1) > γ in (3)

(c) γ^{-2} = 1- $v^2/c^2 \Rightarrow v^2/c^2 = 1-\gamma^{-2}$. Hence for case 1: v^2/c^2 = 1 – 1/4 = 0.75; case 2: v^2/c^2 = 1 – 1/9 = 0.89; case 3: v^2/c^2 = 1 – 9/16 = 0.4375. Therefore, the answer is: v^2/c^2 in (2) > v^2/c^2 in (1) > v^2/c^2 in (3)

PROBLEMS

1. Space Travel (from Cutnell and Johnson, pg 861,863)
Alpha Centauri, a nearby star in our galaxy, is 4.3 light-years away. If a rocket leaves for Alpha Centauri and travels at a speed of v = 0.95c relative to the Earth, (i) by how much will the passengers have aged, according to their own clock, when they reach their destination? ii) What is the distance between Earth and Alpha Centauri as measured by the passengers in the rocket? Assume that the Earth and Alpha Centauri are stationary with respect to one another.

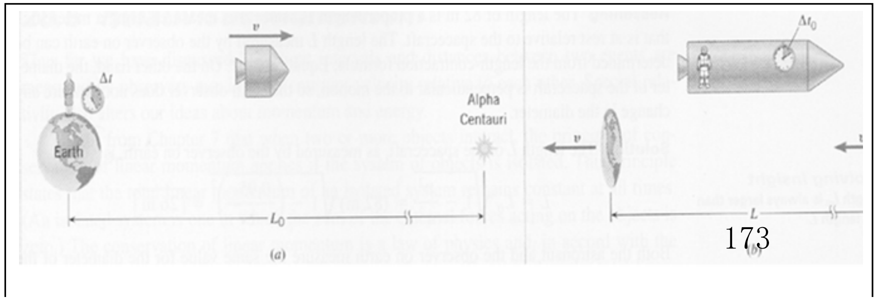


Figure: (a) As measured by an observer on the earth, the distance to Alpha Centauri is L_0, and the time required to make the trip is Δt. (b) According to the passenger on the spacecraft, the earth and Alpha Centauri move with speed v relative to the craft. The passenger measures the distance and time of the trip to be L and Δt_0 respectively, both quantities being less than those in part (a).

Reasoning

The two events in this problem are the departure from Earth and the arrival at Alpha Centauri. At departure, Earth is just outside the spaceship. Upon arrival at the destination, Alpha Centauri is just outside. Therefore, relative to the passengers, the two events occur at the same place - namely, 'just outside the spaceship. Thus, the passengers measure the proper time interval Δt_0 on their clock, and it is this interval that we must find. For a person left behind on Earth, the events occur at different places, so such a person measures the dilated time interval Δt rather than the proper time interval. To find Δt we note that the time to travel a given distance is inversely proportional to the speed. Since it takes 4.3 years to traverse the distance between earth and Alpha Centauri at the speed of light, it would take even longer at the slower speed of $v = 0.95c$. Thus, a person on earth measures the dilated time interval to be Δt = (4.3 years)/0.95 = 4.5 years. This value can be used with the time-dilation equation to find the proper time interval Δt_0.

Solution

Using the time-dilation equation, we find that the proper time interval by which the Passengers judge their own aging is
$\Delta t_0 = \Delta t\sqrt{(1-v^2/c^2)}$ = 4.5 years $\sqrt{(1-0.95^2)}$ = 1.4 years.

Thus, the people aboard the rocket will have aged by only 1.4 years when they reach Alpha Centauri, and not the 4.5 years an earthbound observer has calculated.

Both the earth-based observer and the rocket passenger agree that the relative speed between the rocket and earth is $v = 0.95c$. Thus, the Earth observer determines the distance to Alpha Centauri to be $L_0 = v\Delta t$ = (0.95c)(4.5 years) = 4.3 light-years. On the other hand, a passenger aboard the rocket finds

SESSI 04/05/ TUTORIAL 1

the distance is only $L = v\Delta t_0$ = (0.95c)(1.4 years) = 1.3 light-years. The passenger, measuring the shorter time, also measures the shorter distance - length contraction.

Problem solving insight

In dealing with time dilation, decide which interval is the proper time interval as follows: (1) Identify the two events that define the interval. (2) Determine the reference frame in which the events occur at the same place; an observer at rest in this frame measures the proper time interval Δt_0.

2) The Contraction of a Spacecraft (Cutnell, pg 863)

An astronaut, using a meter stick that is at rest relative to a cylindrical spacecraft, measures the length and diameter of the spacecraft to be 82 and 21 m respectively. The spacecraft moves with a constant speed of $v = 0.95c$ relative to the Earth. What are the dimensions of the spacecraft, as measured by an observer on Earth?

Reasoning

The length of 82 m is a proper length L_o since it is measured using a meter stick that is at rest relative to the spacecraft. The length L measured by the observer on Earth can be determined from the length-contraction formula. On the other hand, the diameter of the spacecraft is perpendicular to the motion, so the Earth observer does not measure any change in the diameter.

Solution

The length L of the spacecraft, as measured by the observer on Earth, is

$$L = L_0\sqrt{1-\frac{v^2}{c^2}} = 82m\sqrt{1-\frac{(0.95c)^2}{c^2}} = 26 \text{ m}$$

Both the astronaut and the observer on Earth measure the same value for the diameter of the spacecraft: Diameter = 21 m

Problem solving insight The proper length L_0 is always larger than the contracted length L.

3) *Additional problem 36, Cutnell pg. 879.*
Two spaceship A and B are exploring a new planet. Relative to this planet, spaceship A has a speed of $0.60c$, and spaceship B has a speed of $0.80c$. What is the ratio D_A/D_B of the values for

the planet's diameter that each spaceship measures in a direction that is parallel to its motion?

Solution

Length contraction occurs along the line of motion, hence both spaceship observe length contraction on the diameter of the planet. The contracted length measures by a moving observer is inversely proportional to the Lorentz factor γ. Hence,

$$\frac{L_A}{L_B} = \frac{\gamma_B}{\gamma_A} = \sqrt{\frac{1-\left(\frac{v_A}{c}\right)^2}{1-\left(\frac{v_B}{c}\right)^2}} = \sqrt{\frac{1-(0.6)^2}{1-(0.8)^2}} = 4/3.$$

4) The Energy Equivalent of a Golf Ball (Cutnell, pg 866)
A 0.046-kg golf ball is lying on the green. (a) Find the rest energy of the golf ball. (b) If this rest energy were used to operate a 75-W light bulb, for how many years could the bulb stay on?

Reasoning
The rest energy E_0 that is equivalent to the mass m of the golf ball is found from the relation $E_0 = mc^2$. The power used by the bulb is 75 W, which means that it consumes 75 J of energy per second. If the entire rest energy of the ball were available for use, the bulb could stay on for a time equal to the rest energy divided by the power.

Solution
(a) The rest energy of the ball is

$$E_0 = mc^2 = (0.046 \text{ kg})(3.0 \times 10^8 \text{ m/s})^2 = 4.1 \times 10^{15} \text{ J}$$

(b) This rest energy can keep the bulb burning for a time t given by
t = Rest energy/ Power = 4.1×10^{15} J/75 W = 5.5×10^{13} s = 1.7 million years!

5) A High-Speed electron (Cutnell pg. 867)
An electron (mass = 9.1×10^{-31} kg) is accelerated to a speed of $0.9995c$ in a particle accelerator. Determine the electron's (a) rest energy, (b) total energy, and (c) kinetic energy in MeV

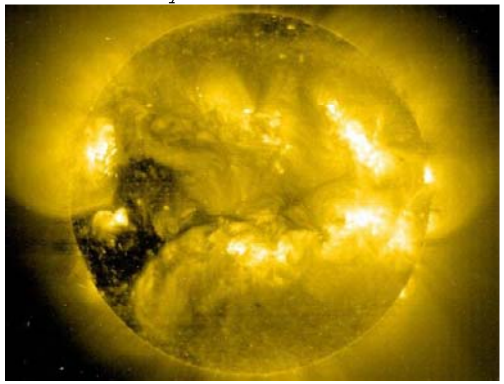
(a) $E_0 = mc^2 = 9.109\times10^{-31} kg \times (3\times10^8)^2 m/s = 8.19\times10^{-14} J = 0.51 MeV$

(b) Total energy of the traveling electron,

$$E = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{0.51 MeV}{\sqrt{1-0.995^2}} = 16.2 MeV$$

(c) The kinetic energy = $E - E_0$ = 15.7 MeV

6) The Sun Is Losing Mass (Cutnell, pg 868)
The sun radiates electromagnetic energy at the rate of 3.92×10^{26} W. (a) What is the change in the sun's mass during each second that it is radiating energy? (b) The mass of the sun is 1.99×10^{30} kg. What fraction of the sun's mass is lost during a human lifetime of 75 years?



Reasoning
Since a W = I J/s the amount of electromagnetic energy radiated during each second is 3.92×10^{26} J. Thus, during each second, the sun's rest energy decreases by this amount. The change ΔE_0 in the sun's rest energy is related to the change Δm in its mass by $\Delta E_0 = \Delta m\ c^2$.
Solution
(a) For each second that the sun radiates energy, the change in its mass is $\Delta m = \Delta E_0/c^2 = 3.92\times10^{26}$ J/$(3\times10^8 \text{ m/s})^2$ = (4.36×10^9) kg. Over 4 billion kilograms of mass are lost by the sun during each second.

(b) The amount of mass lost by the sun in 75 years is
$\Delta m = (4.36\times10^9)$ kg $\times (3.16\times10^7$ s/year$) \times (75$ years$) = 1\times10^{19}$ kg
Although this is an enormous amount of mass, it represents only a tiny fraction of the sun's total mass:

$$\Delta m/m = 1.0\times10^{19} \text{ kg}/1.99\times10^{30} \text{ kg} = 5.0\times10^{-12}$$

Figure 28.12 An intergalactic cruiser, closing in on a hostile spacecraft, fires a beam of laser light.

7) The Speed of a Laser Beam (Cutnell, pg 871)
Figure below shows an intergalactic cruiser approaching a hostile spacecraft. The velocity of the cruiser relative to the spacecraft is $v_{CS} = +0.7c$. Both vehicles are moving at a constant velocity. The cruiser fires a beam of laser light at the enemy. The velocity of the laser beam relative to the cruiser is $v_{LC} = +c$. (a) What is the velocity of the laser beam v_{LS} relative to the renegades aboard the spacecraft? (b) At what velocity do the renegades aboard the spacecraft see the laser beam move away from the cruiser?

Reasoning and Solution

(a) Since both vehicles move at a constant velocity, each constitutes an inertial reference frame. According to the speed of light postulate, all observers in inertial reference frames measure the speed of light in a vacuum to be c. Thus, the renegades aboard the hostile spacecraft see the laser beam travel toward them at the speed of light, even though the beam is emitted from the cruiser, which itself is moving at seven-tenths the speed of light.

More formally, we can use Lorentz transformation of velocities to calculate v_{LS}. We will take the direction as +ve when a velocity is pointing from left to right. We can take view that the hostile spacecraft is at rest (as the stationary frame, O) while the cruiser is approaching it with velocity $v_{CS} = +0.7c$ (according to our choice of the sign). In this case, the cruiser is the moving frame, O'. The light beam as seen in the moving frame O' is $v_{LC} = +c$. We wish to find out what is the speed of this laser beam from O point of view, e.g. what v_{LS} is.

We may like to identify v_{LS}, v_{LC} and v_{CS} with the definitions used in the Lorentz formula: $u_x = \dfrac{u'_x + u}{1 + \dfrac{u'_x u}{c^2}}$. In fact, a little contemplation would allow us to make the identification that, with our choice of frames (that the hostile spacecraft as the stationary frame): $v_{LC} \equiv u_{x'} = +c$; $v_{CS} \equiv u = +0.7c$ and $v_{LS} = u_x$ = the speed of laser beam as seen by the stationary frame O (the quantity we are seeking). Hence, we have

SESSI 04/05/ TUTORIAL 1

$$u_x = \frac{u'_x + u}{1 + \frac{u'_x u}{c^2}} \equiv v_{LS} = \frac{v_{LC} + v_{CS}}{1 + \frac{v_{LC} v_{CS}}{c^2}} = \frac{(+c) + (+0.7c)}{1 + \frac{(+c)(+0.7c)}{c^2}} = \frac{1.7c}{1.7c} = +c$$

, i.e. the laser beam is seen, from the view point of the hostile spacecraft, to be approaching it with a velocity +c (+ve means the velocity is from left to right).

(b) The renegades aboard the spacecraft see the cruiser approach them at a relative velocity of $v_{CS} = +0.7c$, and they also see the laser beam approach them at a relative velocity Of v_{LS} +c. Both these velocities are measured relative to the same inertial reference frame-namely, that of the spacecraft. Therefore, the renegades aboard the spacecraft see the laser beam move away from the cruiser at a velocity that is the difference between these two velocities, or $+c - (+0.7c) = +0.3c$. The relativistic velocity-addition formula, is not applicable here because both velocities are measured relative to the same inertial reference frame (the spacecraft's reference frame). The relativistic velocity-addition formula can be used only when the velocities are measured relative to different inertial reference frames.

8) The Relativistic Momentum of a High-Speed Electron (Cutnell, pg 865)
The particle accelerator at Stanford University is three kilometers long and accelerates electrons to a speed of 0.999 999 999 7c, which is very nearly equal to the speed of light. Find the magnitude of the relativistic momentum of an electron that emerges from the accelerator, and compare it with the non-relativistic value.

Reasoning and Solution

The magnitude of the electron's relativistic momentum can be obtained from $p = \gamma m_0 v = 1\times10^{-17}$ Ns, where $m_0 = 9.1\times10^{-31}$ kg, $v\gamma = \dfrac{0.999999997c}{\sqrt{1-\dfrac{(0.999999997c)^2}{c^2}}} = 1.09989\times10^{13}$ m/s. The relativistic momentum is greater than the non-relativistic momentum by a factor of $\gamma = \dfrac{1}{\sqrt{1-\dfrac{(0.999999997c)^2}{c^2}}} = 4\times10^4$.

9) Resnick and Halliday, Sample problem 37-8, pg. 1047.
The most energetic proton ever detected in the cosmic rays coming to Earth from space had an astounding kinetic energy of

3.0 x 10^{20} eV. (a) What were the proton's Lorentz factor γ and speed v (both relative to the ground-based detector)?

Solution

$$\gamma = \frac{E}{m_0c^2} = \frac{m_0c^2 + K}{m_0c^2} = 1 + \frac{K}{m_0c^2} \Rightarrow \gamma = 1 + \frac{3.0\times10^{20}\,\text{eV}}{938\times10^{6}\,\text{eV}} \approx 3.2\times10^{11}$$

$$\gamma^{-1} = \sqrt{1-\left(\frac{v}{c}\right)^2} = \sqrt{\left(1-\frac{v}{c}\right)\left(1+\frac{v}{c}\right)}.\ \text{But } 1+\frac{v}{c}\approx 2 \Rightarrow \gamma^{-2} \approx 2\left(1-\frac{v}{c}\right) = 9.766\times10^{-24}$$

$$\Rightarrow v \approx \left(1-5\times10^{-24}\right)c = 0.999999999999999999999995c$$

Tutorial 2

Matter and Wave; Blackbody radiation

Conceptual Questions

1. **What is ultraviolet catastrophe? What is the significance of it in the development of modern physics? (My own question)**

   ANS
   The classical theory explanation of the blackbody radiation by Rayleigh-Jeans fails in the limit $\lambda \to 0$ (or equivalently, when frequency $\to \infty$), i.e. $R(\lambda) \to \infty$ at $\lambda \to 0$. The failure prompted Planck to postulate that the energy of electromagnetic waves is quantised (via $\varepsilon = h\nu$) as opposed to the classical thermodynamics description ($\varepsilon = \kappa T$). With Planck's postulate, radiation now has particle attributes instead of wave.

2. **What assumptions did Planck make in dealing with the problem of blackbody radiation? Discuss the consequences of the assumptions.**

ANS
Planck made two new assumptions: (1) Radiation oscillator energy is quantized and (2) they emit or absorb energy in discrete irreducible packets. The "oscillator" here actually refers to the molecules or atoms that made up the walls of the blackbody cavity. These assumptions contradict the classical idea of energy as continuously divisible.

3. **The classical model of blackbody radiation given by the Rayleigh-Jeans law has two major flaws. Identify them and explain how Planck's law deals with them.**

   ANS
   The first flaw is that the Rayleigh–Jeans law predicts that the intensity of short wavelength radiation emitted by a blackbody approaches infinity as the wavelength decreases. This is known as the *ultraviolet catastrophe*. The second flaw is the prediction much more power output from a black-body than is shown experimentally. The intensity of radiation from the blackbody is given by the area under the red $I(\lambda,\ T)$ *vs.* λ curve in Figure 40.5 in the text, not by the area under the blue curve.
   Planck's Law dealt with both of these issues and brought the theory into agreement with the experimental data by adding an exponential term to the denominator that

depends on $\frac{1}{\lambda}$. This both keeps the predicted intensity from approaching infinity as the wavelength decreases and keeps the area under the curve finite.

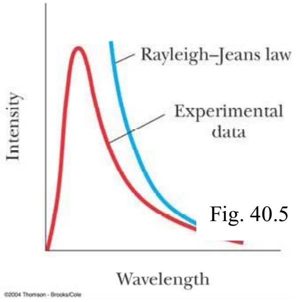


Fig. 40.5

4. What are the most few distinctive physical characteristics, according to your point of view, that exclusively differentiate a classical particle from a wave? Construct a table to compare these two.

ANS (my suggestions)

Particle	Wave
Complete localized	Cannot be confined to any particular region of space. A wave can be "simultaneously everywhere" at a given instance in time
Mass and electric charge can be identified with infinite precision	No mass is associated with a wave.
Energy carried by a particle is concentrated in it and is not spreading over the boundary that define its physical location	Energy carried by wave spreads over an infinite regions of space along the direction the wave propagates
Momentum and position can be identified with infinite precision.	Wavelength and position of a wave cannot be simultaneously measured to infinite precision, they must obey the classical wave uncertainty relation $\Delta\lambda\,\Delta x \geq \lambda^2$
There is not definition of wavelength for a particle	There is not definition of momentum for waves
Does not undergo diffraction and interference	Waves undergo diffraction and interference

(others)	(others)

Problems

1. For a blackbody, the total intensity of energy radiated over all wavelengths, *I*, is expected to rise with temperature. In fact one find that the total intensity increases as the fourth power of the temperature. We call this the *Stefan's law*: $I = \sigma T^4$, where σ is the Stefan's constant $\sigma = 5.67\times10^{-8}\,\text{W/m}^2\cdot\text{K}^4$. How does the total intensity of thermal radiation vary when the temperature of an object is doubled?

ANS

Intensity of thermal radiation $I \propto T^4$. Hence, when T is double, ie. $T \to 2T$, $I \to I'(2)^4 = 16I$, i.e. the total intensity of thermal radiation increase by 16 times.

2. (Krane, pg. 62)

In the spectral distribution of blackbody radiation, the wavelength λ_{max} at which the intensity reaches its maximum value decreases as the temperature is increased, in inverse proportional to the temperature: $\lambda_{max} \propto 1/T$. This is called the *Wein's displacement law*. The proportional constant is experimentally determined to be $\lambda_{max}T = 2.898\times10^{-3}\,\text{m}\cdot\text{K}$

(a) At what wavelength does a room-temperature (T = 20°C) object emit the maximum thermal radiation?
(b) To what temperature must we heat it until its peak thermal radiation is in the red region of the spectrum?
(c) How many times as much thermal radiation does it emit at the higher temperature?

ANS

(a) Converting to absolute temperature, T = 293 K, and from Wien's displacement law, $\lambda_{max}T = 2.898\times10^{-3}\,\text{m}\cdot\text{K}$
λ_{max} = 2.898×10^{-3} m·K/293K = 9.89 μm

(b) Taking the wavelength of red light to be =650 nm, we again use Wien's displacement law to find T:

$T = 2.898\times10^{-3}$ m·K/650×10^{-9} m = 4460 K

(c) Since the total intensity of radiation is proportional to T^4, the ratio of the total thermal emissions will be

$$\frac{T_2^4}{T_1^4} = \frac{4460^4}{293^4} = 5.37\times10^4$$

Be sure to notice the use of absolute (Kelvin) temperatures.

3. **Show that the spectral distribution derived by Planck, $I(\lambda,T) = \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda k_B T}-1\right)}$ reduces to the Rayleigh-Jeans law, $I(\lambda,T) = \frac{2\pi ck_B T}{\lambda^4}$ in the long wavelength limit.**

ANS

In long wavelength limit, $hc \ll \lambda k_B T$, the exponential term is approximated to

$e^{hc/\lambda k_B T} = 1 + \frac{hc}{\lambda k_B T} + \frac{1}{2!}\left(\frac{hc}{\lambda k_B T}\right)^2 + \ldots \approx 1 + \frac{hc}{\lambda k_B T}$. Hence, substituting $e^{hc/\lambda k_B T} \approx 1 + \frac{hc}{\lambda k_B T}$ into the Planck's distribution, we have

$$I(\lambda,T) = \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda k_B T}-1\right)} \approx \frac{2\pi hc^2}{\lambda^5\left[\left(1+\frac{hc}{\lambda k_B T}\right)-1\right]} = \frac{2\pi hc^2}{\lambda^5\left[\frac{hc}{\lambda k_B T}\right]} = \frac{2\pi hc^2 \lambda k_B T}{\lambda^5 hc} = \frac{2\pi ck_B T}{\lambda^4},$$

which is nothing but just the RJ's law.

Tutorial 3

Photoelectricity, Compton scatterings, pair-production/annihilation, X-rays

Conceptual Questions

1. **What is the significance of the Compton wavelength of a given particle (say an electron) to a light that is interacting with the particle? (Own question)**

ANS

The Compton wavelength (a characteristic constant depend solely on the mass of a given particle) characterises the length scale at which the quantum property (or wave) of a given particle starts to show up. In an interaction that is characterised by a length scale larger than the Compton wavelength, particle behaves classically. For interactions that occur at a length scale comparable than the Compton wavelength, the quantum (or, wave) nature of the particle begins to take over from classical physics.

In a light-particle interaction, if the wavelength of the light is comparable to the Compton wavelength of the interacting particle, light displays quantum (granular/particle) behaviour rather than like a wave.

2. **Why doesn't the photoelectric effect work for free electron? (Krane, Question 7, pg 79)**

ANS (verify whether the answer make sense)

Essentially, Compton scattering is a two-body process. The free electron within the target sample (e.g. graphite) is a unbounded elementary particle having no internal structure that allows the photons to be \`absorbed'. Only elastic scattering is allowed here.

Whereas PE effect is a inelastic scattering, in which the absorption of a whole photon by the atom is allowed due to the composite structure (the structure here refers the system of the orbiting electrons and nuclei hold together via electrostatic potential) of the atom. A whole photon is allowed to get absorbed by the atom in which the potential energy acts like a medium to transfer the energy absorbed from the photon, which is then \`delivered' to the bounded electrons (bounded to the atoms) that are then \`ejected' out as photoelectrons.

3. **How is the wave nature of light unable to account for the observed properties of the photoelectric effect? (Krane, Question 5, pg 79)**

ANS

See lecture notes

4. In the photoelectric effect, why do some electrons have kinetic energies smaller than K_{max}? (Krane, Question 6, pg 79)

ANS

By referring to $K_{max} = h\nu - \phi$, K_{max} corresponds to those electrons knocked loose from the surface by the incident photon whenever $h\nu > \phi$. Those below the surface required an energy greater than ϕ and so come off with less kinetic energy.

5. Must Compton scattering take place only between x-rays and free electrons? Can radiation in the visible (say, a green light) Compton scatter a free electron? (My own question)

ANS

In order to Compton scatter the electron, the wavelength of the radiation has to be comparable to the Compton wavelength of the electron. If such criterion is satisfied the cross section (the probability for which a scattering process can happen) of Compton scattering between the radiation and the electron would be highly enhanced. It so happen that the Compton wavelength of the electron, $\lambda_e = \frac{h}{m_e c} \sim 10^{-12}\text{m}$ is ~ the order the X-rays', $\lambda_{X-ray} \sim 10^{-12}\text{m}$, hence X-rays' Compton scattering with electrons is most prominent compared to radiation at other wavelengths. This means that at other wavelength (such as in the green light region, where $\lambda_{green} << \lambda_e$) the cross section of Compton scattering would be suppressed.

Problems

1. The diameter of an atomic nucleus is about 10×10^{-15} m. Suppose you wanted to study the diffraction of photons by nuclei. What energy of photons would you choose? Why? (Krane, Question 1, pg 79)

Solution

Diffraction of light by the nucleus occurs only when the wavelength of the photon is smaller or of the order of the size of the nucleus, $\lambda \sim D$ (D = diameter of the nucleus). Hence, the minimum energy of the photon would be $E = hc/\lambda \sim hc/D \sim 120$ MeV.

2. Photons from a Light Bulb (Cutnell, pg884)
In converting electrical energy into light energy, a sixty-watt incandescent light bulb operates at about 2.1% efficiency. Assuming that all the light is green light (vacuum wavelength 555 nm), determine the number of photons per second given off by the bulb.

Reasoning

The number of photons emitted per second can be found by dividing the amount of light energy emitted per second by the energy E of one photon. The energy of a single photon is $E = hf$. The frequency of the photon is related to its wavelength λ by $\nu = c/\lambda$.

Solution

At an efficiency of 2.1%, the light energy emitted per second by a sixty-watt bulb is (0.021)(60.0 J/s)=1.3 J/s. The energy of a single photon is

$E = hc/\lambda = (6.63\times10^{-34}\text{Js})(3\times10^{8}\text{ m/s})/555\times10^{-9}\text{ nm} = 3.58\times10^{-19}\text{ J}$

Therefore, number of photons emitted per second =
$1.3\text{ J/s}/\ (3.58\times10^{-19}\text{ J/photon}) = 3.6\times10^{18}$ photon per second

3. Ultraviolet light of wavelength 350 nm and intensity 1.00 W/m^2 is directed at a potassium surface. (a) Find the maximum KE of the photoelectrons. (b) If 0.50 percent of the incident photons produce photoelectrons, how many are emitted per second if the potassium surface has an area of 1.00 cm^2? (Beiser, pg. 63)

Solution

(a) The energy of the photons is, $E_p = hc/\lambda$ = 3.5eV. The work function of potassium is 2.2 eV. So,
KE = $h\nu - \phi$ = 3.5 eV - 2.2 eV = 5.68×10^{-19} J

(b) The photon energy in joules is 5.68×10^{-19} J. Hence the number of photons that reach the surface per second is
$n_p = (E/t)/E_p = (E/A)(A)/E_p$
$= (1.00\text{ W/m}^2)(1.00\times10^{-4}\text{ m}^2)/5.68\times10^{-19}\text{ J}$
$= 1.76\times10^{14}$ photons/s
The rate at which photoelectrons are emitted is therefore n_e = $(0.0050)n_p$ = 8.8×10^{11} photoelectrons/s

4. The work function for tungsten metal is 4.53 eV. (a) What is the cut-off wavelength for tungsten? (b) What is the maximum kinetic energy of the electrons when radiation of wavelength 200.0 nm is used? (c) What is the stopping potential in this case? (Krane, pg. 69)

Solution

(a) The cut-off frequency is given by $\lambda_c = \frac{hc}{\phi} = \frac{1240\text{eV}\cdot\text{nm}}{200\text{nm}} = 274\text{nm}$, in the uv region

(b) At the shorter wavelength,
$$K_{\max} = h\frac{c}{\lambda} - \phi = \frac{1240eV\cdot nm}{200nm} - 4.52eV = 1.68eV$$

(c) The stopping potential is just the voltage corresponding to $K_{\max}$:
$$V_s = K_{\max}/e = \frac{1.68eV}{e} = 1.68\text{V}$$

5. X-rays of wavelength 10.0 pm (1 pm = 10^{-12} m) are scattered from a target. (a) Find the wavelength of the x-rays scattered through 45°. (b) Find the maximum wavelength present in the scattered x-rays. (c) Find the maximum kinetic energy of the recoil electrons. (Beiser, pg. 75)

Solution

(a) The Compton shift is given by $\Delta\lambda = \lambda' - \lambda = \lambda_c(1-\cos\varphi)$, and so

$\lambda' = \lambda + \lambda_c(1-\cos 45^o) = 10.0\,pm + 0.293\lambda_c = 10.7$ pm

(b) $\Delta\lambda$ is a maximum when $1-\cos\varphi$ = 2, in which case, $\Delta\lambda = \lambda + 2\lambda_c$ = 10.0 pm + 4.9 pm = 14.9 pm

(c) The maximum recoil kinetic energy is equal to the difference between the energies of the incident and scattered photons, so

$KE_{max} = h(\nu - \nu') = hc(\frac{1}{\lambda} - \frac{1}{\lambda'}) = 40.8$ eV

6. Gautreau and Savin, page 70, Q 9.28

A photon of wavelength 0.0030 Å in the vicinity of a heavy nucleus produces an electron-positron pair. Determine the kinetic energy of each of the particles if the kinetic energy of the positron is twice that of the electron.

Solution:

From (total relativistic energy before) = (total relativistic energy after),

$$\frac{hc}{\lambda} = 2m_ec^2 + K_+ + K_- = 2m_ec^2 + 3K_-$$

$$\frac{12.4\times10^{-3}\,\text{MeV}\cdot\text{Å}}{0.0030\,\text{Å}} = 2(0.511\text{MeV})\cdot 3K_-$$

$$K_- = 1.04\text{MeV};\ K_+ = 2K_- = 2.08\text{MeV}$$

7. Gautreau and Savin, page 71, Q 9.32

Annihilation occurs between an electron and positron at rest, producing three photons. Find the energy of the third photon of the energies of the two of the photons are 0.20 MeV and 0.30 MeV.

Solution:

From conservation of energy, 2(0.511 MeV) = 0.20 MeB + 0.30 MeV = E_3 or E_3 = 0.522 MeV

8. Gautreau and Savin, page 71, Q 9.33

How Many positrons can a 200 MeV photon produce?

Solution:

The energy needed to produce an electron-positron pair at rest is twice the rest energy of an electron, or 1.022 MeV. Therefore, Maximum number of positrons =

$$(200\text{ MeV})\left(\frac{1\text{ pair}}{1.022\text{ MeV}}\right)\left(1\frac{\text{positron}}{\text{pair}}\right) = 195\text{ positrons}$$

Tutorial 4
Wave particle duality, de Brolie postulate, Heisenberg Uncertainty principle

Conceptual Questions

1. **What difficulties does the uncertainty principle cause in trying to pick up an electron with a pair of forceps? (Krane, Question 4, pg. 110)**

ANS

When the electron is picked up by the forceps, the position of the electron is ``localised' (or fixed), i.e. $\Delta x$ = 0. Uncertainty principle will then render the momentum to be highly uncertainty. In effect, a large $\Delta p$ means the electron is ``shaking'' furiously against the forceps' tips that tries to hold the electron ``tightly''.

2. **An electron and a proton both moving at nonrelativistic speeds have the same de Broglie wavelength. Which of the following are also the same for the two particles?**
(a) speed (b) kinetic energy (c) momentum
(d) frequency

ANS

(c). According to de Broglie's postulate, $\lambda = \frac{h}{p} = \frac{h}{mv}$, two particles with the same de Broglie wavelength will have the same momentum $p = mv$. If the electron and proton have the same momentum, they cannot have the same speed (a) because of the difference in their masses. For the same reason, because $K = p^2/2m$, they cannot have the same kinetic energy (b). Because the particles have different kinetic energies, Equation $\lambda = \frac{h}{p} = \frac{h}{mv}$ tells us that the particles do not have the same frequency (d).

3. **The location of a particle is measured and specified as being exactly at x = 0, with *zero* uncertainty in the x direction. How does this affect the uncertainty of its velocity component in the y direction?**
(a) It does not affect it.
(b) It makes it infinite.
(c) It makes it zero.

ANS

(a). The uncertainty principle relates uncertainty in position and velocity along the same axis. The zero uncertainty in position along the x axis results in infinite uncertainty in its velocity component in the x direction, but it is unrelated to the y direction.

4. **You use a large potential difference to accelerate particles from rest to a certain kinetic energy. For a certain potential difference, the particle that will give you the highest resolution when used for the application as a microscope will be a) an electron, b) a proton, c) a neutron, or d) each particle will give you the same resolution under these circumstances. (Serway QQ)**

   ANS

   (b). The equation $\lambda = h/(2mq\Delta V)^{1/2}$ determines the wavelength of a particle. For a given potential difference and a given charge, the particle with the highest mass will have the smallest wavelength, and can be used for a microscope with the highest resolution. Although neutrons have the highest mass, their neutral charge would not allow them to be accelerated due to a potential difference. Therefore, protons would be the best choice. Protons, because of their large mass, do not scatter significantly off the electrons in an atom but can be used to probe the structure of the nucleus.

5. **Why was the demonstration of electron diffraction by Davisson and Germer and important experiment? (Serway, Q19, pg. 1313)**

   ANS

   The discovery of electron diffraction by Davisson and Germer was a fundamental advance in our understanding of the motion of material particles. Newton's laws fail to properly describe the motion of an object with small mass. It moves as a wave, not as a classical particle. Proceeding from this recognition, the development of quantum mechanics made possible describing the motion of electrons in atoms; understanding molecular structure and the behavior of matter at the atomic scale, including electronics, photonics, and engineered materials; accounting for the motion of nucleons in nuclei; and studying elementary particles.

6. **If matter has wave nature why is this wave-like character not observed in our daily experiences? (Serway, Q21, pg. 1313)**

   ANS

   Any object of macroscopic size—including a grain of dust—has an undetectably small wavelength and does not exhibit quantum behavior.

Problems

1. **Beiser, pg. 100, example 3.3**

   An electron has a de Broglie wavelength of 2.00 pm. Find its kinetic energy and the phase and the group velocity of its de Broglie waves.

   Solution

   (a) First calculate the pc of the electron

   $pc = hc/\lambda$ = 1.24 keV.nm / 2.00 pm = 620 keV

   The rest energy of the electron is E_0=511 keV, so the KE of the electron is

   $KE = E - E_0 = [E_0^2 - (pc)^2]^{1/2} - E_0 = \ldots 292$ keV

   (b) The electron's velocity is to be found from

   $\gamma = E/E_0 = (KE + E_0)/E_0 = 803/511 = 1.57$

   $$\frac{1}{\gamma^2} = 1 - \frac{v^2}{c^2} = 0.405 \Rightarrow \frac{v^2}{c^2} = 1 - 0.405 = 0.595$$

   $\Rightarrow v = 0.771c$

   Hence, the phase velocity is $v_p = \dfrac{c^2}{v} = \dfrac{c^2}{0.771c} = 1.29c$

   The group velocity is $v_g = v = 0.771c$

2. **Find the de Broglie wave lengths of (a) a 46-g ball with a velocity of 30 m/s, and (b) an electron with a velocity of 10^7 m/s (Beiser, pg. 92)**

   Solution

   (a) Since $v << c$, we can let $m = m_o$. Hence

   $\lambda = h/mv = 6.63\times10^{-34}$ Js/(0.046 kg)(30 m/s)
   $= 4.8\times10^{-34}$ m

   The wavelength of the golf ball is so small compared with its dimensions that we would not expect to find any wave aspects in its behaviour.

   (b) Again $v << c$, so with $m = m_o = 9.1\times10^{-31}$ kg, we have

   $\lambda = h/mv = 6.63\times10^{-34}$ Js/$(9.1\times10^{-31}$ kg)$(10^7$ m/s)
   $= 7.3\times10^{-11}$ m

   The dimensions of atoms are comparable with this figure - the radius of the hydrogen atom, for instance, is 5.3×10^{-11} m. It is therefore not surprising that the wave character of moving electrons is the key to understanding atomic structure and behaviour.

3. **The de Broglie Wavelength (Cutnell, pg. 897)**
An electron and a proton have the same kinetic energy and are moving at non-relativistic speeds. Determine the ratio of the de Broglie wavelength of the electron to that of the proton.

ANS
Using the de Broglie wavelength relation $p = h/\lambda$ and the fact that the magnitude of the momentum is related to the kinetic energy by $p = (2mK)^{1/2}$, we have

$$\lambda = h/p = h/(2mK)^{1/2}$$

Applying this result to the electron and the proton gives

$$\lambda_e/\lambda_p = (2m_pK)^{1/2}/(2m_eK)^{1/2} = (m_p/m_e)^{1/2} = (1.67\times10^{-27}\,\text{kg}/9.11\times10^{-31}\,\text{kg})^{1/2} = 42.8$$

As expected, the wavelength for the electron is greater than that for the proton.

4. **Find the kinetic energy of a proton whose de Broglie wavelength is 1.000 fm = 1.000×10^{-15} m, which is roughly the proton diameter (Beiser, pg. 92)**

ANS
A relativistic calculation is needed unless pc for the proton is much smaller than the proton rest mass of E_o = 0.938 GeV.

So we have to first compare the energy of the de Broglie wave to E_o:

$E = pc = \dfrac{hc}{\lambda} = \dfrac{1242 eV\cdot nm}{10^{-6} nm} = 1.24$ GeV, c.f. E_o = 0.938 GeV. Since the energy of the de Broglie wave is larger than the rest mass of the proton, we have to use the relativistic kinetic energy instead of the classical $K = p^2/2m$ expression.

The total energy of the proton is

$E = \sqrt{E_0^2 + (pc)^2} = \sqrt{(0.938\,GeV)^2 + (1.24\,GeV)^2}$ =1.555 GeV.

The corresponding kinetic energy is
KE = $E - E_o$ = (1.555 - 0.938) GeV = 0.617 GeV = 617 MeV

SESSI 04/05/ TUTORIAL 4

5. **A hydrogen atom is 5.3x10^{-11} m in radius. Use the uncertainty principle to estimate the minimum energy an electron can have in this atom. (Beiser, pg 114)**

ANS
Here we find that with Δx = 5.3×10^{-11} m.

$\Delta p \ \geq \ \dfrac{\hbar}{2\pi}$ = 9.9×10^{-25} Ns.

An electron whose momentum is of this order of magnitude behaves like a classical particle, an its kinetic energy is $K = p^2/2m \geq (9.9\times10^{-25}\text{ Ns})^2/2\times9.110^{-31}$ kg = 5.4×10^{-19} J, which is 3.4 eV. The kinetic energy of an electron in the lowest energy level of a hydrogen atom is actually 13.6 eV.

6. **A measurement established the position of a proton with an accuracy of $\pm1.00\times10^{-11}$m. Find the uncertainty in the proton's position 1.00 s later. Assume v << c. (Beiser, pg. 111)**

ANS
Let us call the uncertainty in the proton's position Δx_0 at the time t = 0. The uncertainty in its momentum at this time is therefore $\Delta p \geq \dfrac{\hbar}{2\Delta x_0}$. Since $v << c$, the momentum uncertainty is $\Delta p \geq \Delta(mv) = m_0\Delta v$ and the uncertainty in the proton's velocity is $\Delta v \geq \dfrac{\Delta p}{m_0} \geq \dfrac{\hbar}{2m_0\Delta x_0}$. The distance x of the proton covers in the time t cannot be known more accurately than $\Delta x \geq t\Delta v \geq \dfrac{\hbar t}{2m_0\Delta x_0}$. Hence Δx is inversely proportional to Δx_0: the more we know about the proton's position at t = 0 the les we know about its later position at t. The value of Δx at t = 1.00 s is $\Delta x \geq \dfrac{(1.054\times10^{-34} Js)(1.00 s)}{2(1.672\times10^{-27} kg)(1.00\times10^{-11} m)} = 3.15\times10^3$m. This is 3.15 km! What has happened is that the original wave group has spread out to a much wider one because the phase velocities of the component wave vary with wave number and a large range of wave numbers must have been present to produce the narrow original wave

7. **Broadening of spectral lines due to uncertainty principle: An excited atom gives up it excess energy by emitting a photon of characteristic frequency. The average period that elapses between the excitation of an atom and the time is radiates is**

1.0×10^{-8} s. Find the inherent uncertainty in the frequency of the photon. (Beiser, pg. 115)

ANS

The photon energy is uncertain by the amount $\Delta E \geq \frac{\hbar}{2\Delta t} = \frac{1.054\times10^{-34}\,Js}{2(1.0\times10^{-8}\,s)} = 5.3\times10^{-27}$ J. The corresponding uncertainty in the frequency of light is $\Delta\nu = \frac{\Delta E}{h} \geq 8\times10^{6}$ Hz. This is the irreducible limit to the accuracy with which we can determine the frequency of the radiation emitted by an atom. As a result, the radiation from a group of excited atoms does not appear with the precise frequency ν. For a photon whose frequency is, say, 5.0×10^{14} Hz, $\frac{\Delta\nu}{\nu} = 1.6\times10^{-8}$.

Tutorial 5
Atomic models

Conceptual Questions

1. **What is the ONE essential difference between the Rutherford model and the Bohr's model? (My own question)**

   ANS
   Rutherford's model is a classical model, in which EM wave will be radiated rendering the atom to collapse. Whereas the Bohr's model is a semi-classical model in which quantisation of the atomic orbit happens.

2. **Conventional spectrometers with glass components do not transmit ultraviolet light ($\lambda \lesssim$ 380 nm). Explain why non of the lines in the Lyman series could be observed with a conventional spectrometer. (Taylor and Zafiratos, pg. 128)**

   ANS

   For Lyman series, n_f = 1. According to $\frac{1}{\lambda} = Z^2 R_\infty\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$, the wavelength corresponding to n_i = 2 in the Lyman series is predicted to be $\lambda = \frac{4}{3R_\infty} = \frac{4}{3(109{,}737\,\mathrm{cm}^{-1})}$ =121.5 nm. Similarly, for n_i = 3, one finds that λ=102 nm, and inspection of $\frac{1}{\lambda} = Z^2 R_\infty\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ shows that the larger we take n, the smaller the corresponding wavelength. Therefore, all lines in the Lyman series lie well into the ultraviolet and are unobservable with a conventional spectrometer.

3. **Does the Thompson model fail at large scattering angles or at the small scattering angle? Why? (Krane, Questions 1, pg. 173)**

   ANS
   Thompson model fails at large angle (but is consistent with scattering experiments at small angle). Thompson model predicts that the average scattered angle is given by a small value of θ_{ave} ~ 1°. However, in the experiment, alpha particles are observed to be scattered at angle in excess of 90°. This falsifies Thompson model at large angle.

4. **In which Bohr orbit does the electron have the largest velocity? Are we justified in treating the electron non-relativistically? (Krane, Questions 6. pg. 174)**

ANS

The velocity in an orbit n is given by $v = h/2\pi mnr_0$, which means that the velocity is inversely proportional to the n number. Hence the largest velocity corresponds to the n = 1 state,

$v(n=1)/c = h/2c\pi mr_0$

$= 6.63\times10^{-34}/2\pi(9.1\times10^{-31})(0.53\times10^{-10})/c$

$= 0.007.$

Hence, nonrelativistic treatment is justified.

5. **How does a Bohr atom violate the $\Delta x\Delta p \geq \frac{\hbar}{2}$ uncertainty relation? (Krane, Question 11, pg. 174)**

ANS

The uncertainty relation in the radial direction of an electron in a Bohr orbit is $\Delta r\Delta p_r \geq \frac{\hbar}{2}$. However, in the Bohr model, the Bohr orbits are assumed to be precisely known $(=r_n = n^2 r_0)$ for a given n. This tantamount to $\Delta r = 0$, which must render the momentum in the radial direction to become infinite. But in the Bohr atom the electron does not have such radial motion caused by this uncertainty effect. So in this sense, the discrete Bohr orbit violates the uncertainty relation $\Delta x\Delta p \geq \frac{\hbar}{2}$.

Problem

1. **If we assume that in the ground of the hydrogen the position of the electron along the Bohr orbit is not known and not knowable, then the uncertainty in the position is about $\Delta x \approx 2r_0 = 10^{-10}$ m, (a) what is the magnitude of the momentum of the electron at the ground state? (b) What is the corresponding quantum uncertainty in the momentum? (Ohanian, pg. 152)**

ANS

(a) Angular momentum, $|L| \equiv |p|r = n\hbar$. Hence, in the ground state, $|p| = \hbar/r_0 = 2.1\times10^{-24}$ Ns

(b) $\Delta p_x \geq \frac{\hbar}{2\Delta x} = \frac{\hbar}{2(2r_0)} = 5.3\times10^{-25}$ Ns.

2. **Serway and Mosses, Problem 13(a), page 148**
What value of n is associated with the Lyman series line in hydrogen whose wavelength is 102.6 nm?

Solution:

$\lambda = 102.6$ nm ; $\frac{1}{\lambda} = R\left(1-\frac{1}{n^2}\right) \Rightarrow n = \frac{R}{\left(R-\frac{1}{\lambda}\right)^{1/2}} = \frac{R}{\left(R-\frac{1}{102.6\times10^{-9}\text{ m}}\right)^{1/2}} = 2.99 \approx 3$

3. **Serway and Moses, Problem 22**
Find the potential energy and kinetic energy of an electron in the ground state of the hydrogen atom.

Solution:

$E = K + U = \frac{mv^2}{2} - \frac{ke^2}{r}$. But $\frac{mv^2}{2} = \left(\frac{1}{2}\right)\frac{ke^2}{r}$. Thus $E = \left(\frac{1}{2}\right)\left(\frac{-ke^2}{r}\right) = \frac{U}{2}$, so

$U = 2E = 2(-13.6\text{ eV}) = -27.2\text{ eV}$ and $K = E - U = -13.6\text{ eV} - (-27.2\text{ eV}) = 13.6\text{ eV}$.

4. **Serway and Moses, Problem 21**
Calculate the longest and shortest wavelengths for the Paschen series. (b) Determine the photon energies corresponding to these wavelengths.

Solution

(a) For the Paschen series; $\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n_i^2}\right)$; the maximum wavelength corresponds to $n_i = 4$, $\frac{1}{\lambda_{max}} = R\left(\frac{1}{3^2} - \frac{1}{4^2}\right)$;

$\lambda_{max} = 1\,874.606$ nm. For minimum wavelength, $n_i \to \infty$,

$\frac{1}{\lambda_{min}} = R\left(\frac{1}{3^2} - \frac{1}{\infty}\right)$; $\lambda_{min} = \frac{9}{R} = 820.140$ nm.

(b) $\frac{hc}{\lambda_{min}} = \frac{\left(\frac{hc}{1874.606\text{ nm}}\right)}{1.6\times10^{-19}\text{ J/eV}} = 0.662\,7$ nm , $\frac{hc}{\lambda_{min}} = \frac{\left(\frac{hc}{820.140\text{ nm}}\right)}{1.6\times10^{-19}\text{ J/eV}} = 1.515$ nm

5. **Hydrogen atoms in states of high quantum number have been created in the laboratory and observed in space. (a) Find the quantum number of the Bohr orbit in a hydrogen atom whose radius is 0.0199 mm. (b) What is the energy of a hydrogen atom in this case? (Beiser, pg. 133)**

Solution

(a) From $r_n = n^2 r_0$, we have $n = \sqrt{\frac{r_n}{r_0}} = \sqrt{\frac{0.0100\times10^{-3}}{5.3\times10^{-11}}} = 434$

(b) From $E_n = -\frac{13.6}{n^2}$eV, we have $E_n = -\frac{13.6}{434^2}$eV = -0.000072 eV.

Such an atom would obviously be extremely fragile and be easily ionised (compared to the kinetic energy of the atom at temperature T, kT ~ (1.38×10^{-23} J/K)$\times$(300 K) =0.03 eV)

6. **(a) Find the frequencies of revolution of electrons in n = 1 and n = 3 Bohr orbits. (b) What is the frequency of the photon emitted when an electron in the n = 2 orbit drops to an n = 1 orbit? (c) An electron typically spends about 10^{-8} s in an excited state before it drops to a lower state by emitting a photon. How many revolutions does an electron in an n = 2 Bohr orbit make in 10^{-8} s? (Beiser, pg. 137)**

Solution

(a) Derive the frequency of revolution from scratch: Forom Bohr's postulate of quantisation of angular momentum, $L = (mv)r = nh/2\pi$, the velocity is related to the radius as $v = nh/2mr\pi$. Furthermore, the quantised radius is given in terms of Bohr's radius as $r_n = n^2 r_0$. Hence, $v = h/2\pi mnr_0$.

The frequency of revolution $f = 1/T$ (where T is the period of revolution) can be obtained from $v = 2\pi r/T = 2\pi n^2 r_0 f$. Hence, $f = v/2\pi r = (h/2\pi mnr_0)/2\pi r = h/4\pi^2 mn^3(r_0)^2$.

For n = 1, $f_1 = h/4\pi^2 m(r_0)^2 = 6.56\times10^{15}$ Hz.
For n = 2, $f_2 = h/4\pi^2 m(2)^3(r_0)^2 = 6.56\times10^{15}/8$ Hz $= 8.2\times10^{14}$.

(b) $$\nu = \frac{\Delta E}{h} = \frac{13.6eV}{h}\left(\frac{1}{1^2}-\frac{1}{2^2}\right) = \frac{3c}{4}\frac{13.6eV}{1242eV\cdot nm} = 0.00821\times(3\times10^8 m/s)/10^{-9} m$$
$= 2.463\times10^{15}$ Hz. The frequency is intermediate between f_1 and f_2.

(c) The number of revolutions the electron makes is $N = f_2\Delta t = (8.2\times10^{14})\times10^{8} = 8.2\times10^{22}$ rev.

Tutorial 1

Special Relativity

Conceptual Questions

1) **The speed of light in water is c/n, where n = 1.33 is the index of refraction of water. Thus the speed of light in water is less than c. Why doesn't this violate the speed of light postulate?**

ANS
The constancy of light postulate only applies to light propagating in vacuum. So, a light propagating in a medium which is otherwise could still has a travelling speed other than c.

2) **What is the significance of the negative result of Michelson-Morley experiment?**

ANS
The negative result of the MM experiment contradicts with the prediction of the absolute frame (the Ether frame) of reference, in which light is thought to propagate with a speed c. In the Ether postulate, the speed of light that is observed in other initial reference frame (such as the Earth that is moving at some constant speed relative to the Absolute frame), according to the Galilean transformation, would be different than that of the Ether frame. In other words, the MM negative result provides the first empirical evidence to the constancy of light postulate by Einstein.

3) **Is it possible to have particles that travel at the speed of light?**

ANS
Particle travelling at the speed of light would have an infinite mass, as per $m = \dfrac{m_0}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$. Hence it is physically not possible to supply infinite amount of energy to boost a particle from rest to the speed of light.

4) **What is the twin-paradox? What is the solution to the paradox?**

ANS
Refer to page 43-44, Krane.

PROBLEMS

1) **Space Travel (from Cutnell and Johnson, pg 861,863)**
Alpha Centauri, a nearby star in our galaxy, is 4.3 light-years away. If a rocket leaves for Alpha Centauri and travels at a speed of v = 0.95c relative to the Earth, (i) by how much will the passengers have aged, according to their own clock, when they reach their destination? ii) What is the distance between Earth and Alpha Centauri as measured by the passengers in the rocket? Assume that the Earth and Alpha Centauri are stationary with respect to one another.

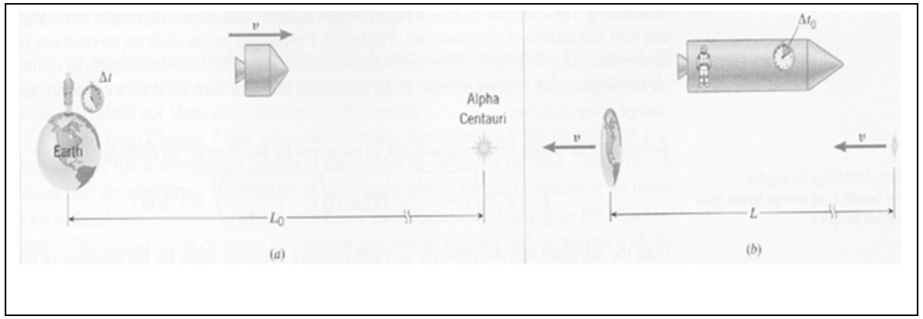


Figure: (a) As measured by an observer on the earth, the distance to Alpha Centauri is L_0, and the time required to make the trip is Δt. (b) According to the passenger on the spacecraft, the earth and Alpha Centauri move with speed v relative to the craft. The passenger measures the distance and time of the trip to be L and Δt_0 respectively, both quantities being less than those in part (a).

Reasoning

The two events in this problem are the departure from Earth and the arrival at Alpha Centauri. At departure, Earth is just outside the spaceship. Upon arrival at the destination, Alpha Centauri is just outside. Therefore, relative to the passengers, the two events occur at the same place - namely, 'just outside the spaceship. Thus, the passengers measure the proper time interval Δt_0 on their clock, and it is this interval that we must find. For a person left behind on Earth, the events occur at different places, so such a person measures the dilated time interval Δt rather than the proper time interval. To find Δt we note that the time to travel a given distance is inversely proportional to the speed. Since it takes 4.3 years to traverse the distance between earth and Alpha Centauri at the speed of light, it would take even longer at the slower speed of $v = 0.95c$. Thus, a person on earth measures the dilated time interval to be Δt = (4.3 years)/0.95 = 4.5 years. This value

SESSI 03/04/ TUTORIAL 1

can be used with the time-dilation equation to find the proper time interval Δt_0.

Solution

Using the time-dilation equation, we find that the proper time interval by which the Passengers judge their own aging is
$\Delta t_0 = \Delta t\sqrt{(1-v^2/c^2)}$ = 4.5 years $\sqrt{(1-0.95^2)}$ = 1.4 years.

Thus, the people aboard the rocket will have aged by only 1.4 years when they reach Alpha Centauri, and not the 4.5 years an earthbound observer has calculated.

Both the earth-based observer and the rocket passenger agree that the relative speed between the rocket and earth is $v = 0.95c$. Thus, the Earth observer determines the distance to Alpha Centauri to be $L_0 = v\Delta t$ = (0.95c)(4.5 years) = 4.3 light-years. On the other hand, a passenger aboard the rocket finds the distance is only L =
$v\Delta t_0$ = (0.95c)(1.4 years) = 1.3 light-years. The passenger, measuring the shorter time, also measures the shorter distance - length contraction.

Problem solving insight

In dealing with time dilation, decide which interval is the proper time interval as follows: (1) Identify the two events that define the interval. (2) Determine the reference frame in which the events occur at the same place; an observer at rest in this frame measures the proper time interval Δt_0.

2) **The Contraction of a Spacecraft (Cutnell, pg 863)**

An astronaut, using a meter stick that is at rest relative to a cylindrical spacecraft, measures the length and diameter of the spacecraft to be 82 and 21 m respectively. The spacecraft moves with a constant speed of $v = 0.95c$ relative to the Earth. What are the dimensions of the spacecraft, as measured by an observer on Earth?

Reasoning

The length of 82 m is a proper length *Lo* since it is measured using a meter stick that is at rest relative to the spacecraft. The length *L* measured by the observer on Earth can be determined from the length-contraction formula. On the other hand, the diameter of the spacecraft is perpendicular to the motion, so the Earth observer does not measure any change in the diameter.

Solution

The length L of the spacecraft, as measured by the observer on Earth, is

$$L = L_0\sqrt{1-\frac{v^2}{c^2}} = 82m\sqrt{1-\frac{(0.95c)^2}{c^2}} = 26 \text{ m}$$

Both the astronaut and the observer on Earth measure the same value for the diameter of the spacecraft: Diameter = 21 m

Problem solving insight The proper length L_0 is always larger than the contracted length L.

3) ***Additional problem 36, Cutnell pg. 879.***
Two spaceship A and B are exploring a new planet. Relative to this planet, spaceship A has a speed of 0.60*c*, and spaceship B has a speed of 0.80*c*. What is the ratio D_A/D_B of the values for the planet's diameter that each spaceship measures in a direction that is parallel to its motion?

Solution

Length contraction occurs along the line of motion, hence both spaceship observe length contraction on the diameter of the planet. The contracted length measures by a moving observer is inversely proportional to the Lorentz factor γ. Hence,

$$\frac{L_A}{L_B} = \frac{\gamma_B}{\gamma_A} = \sqrt{\frac{1-\left(\frac{v_A}{c}\right)^2}{1-\left(\frac{v_B}{c}\right)^2}} = \sqrt{\frac{1-(0.6)^2}{1-(0.8)^2}} = 4/3.$$

4) **The Relativistic Momentum of a High-Speed Electron (Cutnell, pg 865)**
The particle accelerator at Stanford University is three kilometers long and accelerates electrons to a speed of 0.999 999 999 7*c*, which is very nearly equal to the speed of light. Find the magnitude of the relativistic momentum of an electron that emerges from the accelerator, and compare it with the non-relativistic value.

Reasoning and Solution

The magnitude of the electron's relativistic momentum can be obtained from $p = \gamma m_0 v = 1\times10^{-17}$ Ns, where $m_0 = 9.1\times10^{-31}$ kg, $v\gamma = \frac{0.999999997c}{\sqrt{1-\frac{(0.999999997c)^2}{c^2}}} = 1.09989\times10^{13}$ m/s. The relativistic momentum is greater than the non-relativistic momentum by a factor of $\gamma = \frac{1}{\sqrt{1-\frac{(0.999999997c)^2}{c^2}}} = 4\times10^4$.

5) **The Energy Equivalent of a Golf Ball (Cutnell, pg 866)**
A 0.046-kg golf ball is lying on the green. (a) Find the rest energy of the golf ball. (b) If this rest energy were used to operate a 75-W light bulb, for how many years could the bulb stay on?

Reasoning

The rest energy E_0 that is equivalent to the mass m of the golf ball is found from the relation $E_0 = mc^2$. The power used by the bulb is 75 W, which means that it consumes 75 J of energy per second. If the entire rest energy of the ball were available for use, the bulb could stay on for a time equal to the rest energy divided by the power.

Solution

(a) The rest energy of the ball is

$E_0 = mc^2 = (0.046 \text{ kg})(3.0 \times 10^8 \text{ m/s})^2 = 4.1 \times 10^{15}$ J

(b) This rest energy can keep the bulb burning for a time t given by

t = Rest energy/ Power = 4.1×10^{15} J/75 W = 5.5×10^{13} s = 1.7 million years!

6) **A High-Speed electron (Cutnell pg. 867)**
An electron (mass = 9.1×10^{-31} kg) is accelerated to a speed of 0.9995*c* in a particle accelerator. Determine the electron's (a) rest energy, (b) total energy, and (c) kinetic energy in MeV

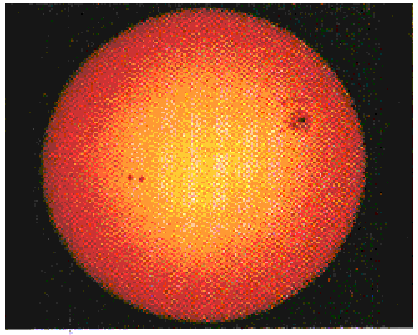
(a) $E_0 = mc^2 = 9.109\times10^{-31} kg \times (3\times10^8)^2 m/s = 8.19\times10^{-14} J = 0.51 MeV$

(b) Total energy of the traveling electron,

$$E = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{0.51MeV}{\sqrt{1-0.995^2}} = 16.2MeV$$

(c) The kinetic energy = $E - E_0$ = 15.7 MeV

7) **The Sun Is Losing Mass (Cutnell, pg 868)**
The sun radiates electromagnetic energy at the rate of 3.92×10^{26} W. (a) What is the change in the sun's mass during each second that it is radiating energy? (b) The mass of the sun is 1.99×10^{30} kg. What fraction of the sun's mass is lost during a human lifetime of 75 years?



Visible light image

Reasoning

Since a W = I J/s the amount of electromagnetic energy radiated during each second is 3.92×10^{26} J. Thus, during each second, the sun's rest energy decreases by this amount. The change ΔE_0 in the sun's rest energy is related to the change Δm in its mass by $\Delta E_0 = \Delta m\ c^2$.

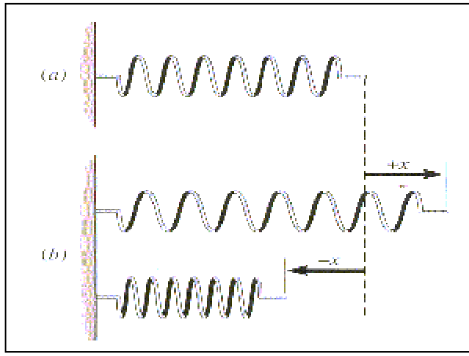
Solution

(a) For each second that the sun radiates energy, the change in its mass is
$\Delta m = \Delta E_0/c^2 = 3.92\times10^{26}\ \text{J}/(3\times10^8\ \text{m/s})^2 = (4.36\times10^9)$ kg.
Over 4 billion kilograms of mass are lost by the sun during each second.

(b) The amount of mass lost by the sun in 75 years is
$\Delta m = (4.36\times10^9)\,\text{kg} \times (3.16\times10^7\ \text{s/year}) \times (75\ \text{years}) = 1\times10^{19}$ kg
Although this is an enormous amount of mass, it represents only a tiny fraction of the sun's total mass:
$\Delta m/m = 1.0\times10^{19}\ \text{kg}/1.99\times10^{30}\ \text{kg} = 5.0\times10^{-12}$

SESSI 03/04/ TUTORIAL 1

8) **Figure below shows the top view of a spring lying on a horizontal table. The spring is initially unstrained. Suppose that the spring is either stretched or compressed by an amount *x* from its unstrained length, as part (b) of the drawing shows. Has the mass of the spring changed? If so, is the change greater, smaller, or the same when the spring is stretched rather than compressed? (Cutnell, pg 868)**



(a) This spring is unstrained. (b) When the spring is either stretched or compressed by an amount *x*, it gains elastic potential energy and hence, mass.

Reasoning and Solution

Whenever a spring is stretched or compressed, its elastic potential energy changes. The elastic potential energy of an ideal spring is equal to $1/2kx^2$ where *k* is the spring constant and *x* is the amount of stretch or compression. Consistent with the theory of special relativity, any change in the total energy of a system, including a change in the elastic potential energy, is equivalent to a change in the mass of the system. Thus, the mass of a strained spring is greater than that of an unstrained spring. Furthermore, since the elastic potential energy depends on x^2, the increase in mass of the spring is the same whether it is compressed or stretched, provided the magnitude of *x* is the same in both cases. The increase is exceedingly small because the factor c^2 is so large.

9) The Speed of a Laser Beam (Cutnell, pg 871)
Figure below shows an intergalactic cruiser approaching a hostile spacecraft. The velocity of the cruiser relative to the spacecraft is v_{CS} = +0.7*c*. Both vehicles are moving at a constant velocity. The cruiser fires a beam of laser light at the enemy. The velocity of the laser beam relative to the cruiser is v_{LC} = +*c*. (a) What is the velocity of the laser beam v_{LS} relative to the renegades aboard the spacecraft? (b) At what velocity do the renegades aboard the spacecraft see the laser beam move away from the cruiser?

Figure 28.12 An intergalactic cruiser, closing in on a hostile spacecraft, fires a beam of laser light.

Reasoning and Solution

(a) Since both vehicles move at a constant velocity, each constitutes an inertial reference frame. According to the speed of light postulate, all observers in inertial reference frames measure the speed of light in a vacuum to be *c*. Thus, the renegades aboard the hostile spacecraft see the laser beam travel toward them at the speed of light, even though the beam is emitted from the cruiser, which itself is moving at seven-tenths the speed of light.

More formally, we can use Lorentz transformation of velocities to calculate v_{LS}. We will take the direction as +ve when a velocity is pointing from left to right. We can take view that the hostile spacecraft is at rest (as the stationary frame, O) while the cruiser is approaching it with velocity v_{CS} = + 0.7c (according to our choice of the sign). In this case, the cruiser is the moving frame, O'. The light beam as seen in the moving frame O' is v_{LC} = +c. We wish to find out what is the speed of this laser beam from O point of view, e.g. what v_{LS} is.

We may like to identify v_{LS}, v_{LC} and v_{CS} with the definitions used in the Lorentz formula: $u_x = \dfrac{u'_x + u}{1 + \dfrac{u'_x u}{c^2}}$. In fact, a little contemplation would allow us to make the identification that, with our choice of frames (that the hostile spacecraft as the stationary frame): $v_{LC} \equiv u_{x'} = +c$; $v_{CS} \equiv u = +0.7c$ and $v_{LS} = u_x$ = the speed of laser beam as seen by the stationary frame O (the quantity we are seeking). Hence, we have

SESSI 03/04/ TUTORIAL 1

$$u_x = \frac{u'_x + u}{1 + \dfrac{u'_x u}{c^2}} \equiv v_{LS} = \frac{v_{LC} + v_{CS}}{1 + \dfrac{v_{LC} v_{CS}}{c^2}} = \frac{(+c)+(+0.7c)}{1 + \dfrac{(+c)(+0.7c)}{c^2}} = \frac{1.7c}{1.7c} = +c$$

, i.e. the laser beam is seen, from the view point of the hostile spacecraft, to be approaching it with a velocity +c (+ve means the velocity is from left to right).

(b) The renegades aboard the spacecraft see the cruiser approach them at a relative velocity of v_{CS} = +0.7c, and they also see the laser beam approach them at a relative velocity Of v_{LS} +c. Both these velocities are measured relative to the same inertial reference frame-namely, that of the spacecraft. Therefore, the renegades aboard the spacecraft see the laser beam move away from the cruiser at a velocity that is the difference between these two velocities, or +*c* - (+0.7*c*) = +0.3*c*. The relativistic velocity-addition formula, is not applicable here because both velocities are measured relative to the same inertial reference frame (the spacecraft's reference frame). The relativistic velocity-addition formula can be used only when the velocities are measured relative to different inertial reference frames.

10) Mass and Energy (Cutnell, pg 873)
The rest energy E_0 and the total energy *E* of three particles, expressed in terms of a basic amount of energy *E'* = 5.98 x 10^{-10} J, are listed in the table below. The speeds of these particles are large, in some cases approaching the speed of light. For each particle, determine its mass and kinetic energy.

Particle	Rest Energy	Total Energy
a	E'	2E'
b	E'	4E'
c	5E'	6E'

Concept Questions and Answers

Given the rest energies specified in the table, what is the ranking (largest first) of the masses of the particles?

Answer

The rest energy is the energy that an object has when its speed is zero. According to special relativity, the rest energy E_0 and the mass *m* are equivalent. Thus, the rest energy is directly proportional to the mass. From the table it can be seen that particles a and b have identical rest energies, so they have identical masses. Particle c has the greatest rest energy, so it has the greatest mass. The ranking of the masses, largest first, is c, then a and b.

What is the ranking (largest first) of the kinetic energies of the particles?

According to special relativity, the kinetic energy is the difference between the total energy E and the rest energy E_0, so KE = $E - E_0$. Therefore, we can examine the table and determine the kinetic energy of each particle in terms of E'. The kinetic energies of particles a, b, and c are, respectively, $2E' - E' = E'$, $4E' - E' = 3E'$, and $6E' - 5E' = E'$. The ranking of the kinetic energies, largest first, is b, then a and c.

Solution

(a) The mass of particle a can be found from its rest energy $E_0 = mc^2$. Since $E_0 = E'$ (see the table), its mass is $m_a = E'/c^2 = 5.98\times10^{-10}$ J/(3x10^{8} m/s)^2 = 6.64×10^{-27} kg

In a similar manner, we find that the masses of particles b and c are

$$m_b = 6.64\times10^{-27} \text{ kg}, \; m_c = 33.2\times10^{-27} \text{ kg},$$

As expected, the ranking is $m_c > m_a = m_b$

(b) The kinetic energy KE of a particle is KE = $E - E_0$. For particle a, its total energy is $E = 2E'$ and its rest energy is $E_0 = E'$, so its kinetic energy is

$$KE_a = 2E' - E' = E' = 5.98\times10^{-10} \text{ J}.$$

The kinetic energies of particles b and c can be determined in a similar fashion:

$$KE_b = 17.9\times10^{-10} \text{ J}, \; KE_c = 5.98\times10^{-10} \text{ J}$$

As anticipated, the ranking is $KE_b > KE_a = KE_c$.

Tutorial 2
Preliminaries, Blackbody radiation, particle nature of waves

Conceptual Questions

1. **Explain in your own words the essential differences between the concept of wave from that of particle (Own question)**

ANS
Particle is finite in size and is localised both in space and time, whereas wave is not.

2. **What is ultraviolet catastrophe? What is the significance of it in the development of modern physics? (Own question)**

ANS
The classical theory explanation of the blackbody radiation by Rayleigh-Jeans fails in the limit $\lambda \to 0$ (or equivalently, when frequency $\to \infty$), i.e. $R(\lambda) \to \infty$ at $\lambda \to 0$. The failure prompted Planck to postulate that the energy of electromagnetic waves is quantised (via $\varepsilon = h\nu$) as opposed to the classical thermodynamics description ($\varepsilon = kT$). With Planck's postulate, radiation now has particle attributes instead of wave.

3. **What is the significance of the Compton wavelength of a given particle? What does the Compton wavelength of a particle mean to light that interacts with it? (Own question)**

ANS
The Compton wavelength (a characteristic constant depend solely on the mass of a given particle) characterises the length scale at which the quantum property (or wave) of a given particle starts to show up. In an interaction that is characterised by a length scale larger than the Compton wavelength, particle behaves classically. For interaction that occurs at a length scale comparable or smaller than the Compton wavelength, the quantum (or, wave) nature starts of the particle begins to take over from classical physics.

In a light-particle interaction, if the wavelength of the light is comparable to the Compton wavelength of the interacting particle, light displays quantum (granular/particle) behaviour rather than as a wave.

4. **How does the Rayleigh scattering could be explained by the Compton scattering relation, $\Delta\lambda = \lambda_c(1-\cos\theta)$? In the γ-ray region, which effect, Compton scattering or Rayleigh scattering is dominant? Explain. (Own question)**

ANS
Rayleigh scattering refers to unresolved peaks of the scattered x-ray, ie. $\Delta\lambda = 0$, which is due to the extremely small Compton wavelength of the whole ATOM, as seen by the x-ray $\lambda_c = h/Mc \to 0$, where M = mass of the atom (instead of $m_e << M$).

5. **Why doesn't the photoelectric effect work for free electron? (Krane, Question 7, pg 79)**

ANS (to be verified)
Essentially, Compton scattering is a two-body process. The free electron within the target sample (e.g. graphite) is a unbounded elementary particle having no internal structure that allows the photons to be `absorbed'. Only elastic scattering is allowed here.

Whereas PE effect is a inelastic scattering, in which the absorption of a whole photon by the atom is allowed due to the composite structure (the structure here refers the system of the orbiting electrons and nuclei hold together via electrostatic potential) of the atom. A whole photon is allowed to get absorbed by the atom in which the potential energy acts like a medium to transfer the energy absorbed from the photon, which is then `delivered' to the bounded electrons (bounded to the atoms) that are then `ejected' out as photoelectrons.

6. **How is the wave nature of light unable to account for the observed properties of the photoelectric effect? (Krane, Question 5, pg 79)**

ANS
See lecture notes

7. **In the photoelectric effect, why do some electrons have kinetic energies smaller than K_{max}? (Krane, Question 6, pg 79)**

ANS
By referring to $K_{max} = h\nu - \phi$, K_{max} corresponds to those electrons knocked loose from the surface by the incident photon whenever $h\nu > \phi$. Those below the surface required an energy greater than ϕ and so come off with less kinetic energy.

Problems

1. **The diameter of an atomic nucleus is about 10×10^{-15} m. Suppose you wanted to study the diffraction of photons by nuclei. What energy of photons would you choose? Why? (Krane, Question 1, pg 79)**

ANS
Diffraction of light by the nucleus occurs only when the wavelength of the photon is smaller or of the order of the size of the nucleus, $\lambda \sim D$ (D = diameter of the nucleus). Hence, the minimum energy of the photon would be $E = hc/\lambda \sim hc/D \sim 120$ MeV.

2. **How does the total intensity of thermal radiation vary when the temperature of an object is doubled? (Krane, Question 4, pg 79)**

ANS
Intensity of thermal radiation $I \propto T^4$. Hence, when T is double, ie. $T \to 2T$, $I \to I'(2)^4 = 16I$, i.e. the total intensity of thermal radiation increase by 16 times.

3. **Photons from a Light Bulb (Cutnell, pg884)**
In converting electrical energy into light energy, a sixty-watt incandescent light bulb operates at about 2.1% efficiency. Assuming that all the light is green light (vacuum wavelength 555 nm), determine the number of photons per second given off by the bulb.

Reasoning
The number of photons emitted per second can be found by dividing the amount of light energy emitted per second by the energy E of one photon. The energy of a single photon is $E = hf$. The frequency of the photon is related to its wavelength λ by $\nu = c/\lambda$.

Solution
At an efficiency of 2. 1%, the light energy emitted per second by a sixty-watt bulb is (0.021)(60.0 J/s)=1.3 J/s. The energy of a single photon is

$$E = hc/\lambda$$
$$= (6.63\times10^{-34}\text{Js})(3\times10^{8}\text{ m/s})/555\times10^{-9}\text{ nm} = 3.58\times10^{-19}\text{ J}$$

Therefore,
Number of photons emitted per second =
1.3 J/s/ 3.58×10^{-19} J/photon = 3.6×10^{18} photon per second

4. **Ultraviolet light of wavelength 350 nm and intensity 1.00 W/m^2 is directed at a potassium surface. (a) Find the maximum KE of the photoelectrons. (b) If 0.50 percent of the incident photons produce photoelectrons, how many are emitted per second if the potassium surface has an area of 1.00 cm^2? (Beiser, pg. 63)**

(a) The energy of the photons is, $E_P = hc/\lambda$ = 3.5eV. The work function of potassium is 2.2 eV. So,
KE = $h\nu - \phi$ = 3.5 eV - 2.2 eV = 5.68×10^{-19} J
(b) The photon energy in joules is 5.68×10^{-19} J. Hence

the number of photons that reach the surface per second is

$n_p = (E/t)/E_p = (E/A)(A)/E_p$
$= (1.00\ W/m^2)(1.00\times10^{-4}\ m^2)/5.68\times10^{-19}\ J$
$= 1.76\times10^{14}$ photons/s

The rate at which photoelectrons are emitted is therefore

$n_e = (0.0050)n_p = 8.8\times10^{11}$ photoelectrons/s

5. **(Krane, pg. 62)**
(a) At what wavelength does a room-temperature (T = 20°C) object emit the maximum thermal radiation?
(b) To what temperature must we heat it until its peak thermal radiation is in the red region of the spectrum?
(c) How many times as much thermal radiation does it emit at the higher temperature?

ANS

(a) Converting to absolute temperature, T = 293 K, and from Wien's displacement law,

$\lambda_{max}T = 2.898\times10^{-3}$ m·K

$\lambda_{max} = 2.898\times10^{-3}$ m·K/ 293K = 9.89 μm

(b) Taking the wavelength of red light to be =650 nm, we again use Wien's displacement law to find T:

$T = 2.898\times10^{-3}$ m·K/650×10^{-9} m = 4460 K

(c) Since the total intensity of radiation is proportional to T^4, the ratio of the total thermal emissions will be

$$\frac{T_2^4}{T_1^4} = \frac{4460^4}{293^4} = 5.37\times10^4$$

Be sure to notice the use of absolute (Kelvin) temperatures.

6. **The work function for tungsten metal is 4.53 eV. (a) What is the cut-off wavelength for tungsten? (b) What is the maximum kinetic energy of the electrons when radiation of wavelength 200.0 nm is used? (c) What is the stopping potential in this case? (Krane, pg. 69)**

ANS

(a) The cut-off frequency is given by

$\lambda_c = \frac{hc}{\phi} = \frac{1240\text{eV}\cdot\text{nm}}{200\text{nm}} = 274\text{nm}$, in the uv region

(b) At the shorter wavelength,

$$K_{max} = h\frac{c}{\lambda} - \phi = \frac{1240eV\cdot nm}{200nm} - 4.52eV = 1.68eV$$

(c) The stopping potential is just the voltage corresponding to K_{max}:

$$V_s = K_{max}/e = \frac{1.68eV}{e} = 1.68\text{ V}$$

7. **X-rays of wavelength 10.0 pm (1 pm = 10^{-12} m) are scattered from a target. (a) Find the wavelength of the x-rays scattered through 45°. (b) Find the maximum wavelength present in the scattered x-rays. (c) Find the maximum kinetic energy of the recoil electrons. (Beiser, pg. 75)**

Solution

(a) The Compton shift is given by

$\Delta\lambda = \lambda' - \lambda = \lambda_c(1-\cos\varphi)$, and so

$\lambda' = \lambda + \lambda_c(1-\cos 45^o) = 10.0\,pm + 0.293\lambda_c = 10.7$ pm

(b) $\Delta\lambda$ is a maximum when $1-\cos\varphi$ = 2, in which case,

$\Delta\lambda = \lambda + 2\lambda_c$ = 10.0 pm + 4.9 pm = 14.9 pm

(C) The maximum recoil kinetic energy is equal to the difference between the energies of the incident and scattered photons, so

$KE_{max} = h(\nu - \nu') = hc(\frac{1}{\lambda} - \frac{1}{\lambda'}) = 40.8$ eV

Tutorial 3
Matter waves, The Uncertainty Principle and Schrodinger Equation

Conceptual Questions

1. **What difficulties does the uncertainty principle cause in trying to pick up an electron with a pair of forceps? (Krane, Question 4, pg. 110)**

ANS
When the electron is picked up by the forceps, the position of the electron is ``localised' (or fixed), i.e. $\Delta x = 0$. Uncertainty principle will then render the momentum to be highly uncertainty. In effect, a large $\Delta p$ means the electron is ``shaking'' furiously against the forceps' tips that tries to hold the electron ``tightly''.

2. **Is it possible for v_{phase} to be greater than c? Can v_{group} be greater than c? (Krane, Question 12, pg. 111)**

ANS
Is it possible for v_{phase} to be greater than c but not so for v_{group}. This is because the group velocity is postulated to be associated with the physical particle. Since a physical particle (with mass) can never move greater than the speed of light (according to SR), so is v_{group}.

3. **Why is it important for a wave function to be normalised? Is an unrenomalised wave function a solution to the Schrodinger equation? (Krane, Question 2, pg. 143)**

ANS
Due to the probabilistic interpretation of the wave function, the particle must be found within the region in which it exists. Statistically speaking, this means that the probability to find the particle in the region where it exists must be 1. Hence, the square of the wave function, which is interpreted as the probably density to find the particle at an intervals in space, integrated over all space must be one in accordance with this interpretation. Should the wave function is not normalised, that would lead to the consequence that the probability to find the particle associated with the wave function in the integrated region where the particle is suppose to be in is not one, which violates the probabilistic interpretation of the wave function.

A wave function that is not normalised is also a solution to the Schrodinger equation. However, in order for the wave function to be interpreted in accordance to the probabilistic interpretation (so that the wave function could has a physical meaning) it must be normalised.

4. How would the solution to the infinite potential well be different if the width of the well is extended from L to $L + x_0$, where x_0 is a nonzero value of x? How would the energies be different? **(Krane, Question 7, pg. 143)**

ANS
The form of the solutions to the wave functions inside the well remains the same. They still exist as stationary states described by the same sinusoidal functions, except that in the expressions of the observables, such as the quantised energies and the expectation values, the parameter L be replaced by $L + x_0$. For the quantised energies, they will be modified as per

$$E_n = \frac{n^2\pi^2\hbar^2}{2mL^2} \rightarrow \frac{n^2\pi^2\hbar^2}{2m(L+x_0)^2}.$$

5. The infinite quantum well, with width L, as defined in the lecture notes is located between $x = 0$ and $x = L$. If we define the infinite quantum well to be located between $x = -L/2$ to $x = +L/2$ instead (the width remains the same, L), find the solution to the time-independent Schrodinger equation. Would you expect the normalised constant to the wave function and the energies be different than that discussed in the notes? Explain. **(Brehm and Mullin, pg. 234 - 237)**

ANS
By applying the boundary conditions that the solution must vanish at both ends, i.e. $\psi(x=-L/2)=\psi(x=L/2)=0$, the solution takes the form

$$\psi_n(x) = \begin{cases} \sqrt{\frac{2}{L}}\cos\frac{n\pi x}{L}\ (odd\ \ n) \\ \sqrt{\frac{2}{L}}\sin\frac{n\pi x}{L}\ (even\ n) \end{cases} \quad \text{for} \quad -\frac{L}{2} \le x \frac{L}{2}$$

This question is tantamount to re-analyse the same physical system in a shifted coordinates, $x \rightarrow x - L/2$. The normalisation and energies shall remain unchanged under the shift of coordinate system $x \rightarrow x - L/2$. Both of these quantities depends only on the width of the well but not on the coordinate system used.

Problems

1. **Find the de Broglie wave lengths of (a) a 46-g ball with a velocity of 30 m/s, and (b) an electron with a velocity of 10^7 m/s (Beiser, pg. 92)**

   ANS

   (a) Since $v << c$, we can let $m = m_o$. Hence

   $$\lambda = h/mv = 6.63\times10^{-34}\ \text{Js}/(0.046\ \text{kg})(30\ \text{m/s}) = 4.8\times10^{-34}\ \text{m}$$

   The wavelength of the golf ball is so small compared with its dimensions that we would not expect to find any wave aspects in its behaviour.

   (b) Again $v << c$, so with $m = m_o = 9.1\times10^{-31}$ kg, we have

   $$\lambda = h/mv = 6.63\times10^{-34}\ \text{Js}/(9.1\times10^{-31}\ \text{kg})(10^7\ \text{m/s}) = 7.3\times10^{-11}\ \text{m}$$

   The dimensions of atoms are comparable with this figure - the radius of the hydrogen atom, for instance, is 5.3×10^{-11} m. It is therefore not surprising that the wave character of moving electrons is the key to understanding atomic structure and behaviour.

2. **The de Broglie Wavelength (Cutnell, pg. 897)**
   An electron and a proton have the same kinetic energy and are moving at non-relativistic speeds. Determine the ratio of the de Broglie wavelength of the electron to that of the proton.

   ANS

   Using the de Broglie wavelength relation $p = h/\lambda$ and the fact that the magnitude of the momentum is related to the kinetic energy by $p = (2mK)^{1/2}$, we have

   $$\lambda = h/p = h/(2mK)^{1/2}$$

   Applying this result to the electron and the proton gives

   $$\lambda_e/\lambda_p = (2m_pK)^{1/2}/(2m_eK)^{1/2} = (m_p/m_e)^{1/2} = (1.67\times10^{-27}\ \text{kg}/9.11\times10^{-31}\ \text{kg})^{1/2} = 42.8$$

   As expected, the wavelength for the electron is greater than that for the proton.

SESSI 03/04/ TUTORIAL 3

3. **Find the kinetic energy of a proton whose de Broglie wavelength is 1.000 fm = 1.000×10^{-15} m, which is roughly the proton diameter (Beiser, pg. 92)**

   ANS

   A relativistic calculation is needed unless pc for the proton is much smaller than the proton rest mass of E_o = 0.938 GeV.

   So we have to first compare the energy of the de Broglie wave to E_o:

   $E = pc = \dfrac{hc}{\lambda} = \dfrac{1242 eV\cdot nm}{10^{-6} nm} = 1.24$ GeV, c.f. E_o = 0.938 GeV. Since the energy of the de Broglie wave is larger than the rest mass of the proton, we have to use the relativistic kinetic energy instead of the classical $K = p^2/2m$ expression.

   The total energy of the proton is

   $E = \sqrt{E_0^2 + (pc)^2} = \sqrt{(0.938\,GeV)^2 + (1.24\,GeV)^2} = 1.555$ GeV.

   The corresponding kinetic energy is

   KE = $E - E_o$ = (1.555 - 0.938) GeV = 0.617 GeV = 617 MeV

4. **An electron is in a box 0.10 nm across, which is the order of atomic dimensions. Find its permitted energies. (Beiser, pg. 106)**

   ANS

   Here $m = 9.1\times10^{-31}$ kg and $L = 1\times10^{-10}$ m, so that the permitted electron energies are

   $E_n = \dfrac{n^2\pi^2\hbar^2}{2mL^2} = 6.0\times10^{-18} n^2$ J = $38n^2$ eV.

   The minimal energy the electron can have is 38 eV, corresponding to n = 1. The sequence of energy levels continues with E_2 = 152 eV, E_3 = 342 eV, E_4 = 608 eV and so on. If such a box existed, the quantisation of a trapped electron's energy would be a prominent feature of the system. (And indeed energy quantisation is prominent in the case of an atomic electron.)

5. **A 10-g marble is in a box 10 cm across. Find its permitted energies.**

ANS

With m = 1.0×10^{-2} kg and L = 1.0×10^{-1} m,

$$E_n = \frac{n^2\pi^2\hbar^2}{2mL^2} = 5.5\times10^{-64}n^2 \text{ J}$$

The minimum energy the marble can have is 5.5×10^{-64} J, corresponding to n = 1. A marble with this kinetic energy has a speed of only 3.3×10^{-31} m/s and therefore cannot be experimentally distinguished from a stationary marble. A reasonable speed a marble might have is, say, 1/3 m/s - which corresponds to the energy level of quantum number n = 10^{30}! The permissible energy levels are so very close together, then, that there is no way to determine whether the marble can take on only those energies predicted by $E_n = \frac{n^2\pi^2\hbar^2}{2mL^2}$ or any energy whatever. Hence in the domain of everyday experience, quantum effects are imperceptible, which accounts for the success of Newtonian mechanics in this domain.

6. **A hydrogen atom is 5.3×10^{-11} m in radius. Use the uncertainty principle to estimate the minimum energy an electron can have in this atom. (Beiser, pg 114)**

ANS

Here we find that with Δx = 5.3×10^{-11} m.

$\Delta p \geq \frac{\hbar}{2\pi}$ = 9.9×10^{-25} Ns.

An electron whose momentum is of this order of magnitude behaves like a classical particle, an its kinetic energy is $K = p^2/2m \geq (9.9\times10^{-25}\text{ Ns})^2/2\times9.110^{-31}$ kg = 5.4×10^{-19} J which is 3.4 eV. The kinetic energy of an electron in the lowest energy level of a hydrogen atom actually 13.6 eV.

7. **A measurement established the position of a proton with an accrurracy of $\pm1.00\times10^{-11}$m. Find the uncertainty in the proton's position 1.00 s later. Assume $v << c$. (Beiser, pg. 111)**

ANS

Let us call the uncertainty in the proton's position Δx_0 at the time t = 0. The uncertainty in its momentum at this time is therefore

$\Delta p \geq \frac{\hbar}{2\Delta x_0}$. Since $v << c$, the momentum uncertainty is $\Delta p \geq \Delta(mv) = m_0\Delta v$ and the uncertainty in the proton's velocity is $\Delta v \geq \frac{\Delta p}{m_0} \geq \frac{\hbar}{2m_0\Delta x_0}$. The distance x of the proton covers in the time t cannot be known more accurately than

$\Delta x \geq t\Delta v \geq \frac{\hbar t}{2m_0\Delta x_0}$. Hence Δx is inversely proportional to Δx_0: the more we know about the proton's position at t = 0 the les we know about its later position at t. The value of Δx at t = 1.00 s is

$$\Delta x \geq \frac{(1.054\times10^{-34}Js)(1.00s)}{2(1.672\times10^{-27}kg)(1.00\times10^{-11}m)} = 3.15\times10^3 \text{ m}$$

This is 3.15 km! What has happened is that the original wave group has spread out to a much wider one because the phase velocities of the component wave vary with wave number and a large range of wave numbers must have been present to produce the narrow original wave

8. **Broadening of spectral lines due to uncertainty principle: An excited atom gives up it excess energy by emitting a photon of characteristic frequency. The average period that elapses between the excitation of an atom and the time is radiates is 1.0×10^{-8} s. Find the inherent uncertainty in the frequency of the photon. (Beiser, pg. 115)**

ANS

The photon energy is uncertain by the amount

$$\Delta E \geq \frac{\hbar}{2\Delta t} = \frac{1.054\times10^{-34}Js}{2(1.0\times10^{-8}s)} = 5.3\times10^{-27} \text{ J}$$

The corresponding uncertainty in the frequency of light is $\Delta\nu = \frac{\Delta E}{h} \geq 8\times10^6$ Hz.

This is the irreducible limit to the accuracy with which we can determine the frequency of the radiation emitted by an atom. As a result, the radiation from a group of excited atoms does not appear with the precise frequency ν. For a photon whose frequency is, say, 5.0×10^{14} Hz, $\frac{\Delta\nu}{\nu} = 1.6\times10^{-8}$. In practice, other phenomena such as the doppler effect contribute more ian this to the broadening of spectral lines.

9. **If we assume that in the ground of the hydrogen the position of the electron along the Bohr orbit is not known and not knowable, then the uncertainty in the position is about $\Delta x \approx 2r_0 = 10^{-10}$ m, (a) What is the magnitude of the momentum of the electron at the ground state? (b) What is the corresponding quantum uncertainty in the momentum? (Ohanian, pg. 152)**

ANS

(a) Angular momentum, $|L| \equiv |p|r = n\hbar$. Hence, in the ground state, $|p| = \hbar/r_0 = 2.1\times10^{-24}$ Ns

(b) $\Delta p_x \geq \dfrac{\hbar}{2\Delta x} = \dfrac{\hbar}{2(2r_0)} = 5.3\times10^{-25}$ Ns.

10. **Show that $\psi = A\exp(kx-\omega t)$ is solution to the time-independent Schrodinger equation.**

ANS

Taking the partial derivative of ψ wrp to x,

$$\frac{\partial^2}{\partial x^2}\psi = (ik)^2 A\exp(kx-\omega t) = -k^2\psi . \qquad (1)$$

The total energy of the particle is

$E = K + U = p^2/2m + U = \dfrac{\hbar^2 k^2}{2m} + U$

$\Rightarrow k^2 = \dfrac{2m(E-U)}{\hbar^2}$.

Hence, Eq. (1) becomes $\dfrac{\partial^2}{\partial x^2}\psi = -\dfrac{2m(E-U)}{\hbar^2}\psi$. This shows that $\psi = A\exp(kx-\omega t)$ is the solution to the Schrodinger equation.

11. **Consider a quantum particle trapped in an infinite well with width *a*. Assuming that the particle is in the ground state, calculate the expectation values of its position <*x*> and <*x*^{2}>. Obtain the uncertainty in its position, Δ*x*, given**

by standard statistical definition, Δ*x* = <*x*^{2}> - <*x*>^{2}. (Brehm and Mullin, pg.265)

ANS

The solution of the ground state wave function for a particle in an infinite box is $\psi_n(x) = \sqrt{\dfrac{2}{a}}\sin\dfrac{\pi x}{a}$.

$$\langle x\rangle = \int_{-\infty}^{\infty}\psi x\psi dx = \frac{2}{a}\int_0^a x\sin^2\frac{\pi x}{a}dx = \frac{2a}{\pi^2}\int_0^\pi y\sin^2 y dy$$

$$\int_0^\pi y\sin^2 y dy = \frac{y^2}{4} - \frac{y\sin 2y}{4} - \frac{\cos 2y}{8}\Bigg|_0^\pi = \frac{\pi^2}{4}$$

$\therefore \langle x\rangle = \dfrac{a}{2}$. Likewise,

$$\langle x^2\rangle = \int_{-\infty}^{\infty}\psi x^2\psi dx = \frac{2}{a}\int_0^a x^2\sin^2\frac{\pi x}{a}dx = \frac{2a^2}{\pi^3}\int_0^\pi y^2\sin^2 y dy$$

$$\int_0^\pi y^2\sin^2 y dy = \frac{x^3}{6} - \frac{x\cos 2x}{4} + \frac{(1-2x^2)\sin 2x}{8}\Bigg|_0^\pi = \frac{\pi^3}{6} - \frac{\pi}{4}$$

$$\therefore \langle x^2\rangle = \int_{-\infty}^{\infty}\psi x^2\psi dx = a^2\left(\frac{1}{3} - \frac{1}{2\pi^2}\right)$$

Δx = <*x*^{2}> - <*x*>^{2} = $a^2\left(\dfrac{1}{3} - \dfrac{1}{2\pi^2}\right) - \dfrac{a^2}{4} = a^2\left(\dfrac{1}{12} - \dfrac{1}{2\pi^2}\right)$

Tutorial 4
Atomic model

Conceptual Questions

1. **What is the ONE essential difference between the Rutherford model and the Bohr's model? (Own question)**

ANS
Rutherford's model is a classical model, in which EM wave will be radiated rendering the atom to collapse. Whereas the Bohr's model is a semi-classical model in which quantisation of the atomic orbit happens.

2. **Conventional spectrometers with glass components do not transmit ultraviolet light ($\lambda \lesssim$ 380 nm). Explain why non of the lines in the Lyman series could be observed with a conventional spectrometer. (Taylor and Zafiratos, pg. 128)**

ANS
For Lyman series, n_f = 1. According to $\frac{1}{\lambda} = Z^2 R_\infty \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$, the wavelength corresponding to n_i = 2 in the Lyman series is predicted to be $\lambda = \frac{4}{3R_\infty} = \frac{4}{3(109{,}737\text{cm}^{-1})}$=121.5 nm. Similarly, for n_i = 3, one finds that λ=102 nm, and inspection of $\frac{1}{\lambda} = Z^2 R_\infty \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$ shows that the larger we take n, the smaller the corresponding wavelength. Therefore, all lines in the Lyman series lie well into the ultraviolet and are unobservable with a conventional spectrometer.

3. **Does the Thompson model fail at large scattering angles or at the small scattering angle? Why? (Krane, Questions 1, pg. 173)**

ANS
Thompson model fails at large angle (but is consistent with scattering experiments at small angle). Thompson model predicts that the average scattered angle is

given by $\theta_{ave} = \sqrt{N} \cdot \frac{\pi}{4} \cdot z \left(\frac{Ze^2}{4\pi\varepsilon_0 R^3} \right) R^2 \cdot \left(\frac{1}{mv^2} \right)$. One can estimate the order of θ_{ave} in an atomic scattering experiment: R ~ 0.1 nm (a typical atomic radius), N ~ 10^4 (no. of collisions in the target metal foil), kinetic energy of the alpha particle, mv^2 ~ 10 MeV, z = 2 (charge of alpha particle); Z ~ 79 for gold. Putting in all figures, one expects that alpha particle is scattered only for a small scattering angle of θ_{ave} ~ 1°. However, in the experiment, alpha particles are observed to be scattered at angle in excess of 90°. This falsifies Thompson model at large angle.

4. **In which Bohr orbit does the electron have the largest velocity? Are we justified in treating the electron non-relativistically? (Krane, Questions 6. pg. 174)**

ANS
The velocity in an orbit n is given by $v = h/2\pi mnr_0$, which means that the velocity is inversely proportional to the n number. Hence the largest velocity corresponds to the n = 1 state,
$v(n=1)/c = h/2c\pi mr_0$
$= 6.63\times10^{-34}/2\pi(9.1\times10^{-31})(0.53\times10^{-10})/c$
$= 0.007.$
Hence, nonrelativistic treatment is justified.

5. **How does a Bohr atom violate the $\Delta x \Delta p \geq \frac{\hbar}{2}$ uncertainty relation? (Krane, Question 11, pg. 174)**

ANS
The uncertainty relation in the radial direction of an electron in a Bohr orbit is $\Delta r \Delta p_r \geq \frac{\hbar}{2}$. However, in the Bohr model, the Bohr orbits are assumed to be precisely known $(= r_n = n^2 r_0)$ for a given n. This tantamount to $\Delta r = 0$, which must render the momentum in the radial direction to become infinite. But in the Bohr atom the electron does not have such radial motion caused by this uncertainty effect. So in this

sense, the discrete Bohr orbit violates the uncertainty relation $\Delta x \Delta p \geq \frac{\hbar}{2}$.

Problem

1. **Hydrogen atoms in states of high quantum number have been created in the laboratory and observed in space. (a) Find the quantum number of the Bohr orbit in a hydrogen atom whose radius is 0.0199 mm. (b) What is the energy of a hydrogen atom in this case? (Beiser, pg. 133)0**

ANS

(a) From $r_n = n^2 r_0$, we have $n = \sqrt{\frac{r_n}{r_0}} = \sqrt{\frac{0.0100\times10^{-3}}{5.3\times10^{-11}}} = 434$

(b) From $E_n = -\frac{13.6}{n^2}$eV, we have $E_n = -\frac{13.6}{434^2}$eV = -0.000072 eV. Such an atom would obviously be extremely fragile and be easily ionised (compared to the kinetic energy of the atom at temperature T, kT ~ (1.38×10^{-23}J/K)×(300 K) =0.03 eV)

2. **(a) Find the frequencies of revolution of electrons in *n* = 1 and *n* = 3 Bohr orbits. (b) What is the frequency of the photon emitted when an electron in the *n* = 2 orbit drops to an *n* = 1 orbit? (c) An electron typically spends about 10^{-8} s in an excited state before it drops to a lower state by emitting a photon. How many revolutions does an electron in an *n* = 2 Bohr orbit make in 10^{-8} s? (Beiser, pg. 137)**

ANS

(a) Derive the frequency of revolution from scratch: Forom Bohr's postulate of quantisation of angular momentum,

$L = (mv)r = nh/2\pi$, the velocity is related to the radius as $v = nh/2mr\pi$. Furthermore, the quantised radius is given in terms of Bohr's radius as $r_n = n^2 r_0$. Hence, $v = h/2\pi mnr_0$.

The frequency of revolutionm $f = 1/T$ (where T is the period of revolution) can be obtained from $v = 2\pi r/T = 2\pi n^2 r_0 f$. Hence, $f = v/2\pi r = (h/2\pi mnr_0)/2\pi r = h/4\pi^2 mn^3 (r_0)^2$.

For n = 1, $f_1 = h/4\pi^2 m(r_0)^2 = 6.56\times10^{15}$ Hz.
For n = 2, $f_2 = h/4\pi^2 m(2)^3(r_0)^2 = 6.56\times10^{15}/8$ Hz = 8.2×10^{14}.

(b)
$v = \frac{\Delta E}{h} = \frac{13.6eV}{h}\left(\frac{1}{1^2}-\frac{1}{2^2}\right) = \frac{3c}{4}\frac{13.6eV}{1242eV\cdot nm} = 0.00821\times(3\times10^8 m/s)/10^{-9}m =$ 2.463×10^{15}s. The frequency is intermediate between f_1 and f_2.

(c) The number of revolutions the electron makes is $N = f_2 \Delta t = (8.2\times10^{14})\times10^8 = 8.2\times10^{22}$ rev.

3. **Consider a positronium atom consisting of a positron and electron revolving about their common centre of mass, which lies halfway between them. (a) If such a system were a normal atom, how would its emission spectrum compared to that of hydrogen atom? (b) What would be the electron-positron separation, *r*, in the ground state orbit of positronium? (Eisberg, pg. 106)**

ANS
(a) The emission spectrum is described by the general form of $\frac{1}{\lambda} = Z^2 R\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$, where $R \equiv \frac{\mu e^4}{4c\pi\hbar^3(4\pi\varepsilon_0)^2}$, the reduced mass of the positronium is $\mu = \frac{mM}{M+m} = \frac{m_e \cdot m_e}{m_e + m_e} = \frac{m_e}{2}$. Compared to the emission spectrum of hydrogen, which is given by $\frac{1}{\lambda_H} = Z^2 R_\infty\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$. Hence we have $\frac{\lambda_{positronium}}{\lambda_H} = \frac{R_\infty}{R_{positronium}} = \frac{m_e}{\mu_{positronium}} = 2$. That is, the spacing between the spectral lines in the positronium is doubled as compared to the corresponding spacing in that of the hydrogen.

(b) The ground state radius is

$$r_0\left(positronium\right)=\frac{4\pi\hbar^2\varepsilon_0}{Ze^2\mu}=2\left(\frac{4\pi\hbar^2\varepsilon_0}{e^2m_e}\right)=2r_0$$

4. **Ordinary hydrogen atom contains about one part in 6000 of deuterium, or heavy hydrogen. This is a hydrogen atom whose nucleus contains a proton and a neutron. How does the doubled nuclear mass affect the atomic spectrum? (Eisberg, pg 102)**

ANS

The reduced mass is $\mu=\frac{mM}{M+m}=\frac{m_e\cdot 2M}{2M+m}$. The numerical ratio $\frac{\lambda_d}{\lambda_H}=\frac{R_\infty}{R_d}=\frac{m_e}{\mu_d}=m_e\frac{2M+m_e}{m_e\cdot 2M}=\frac{2M+m_e}{2M}\approx m_e$ is the same for both limits $2M >> m$ (for deuterium) or $M >> m$ (for hydrogen). Hence the double nuclear mass does not affect the atomic spectrum in a significant sense. To be more quantitative, the ratio $\frac{m_e}{\mu_d}=\frac{2M+m_e}{2M}=\frac{2(934\text{MeV})+(0.51\text{MeV})}{2(934\text{MeV})}=1.0003$. The nuclear mass to the atomic spectrum only cases a 0.03% shift to the wavelengths of the spectral lines.

5. A muonic atom contains a nucleus of charge e and a negative muon, μ^-, moving about it. The μ^- is an elementary particle with charge $-e$ and a mass 207 times as large as an electron. (a) Calculate the biding energy of the muonic atom. (b) What is the wavelength of the first line in the Lyman series for such an atom? (Eisberg, pg. 106)

ANS

(a) $\mu=\frac{mM}{M+m}=\frac{m_\mu\cdot m_\mu}{m_\mu+m_\mu}=\frac{m_\mu}{2}=\frac{207}{2}m_e=103.5m_e$. The energy levels are given by

$E_n^{muon}=\frac{\mu e^4}{(4\pi\varepsilon_0)^2 2\hbar^2}\frac{1}{n^2}=103.5E_n=103.5\times\frac{-13.6eV}{n^2}$. Hence the biding energy is $\Delta E=E_\infty-E_{n=1}=0-(-1407.6)eV=$ 1407.6 eV.

(b) $\frac{1}{\lambda}=\frac{E_i^{muon}-E_f^{muon}}{hc}=103.5\frac{m_e e^4}{(4\pi\varepsilon_0)^2 2\hbar^2 hc}\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)=103.5R_\infty\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$,

where $R_\infty\equiv\frac{m_e e^4}{4c\pi\hbar^3(4\pi\varepsilon_0)^2}=109{,}737\text{cm}^{-1}$. The first line in Lyman series correspond to $n_i = 2$, $n_f = 1$. Hence this wavelength is given by

$\frac{1}{\lambda}=103.5R_\infty\left(\frac{1}{1^2}-\frac{1}{2^2}\right)=\frac{3\times 103.5}{4}R_\infty=8518334.625\,\text{cm}^{-1}$, or

$\lambda=117.4\text{ nm}$