ZCT 104

MODERN PHYSICS

ACADEMIC SESSION 2005/06
(SECOND SEMESTER)

TOTORIAL PROBLEM SETS

TUTORIAL 1
SPECIAL RELATIVITY
(BASED ON UNDERSTANDING PHYSICS, CUMMINGS et al, John Wiley and Sons)

SEC. 38-2 ORIGINS OF SPECIAL RELATIVITY
1. Chasing Light.

What fraction of the speed of light does each of the following speeds v represent? That is, what is the value of the ratio v/c? (a) A typical rate of continental drift, 3 cm/y. (b) A high way speed limit of 100 km/h. (c) A supersonic plane flying at Mach 2.5 = 3100 km/h. (d) The Earth in orbit around the Sun at 30 km/s. (e) What conclusion(s) do you draw about the need for special relativity to describe and analyze most everyday phenomena? (Note: Some everyday phenomena can be derived from relativity. For example, magnetism can be described as arising from electrostatics plus special relativity applied to the slow-moving charges in wires.) ($v/c = 3.16\times10^{-18}.$; $v/c = 9.26\times10^{-8}.$; $v/c = 2.87\times10^{-6}.$; $v/c = 10^{-4}.$)

SEC. 38-3 . THE PRINCIPLE OF RELATIVITY
3. Examples of the Principles of Relativity

Identical experiments are carried out (1) in a high-speed train moving at constant speed along a horizontal track with the shades drawn and (2) in a closed freight container on the platform as the train passes. Copy the following list and mark with a “yes” quantities that will necessarily be the same as measured in the two frames. Mark with a “no” quantities that are not necessarily the same as measured in the two frames. (a) The time it takes for light to travel one meter in a vacuum; (b) the kinetic energy of an electron accelerated from rest through a voltage difference of one million volts; (c) the time for half the number of radioactive particles at rest to decay; (d) the mass of a proton; (e) the structure of DNA for an amoeba; (f) Newton’s Second Law of Motion: $F = ma$; (g) the value of the downward acceleration of gravity g.

SEC. 38-4. LOCATING EVENTS WITH AN INTELLIGENT OBSERVER
6. Eruption from the Sun

You see a sudden eruption on the surface of the Sun. From solar theory you predict that the eruption emitted a pulse of particles that is moving toward the Earth at one- eighth the speed of light. How long do you have to seek shelter from the radiation that will be emitted when the particle pulse hits the Earth? Take the light-travel time from the Sun to the Earth to be 8 minutes. (56 minutes)

SEC. 38-5 LABORATORY AND ROCKET LATTICEWORKS OF CLOCKS
7. Synchronizing a Clock

In a vast latticework of meter sticks and clocks, you stand next to a lattice clock whose coordinates are x = 8 km, y = 40 km, z = 44 km. When you receive the synchronizing flash, to what time do you quickly set your clock? (2×10^{-4} second)

10. Where and When?

Two firecrackers explode at the same place in the laboratory and are separated by a time of 12 years. (a) What is the spatial distance between these two events in a rocket in which the events are separated in time by 13 years? (b) What is the relative speed of the rocket and laboratory frames? Express your answer as a fraction of the speed of light. (4.7×10^{16} meters.; a little more than one-third the speed of light)

13. Fast-Moving Muons

The half-life of stationary muons is measured to be 1.6 microseconds. Half of any initial number of stationary muons decays in one half-life. Cosmic rays colliding with atoms in the upper atmosphere of the Earth create muons, some of which move downward toward the Earth’s surface. The mean lifetime of high-speed muons in one such burst is measured to be 16 microseconds. (a) Find the speed of these muons relative to the Earth. (b) Moving at this speed, how far will the muons move in one half-life? (c) How far would this pulse move in one half-life if there were no relativistic time stretching? (d) In the relativistic case, how far will the pulse move in 10 half-lives? (e) An initial pulse consisting of 10^8 muons is created at a distance above the Earth’s surface given in part (d). How many will remain at the Earth’s surface? Assume that the pulse moves vertically downward and none are lost to collisions. (Ninety-nine percent of the Earth’s atmosphere lies below 40 km altitude.)

($\frac{v}{c} = 0.995.$; 4.8×10^{3} meters.; 480 meters; 48 kilometers.; 9.8×10^{4})

15. Living a Thousand Years in One Year

Living a Thousand Years in One Year. You wish to make a round trip from Earth in a spaceship, traveling at constant speed in a straight line for 6 months on your watch and then returning at the same constant speed. You wish, further, to find Earth to be 1000 years older on your return. (a) What is the value of your constant speed with respect to Earth? (b) How much do you age during the trip? (c) Does it matter whether or not you travel in a straight line? For example, could you travel in a huge circle that loops back to Earth? ($v/c = 0.9999995.$; one year)

SEC 38-8 . CAUSE AND EFFECT

17. Relations between Events

The table shows the t and x coordinates of three events as observed in the laboratory frame.
Laboratory Coordinates of Three Events

Event	***t*** years	***x*** light-years
Event 1	**2**	**1**
Event 2	**7**	**4**
Event 3	**5**	**6**

On a piece of paper list vertically every pair of these events: (1,2), (1, 3), (2, 3). (a) Next to each pair write “time-like,” “light-like,” 0 “space-like” for the relationship between those two events. (b) Next to each pair, write “Yes” if it is possible for one of the events to cause the other event and “No” if a cause and effect relation between them is not possible. (For full benefit of this exercise construct and analyze your own tables.)

ANS: (1,2) timelike yes; (1,3) spacelike no; (2,3) lightlike yes

22. Proton Crosses Galaxy

Find the energy of a proton that crosses our galaxy (diameter 100 000 light-years) in one minute of its own time. ($5.27\times10^{10}\,mc^{2}$)

38-10 MOMENTUM AND ENERGY

23. Converting Mass to Energy

The values of the masses in the reaction $p + {}^{19}F \to \alpha + {}^{16}O$ have been determined by a mass spectrometer to have the values: $m(p)$ = 1.00782, $m(F)$ = 18.998405u, $m(\alpha)$ = 4.002603u, $m(O)$ = 15.994915u. Here u is the atomic mass unit (Section 1.7). How much energy is released in this reaction? Express your answer in both kilograms and MeV. (1.4467×10^{-29} kilogram ; 1.3020×10^{-12} joules)

27. Powerful Proton

A proton exits an accelerator with a kinetic energy equal to N times its rest energy. Find expressions for its (a) speed and (b) momentum. ($\frac{\left[N\left(N+2\right)\right]^{1/2}}{N+1}c.$; $p = \left[N\left(N+2\right)\right]^{1/2} mc.$)

30. A Box of Light

Estimate the power in kilowatts used to light a city of 8 million inhabitants. If all this light generated during one hour in the evening could be captured and put in a box, how much would the mass of the box increase? (16 million kilowatts; 0.64 g)

SEC. 38-11 . THE LORENTZ TRANSFORMATION

32. Really Simultaneous?

(a) Two events occur at the same time in the laboratory frame and at the laboratory coordinates (x_1 = 10 km, y_1 = 4 km, z_1 = 6 km) and (x_2 = 10 km, y_2 = 7 km, z_2 = -10 km). Will these two events be simultaneous in a rocket frame moving with speed v= 0.8c in the x direction in the laboratory frame? Explain your answer. (b) Three events occur at the same time in the laboratory frame and at the laboratory coordinates (x_0,y_1, z_1), (x_0,y_2, z_2) and (x_0,y_1, z_3) where x_0 has the same value for all three events. Will these three events be simultaneous in a rocket frame moving with speed v in the laboratory x direction? Explain your answer. (c) Use your results of parts (a) and (b) to make a general statement about simultaneity of events in laboratory and rocket frames.

ANS: (a) simultaneous—in the rocket frame ($\Delta t'$ = 0); (b) events are *simultaneous* in both the laboratory and rocket frames for the pair of events in part (a) and for all three pair of events in part (b);

38-12 LORENTZ CONTRACTION

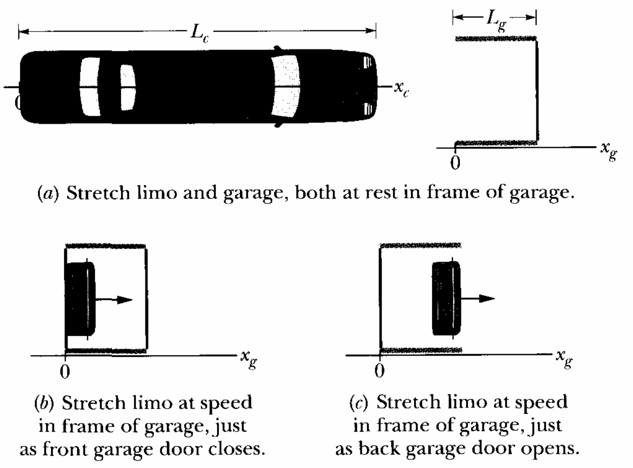
36. Electron Shrinks Distance

An evacuated tube at rest in the /laboratory has a length 3.00 m as measured in the laboratory. An electron moves at speed v = 0.999 987c in the laboratory along the axis of this evacuated tube. What is the length of the tube measured in the rest frame of the electron? (1.53 cm)

39. Traveling to the Galactic Center

(a) Can a person, in principle, /travel from Earth to the center of our galaxy, which is 23 000 ly distant, in one lifetime? Explain using either length contraction or time dilation arguments. (b) What constant speed with respect to the galaxy is required to make the trip in 30 y of the traveler's life time? (Yes; $v/c = 0.999\,999\,15$)

40. Limo in the Garage



(*a*) Stretch limo and garage, both at rest in frame of garage.

(*b*) Stretch limo at speed in frame of garage, just as front garage door closes.

(*c*) Stretch limo at speed in frame of garage, just as back garage door opens.

FIGURE 38-10 ■ Problem 40.

Carman has just purchased the world's longest stretch limo, which has proper length L = 30.0 m. Part (a) of Figure 38-10 shows the limo parked at rest in front of a garage of proper length L_g = 6.00 m, which has front and back doors. Looking at the limo parked in front of the garage, Carman says there is no way that the limo can fit into the garage. "*Au con traire*!" shouts Garageman, "Under the right circumstances the limo can fit into the garage with both garage doors closed and room to spare!" Garageman envisions a fast-moving limo that takes up exactly one-third of the proper length of the garage. Part (b) of Figure 38-10 shows the speeding limo just as the front garage door closes behind it as recorded in the garage frame. Part (c) of Figure 38-10 shows the limo just as the back garage door opens in front of it as recorded in the garage frame. Find the sped of the limo with respect to the garage required for this scenario to take place. ($v = 0.99778c.$)

SEC 38-13 RELETIVITY OF VELOCITIES

42. Separating Galaxies.

Galaxy A is measured to be receding from us on Earth with a speed of 0.3c. Galaxy B, located in precisely the opposite direction, is also receding from us at the same speed. What recessional velocity will an observer on galaxy A measure (a) for our galaxy, and (b) for galaxy B? (0.3c., -0/55*c*)

44. Transit Time

An unpowered spaceship whose rest length 350 meters has a speed 0.82c with respect to Earth. A micrometeorite, also with speed of 0.82c with respect to Earth, passes spaceship on an antiparallel track that is moving in the opposite direction. How long does it take the micrometeorite to pass spaceship as measured on the ship? (1.2×10^{-6} second.)

TUTORIAL 2

Black Body, Photoelectricity, Compton Scattering, X-rays, Pair-production/annihilation

1. The total intensity $I(T)$ radiated from a blackbody (at all wavelengths λ) is equal to the integral over all wavelengths. $0 < \lambda < \infty$, of the Planck distribution $I(\lambda,T) = \dfrac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda k_B T} - 1\right)}$. (a) By changing variables to $x = hc/\lambda kT$, show that $I(T)$ has the form $I(T) = \sigma T^4$, where σ is a constant independent of temperature. This result is called **Stefan's fourth-power law**, after the Austrian physicist Josef Stefan. (b) Given that $\int_0^\infty \dfrac{x^3 dx}{e^x - 1} = \pi^4/15$, show that the Stefan-Boltzmann Constant σ is $\sigma = \dfrac{2\pi^5 k^4}{15h^3c^2}$. (c) Evaluate σ numerically, and find the total power radiated from a red-hot (T = 1000 K) steel hail of radius 1 cm. (Such a ball is well approximated as a blackbody.) (Taylor, Problem 4.4, pg. 141,) **ANS: (c)** 71 W

2. If Planck constant were smaller than it is, would quantum phenomena be more or less conspicuous than they are now? (Beiser, Ex. 1, pg. 89)

3. 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? (Krane, Q.1, pg. 94)

4. Electric current is charge flowing per unit time. If we increase the kinetic energy of the electron by increasing the energy of the photons, shouldn't the current increase, because the charge flows more rapidly? Why doesn't it? (Krane, Q.6, pg. 94)

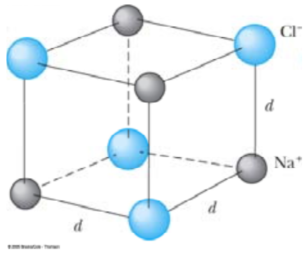
5. What would be the effects on a photoelectric effect if we were to double the frequency of the incident light? If we were to double the wavelength? If we were to double the intensity? (Krane, Q.7, pg. 94)

6. 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? (Krane, Q.16, pg. 95)

7. You have a monoenergetic source of X-rays of energy 84 keV, but for an experiment you need 70 keV X-rays. How would you convert the X-ray energy from 84 to 70 keV? (Krane, Q.16, pg. 95)

8. Show that a photon cannot transfer all of its energy to a free electron. (*Hint*: Note that energy and linear momentum must be conserved.) (Serway, Moses and Moyer, P27. pg. 103)

9. **The determination of Avogadro's number with x—rays**. X-rays. X-rays from a molybdenum (0.626 A) are incident on a NaCl crystal, which has the atomic arrangement shown in Figure below. If NaCl has a density of 2.17 g/cm^3 and the n= 1 diffraction maximum from planes separated by d is found at θ = 6.41°, compute Avogadro's number. (*Hint:* First determine d. Using Figure P3.39, determine the number of NaCl molecules per primitive cell and set the mass per unit volume of the primitive cell equal to the density. (Serway, Moses and Moyer, P39, pg./ 104)



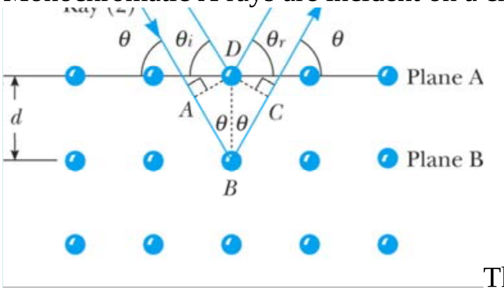
ANS: $N_A = 6.13\times10^{23}$/mole

10. Two light sources are used in a photoelectric experiment to determine the work function for a particular metal surface. When green light from a mercury lamp (λ= 546.1 nm) is used, a retarding potential of 1.70 V reduces the photocurrent to zero. (a) Based on this measurement, what is the work function for this metal? (b) What

stopping potential would be observed when using the yellow light from a helium discharge tube (λ = 587.5 nm)? (Serway, Moses and Moyer. P42, pg 104)

ANS: (a) 0.571 eV; (b) 1.54 V

11. Monochromatic X rays are incident on a crystal in the geometry of Figure below.



The first-order Bragg peak is observed when the angle of incidence is 34.0°. The crystal spacing is known to be 0.347 nm. (a) What is the wavelength of the X rays? (b) Now consider a set of crystal planes that makes an angle of 45° with the surface of the crystal (as in the Figure). For X rays of the same wavelength, find the angle of incidence measured from the surface of the crystal that produces the first-order Bragg peak. At what angle from the surface does the emerging beam appear in this case? (Krane, P3, pg 95)

12. The universe is filled with thermal radiation, which has a bla at an effective temperature of 2.7 K. What is the peak wavelength of this radiation? What is the energy (in eV) of a quanta at the peak wavelength? In what region of the electromagnetic spectrum is this peak wavelength? (Krane. P 20, pg 96)

13. Light from the sun arrives at the earth an average of 1.5×10^{11} m away, at the rate of 1.4×10^{13} W/m of area perpendicular to the direction of the light. Assume that sunlight is monochromatic with a frequency of 5×10^{14} Hz. *(a)* How many photons fall per second on each square meter of Earth's surface directly facing the sun? *(b)* What is the power output of the sun, and how many photons per second does it emit? (*c*) How many photons per cubic meter are there near the earth? (Beiser, Ex. 9, pg. 90)

    ANS: (a) 4.2×10^{21}; (b) 4.2×10^{26}Watt; 1.2×10^{45} photon per second (c) 1.4×10^{13} photon/m^3

14. 1.5 mW of 400-nm light is directed at a photoelectric cell. If 0.10 percent of the incident photons produce photoelectrons, find the current in the cell. (Beiser, Ex. 15, pg. 90)

    ANS: 0.48 μA

15. *(a)* Find the change in wavelength of 80-pm x-rays that are scattered 120° by a target, *(b)* Find the angle between the directions of the recoil electron and the incident photon. *(c)* Find the energy of the recoil electron. (Beiser, Ex. 34, pg. 90)
    ANS: (a) 3.64 pm (b) 29.3° (c) 674 eV

16. A photon of frequency *v* is scattered by an electron initially at rest. Verify that the maximum kinetic energy of the recoil electron is KE$_{max}$ = $(2h^2v^2/mc^2)$ / $(1+ 2hv/mc^2)$ (Beiser, Ex. 35, pg. 90)

17. Show that, regardless of its initial energy, a photon cannot undergo Compton scattering through an angle of more than 60° and still be able to produce an electron-positron pair. *(Hint:* Start by expressing the Compton wavelength of the electron in terms of the maximum photon wavelength needed for pair production.) (Beiser, Ex. 41, pg. 91)

18. (a) Verily that the minimum energy a photon must have to create an electron-positron pair in the presence of a stationary nucleus of mass *M* is $2mc^2/(1 + m/M)$, where *m* is the electron rest mass. (**b**) Find the minimum energy needed for pair production in the presence of a proton. (Beiser, Ex. 42, pg. 91)
    ANS: (b) 1.023 MeV

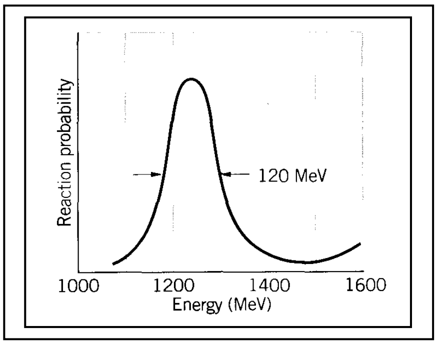
19. Why is it in a pair annihilation the resultant photons cannot be singly produced?

TUTORIAL 3
Wave properties of particles

1. Suppose we cover one slit in the two-slit experiment with a very thin sheet of fluorescent material that emits a photon of light whenever an electron passes through. We then fire electrons one at a time at the double slit; whether or not we see a flash of light tells us which slit the electron went through. What effect does this have on the interference pattern? Why? (*Suggestion: Read Chap. 1, Feynman Lectures on Physics Vol. 3)* (Krane, Q13, pg. 131,)

2. The speed of an electron is measured to within an uncertainty of 2.0×10^4 m/s. What is the size of the smallest region of space in which the electron can be confined? (Krane, P14, pg. 133)

3. A pi meson (pion) and a proton can briefly join together to form a Δ particle. A measurement of the energy of the πp system (see Figure) shows a peak at 1236 MeV, corresponding to the rest energy of the Δ particle, with an experimental spread of 120 MeV. What is the lifetime of the Δ? (Krane, P17, pg. 133)



4. 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 Δt consistent with the uncertainty principle. (*a*) Consider $p \rightarrow p + \pi$. By what amount ΔE is energy conservation violated? (ignore any kinetic energies.) (*b*) For how long a time Δt can the pi meson exist? (*c*) Assuming pi meson to travel at very nearly the speed of light, how far from the proton can it go? (This procedure gives us an estimate of the range of the nuclear force, because we believe that protons and neutron are held together in the nucleus by exchanging pi mesons.) (Krane, P22, pg. 133)

5. Show that the formula for low-energy electron diffraction (LEED), when electrons are incident perpendicular to a crystal surface, may be written as $\sin\phi = \dfrac{nhc}{d\left(2m_e c^2 K\right)^{1/2}}$, where n is the order of the maximum, d is the atomic spacing, m_e is the electron mass, K is the electron's kinetic energy, and ϕ is the angle between the incident and diffracted beams, (b) Calculate the atomic spacing in a crystal that has consecutive diffraction maxima at $\phi = 24.1°$ and $\phi = 54.9°$ for 100-eV electrons. (Serway, M & M, P 14, pg. 188) **ANS:** 33×10^{-10} m for n=1, 33×10^{-10} m for n=2)

6. A woman on a ladder drops small pellets toward a spot on the floor, (a) Show that, according to the uncertainty principle, the miss distance must be at least $\Delta x = \left(\dfrac{\hbar}{2m}\right)^{1/2}\left(\dfrac{H}{2g}\right)^{1/4}$, where H is the initial height of each pellet above the floor and m is the mass of each pellet, (b) If H = 2.0 m and m = 0.50 g, what is Δx? (Serway & M & M, P 21, pg. 188) **ANS: (b)** $\Delta x_{\text{total}} = 5.2\times10^{-16}$ m

7. An excited nucleus with a lifetime of 0.100 ns emits a γ ray of energy 2.00 MeV. Can the energy width (uncertainty in energy, ΔE) of this 2.00-MeV γ emission line be directly measured if the best gamma detectors can measure energies to ±5 eV? (Serway & M & M, P 25, pg. 188)

   ANS: NO

8. Find the de Broglie wavelength of a 1.00-MeV proton. Is a relativistic calculation needed? (Beiser, Ex. 6, pg. 117) **ANS:** 2.86×10^{-14} m; No need.

9. Show that the de Broglie wavelength of a particle of mass *m* and kinetic energy KE is given by $\lambda = \dfrac{hc}{\sqrt{KE(KE+2mc^2)}}$ (Beiser, Ex. 10, pg. 117)

10. What effect on the scattering angle in the Davisson-Germer experiment does increasing the electron energy have? (Beiser, Ex. 23, pg. 117)

11. A beam of 50-keV electrons is directed at a crystal and diffracted electrons are found at an angle of 50° relative to the original beam. What is the spacing of the atomic planes of the crystal? A relativistic calculation is needed for λ. (Beiser, Ex. 26, pg. 117) **ANS:** 3.0 pm

12. The lowest energy possible for a certain particle trapped in a certain box is 1.00 eV. (*a*) What are the next two higher energies the particle can have? (*b*) If the particle is an electron, how wide is the box? (Beiser, Ex. 29, pg. 118)

    ANS: (a) 4 eV, 9 eV; (b) 45 fm

13. Discuss the prohibition of $E = 0$ for a particle trapped in a box L wide in terms of the uncertainty principle. How does the minimum momentum of such a particle compare with the momentum uncertainty required by the uncertainty principle if we take $\Delta x = L$? (Beiser, Ex. 30, pg. 118)

14. (*a*) How much time is needed to measure the kinetic energy of an electron whose speed is 10.0 m/s with an uncertainty of no more than 0.100 percent? How far will the electron have travelled in this period of time? (b) Make the same calculations for a 1.00-g insect whose speed is the same. What do these sets of figures indicate? (Beiser, Ex. 34, pg. 118)

    ANS: (a) 1.2 ms, 1.2 cm; (b) 9.5×10^{-29} s, 9.5×10^{-28} m.

15. How accurately can the position of a proton with $v << c$. be determined without giving it more than 1.00 keV of kinetic energy? (Beiser, Ex. 35, pg. 118). **ANS:** 0.144 pm

16. (*a*) Find the magnitude of the momentum of a particle in a box in its *n*th state. (*b*) The minimum change in the particles momentum that a measurement can cause corresponds to a change of ±1 in the quantum number *n*. If $\Delta x = L$. show that $\Delta p \, \Delta x \geq \hbar / 2$. (Beiser, Ex. 36, pg. 118)

    ANS: (a) $nh/2L$; (b) $h/2L$;

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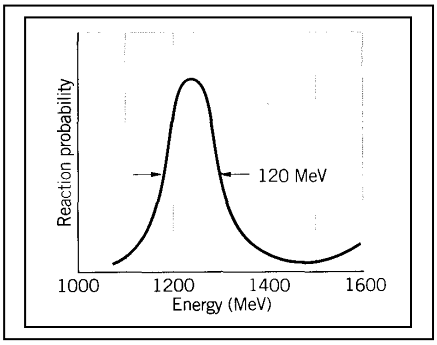

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12. The lowest energy possible for a certain particle trapped in a certain box is 1.00 eV. (*a*) What are the next two higher energies the particle can have? (*b*) If the particle is an electron, how wide is the box? (Beiser, Ex. 29, pg. 118)

    ANS: (a) 4 eV, 9 eV; (b) 45 fm

13. Discuss the prohibition of $E = 0$ for a particle trapped in a box *L* wide in terms of the uncertainty principle. How does the minimum momentum of such a particle compare with the momentum uncertainty required by the uncertainty principle if we take $\Delta x = L$? (Beiser, Ex. 30, pg. 118)

14. (*a*) How much time is needed to measure the kinetic energy of an electron whose speed is 10.0 m/s with an uncertainty of no more than 0.100 percent? How far will the electron have travelled in this period of time? (b) Make the same calculations for a 1.00-g insect whose speed is the same. What do these sets of figures indicate? (Beiser, Ex. 34, pg. 118)

    ANS: (a) 1.2 ms, 1.2 cm; (b) $9.5 \text{ x } 10^{-29}$ s, $9.5 \text{ x } 10^{-28}$ m.

15. How accurately can the position of a proton with $v << c$. be determined without giving it more than 1.00 keV of kinetic energy? (Beiser, Ex. 35, pg. 118). **ANS:** 0.144 pm

16. (*a*) Find the magnitude of the momentum of a particle in a box in its *n*th state. (*b*) The minimum change in the particles momentum that a measurement can cause corresponds to a change of ±1 in the quantum number *n*. If $\Delta x = L$. show that $\Delta p\ \Delta x \geq \hbar/2$. (Beiser, Ex. 36, pg. 118)

    ANS: (a) $nh/2L$; (b) $h/2L$;

TUTORIAL 4
Atomic models

1. How is the quantization of the energy in the hydrogen atom similar to the quantization of the systems discussed in the 1-D infinite quantum well? How is it different? Do the quantizations originate from similar causes? (Krane, Q8, pg. 201)

2. In both the Rutherford theory and the Bohr theory, we used the classical expression for the kinetic energy. Estimate the velocity of an electron in the Bohr atom and of an alpha particle in a typical scattering experiment, and decide if the use of the classical formula is justified. (Krane, Q14, pg. 201)

3. The lifetimes of the levels in a hydrogen atom are of the order of 10^{-8} s. Find the energy uncertainty of the first excited state and compare it with the energy of the state. (Krane, P29, pg. 204)

4. A long time ago, in a galaxy far, far away, electric charge had not yet been invented, and atoms were held together by gravitational forces. Compute the Bohr radius and the n=2 to n = 1 transition energy in a gravitationally hound hydrogen atom. (Krane, P33, pg. 204)

5. The **fine structure constant** is defined as $\alpha = e^2/2\varepsilon_o hc$. This quantity got its name because it first appeared in a theory by the German physicist Arnold Sommerfeld that tried to explain the line structure in spectral lines (multiple lines close together instead of single lines) by assuming that elliptical as well as circular orbits are possible in the Bohr model. Sommerfeld’s approach was on the wrong track, but α has nevertheless turned out to be a useful quantity in atomic physics, (*a*) Show that $\alpha = v_1/c$, where v_1 is the velocity of the electron in the ground state of the Bohr atom, (*b*) Show that the value of α is very close to 1/137 and is a pure number with no dimensions. Because the magnetic behavior of a moving charge depends on its velocity, the small value of α is representative of the relative magnitudes of the magnetic and electric aspects of electron behavior in an atom (*c*) Show that $\alpha\, a_0 = \lambda_c / 2\pi$, where a_0 is the radius of the ground-state Bohr orbit and λ_c is the Compton wavelength of the electron. (Beiser Ex. 9, pg. 158)

6. Show that the energy of the photon emitted when a hydrogen atom makes a transition from state n to state n - 1 is, when n is very large, $\Delta E \cong \alpha^2(mc^2/n^3)$ where α is the fine structure constant. (Krane, P38, pg. 205)

7. Can the electron in the ground state of the hydrogen atom absorb a photon of energy (a) less than 13.6 eV and (b) greater than 13.6 eV? (c) What is the minimum photon energy that can be absorbed by the ground state of the hydrogen atom? (Serway, M & M, Q3, pg. 145)

   ANS: (a) Yes (b) No (c) 10.2 eV

8. Four possible transitions for a hydrogen atom are listed here.

   (A) $n_i = 2; n_f = 5$ (B) $n_i = 5; n_f = 3$ (C) $n_i = 7; n_f = 4$ (D) $n_i = 4; n_f = 7$

   (a) Which transition emits the photons having the shortest wavelength?

   (b) For which transition does the atom gain the most energy? (c) For which transition(s; does the atom lose energy? (Serway, M & M. Q11, pg. 145)

9. An electron initially in the *n* = 3 state of a one-electron atom of mass *M* at rest undergoes a transition to the *n* = 1 ground state. (a) Show that tile recoil speed of the atom from emission of a photon is given approximately by $v=8hR/9M$. (b) Calculate the percent of the 3 → 1 transition energy that is carried off by the recoiling atom if the atom is deuterium. (Serway, M & M. Q29, pg. 148)

   ANS: (b) 3.23×10^{-8} %

10. *The Auger process*. An electron in chromium makes a transition from the *n* = 2 state to the *n* = 1 state with out emitting a photon. Instead, the excess energy is transferred to an outer electron (in the *n* = 4 state), which is ejected by the atom. (This is called an Auger process, and the ejected electron is referred to as an Auger electron.) Use the Bohr theory to find the kinetic energy of the Auger electron. (Serway, M & M. Q28, pg. 148)

    ANS: 5.385 keV

11. In a hot star, a multiply ionized atom with a single remaining electron produces a series of spectral lines as described by the Bohr model. The series corresponds to electronic transitions that terminate in the same final state. The longest and shortest wavelengths of the series are 63.3 nm and 22.8 nm, respectively. (*a*) What is the ion? (*b*) Find the wave lengths of the next three spectral lines nearest to the line of longest wavelength. (Serway, M & M. Q44, pg. 150) **ANS:** (a) O^{7+} ; (b) 41.0 nm , 33.8 nm, 30.4 nm

12. Find the frequency of revolution of the electron in the classical model of the hydrogen atom. In what region of the spectrum are electromagnetic waves of this frequency? (Beiser, Ex. 4, pg. 157) **ANS:** 6.6×10^{15} Hz, ultraviolet

13. What is the shortest wavelength present in the Bracken series of spectral lines? (Beiser, Ex.5, pg. 158)

    ANS: 1459 nm

14. A beam of 13.0-eV electrons is used to bombard gaseous hydrogen. What series of wavelengths will be emitted? (Beiser Ex. 16, pg. 158). **ANS:** Excited to the $n = 4$ level but no higher

15. The longest wavelength in the Lyman series is 121.5 nm and the shortest wavelength in the Balmer series is 364.6 nm. Use the figures to find the longest wavelength of light that could ionize hydrogen. (Beiser, Ex. 23, pg. 158) **ANS:** 91.13 cm

16. When an excited atom emits a photon, the linear momentum of the photon must be balanced by the recoil momentum of the atom. As a result, some of the excitation energy of the atom goes into the kinetic energy of its recoil. (*a*) Modify $E_i - E_f = h\nu$ to include this effect, (*b*) Find the ratio between the recoil energy and the photon energy for the $n = 3$ → n→ 2transition in hydrogen, for which $E_f - E_i = 1.9$ eV. Is the effect a major one? A nonrelativistic calculation is sufficient here. (Beiser, Ex. 27, pg. 158)

    ANS: (a)

    $$E_f - E_i = h\nu \Bigg(1 + \frac{1}{2}\Bigg(1 + \frac{Mc^2}{h\nu}\Bigg)$$

    (b) 1.0 x 10^{-9}; nonrelativistic is sufficient

TUTORIAL 5
Introductory Quantum Mechanics

1. Which of the following wave functions cannot be solutions of Schrodinger's equation for all values of x? Why not? (a) $\psi = A \sec x$; (b) $\psi = A \tan x$; (c) $\psi = A e^{x^2}$; (d) $\psi = A e^{-x^2}$ (Beiser, Ex. 3, pg. 197)

   ANS: only (d) could be a solution

2. The wave function of a certain particle is $\psi = A \cos^2 x$ for $\pi/2 < x < \pi/2$. (a) Find the value of A. (b) Find the probability that the panicle be found between $x = 0$ and $x = \pi/4$ (Beiser, Ex. 5, pg. 197)

   ANS: (a) $\sqrt{\frac{8}{3}}$ **;** (b) 0.462

3. The expectation value $\langle x \rangle$ of a particle trapped in a box a wide is $a/2$ $(0 \le x \le a)$, which means that its average position is the middle of the box. Find the expectation value $\langle x^2 \rangle_n$ in the stationary state n. What is the behaviour of $\langle x^2 \rangle_n$ as n becomes infinity. Is this consistent with classical physics? (Beiser, Ex. 17, pg. 198). **ANS:** $a^2\left(\frac{1}{3} - \frac{1}{2\pi^2 n^2}\right)$.

4. Find the probability that a particle in a box L wide can be found between $x = 0$ and $x = L/n$ when it is in the nth state. (Beiser, Ex. 19, pg. 198)

   ANS: $1/n$.

5. What is the physical meaning of $\int_{-\infty}^{\infty} |\psi|^2 \, dx = 1$ ψ dx = 1? (Krane, Q3, pg/ 168)

6. What are the dimensions of $\psi(x)$? (Krane, Q4, pg. 168)

   ANS: $\sqrt{L}$.

7. What happens to the probability density in the infinite well when n → ∞? Is this consistent with classical physics? (Krane, Q6, pg. 168)

8. How would the solution to the one-dimensional infinite potential energy well be different if the potential energy were not zero for $0 \le x \le L$ but instead had a constant value U_0. What would be the energies of the excited states? What would be the wavelengths of the standing de Broglie waves? Sketch the behavior of the lowest two wave functions. (Krane, Q6, pg. 168)

9. A particle in an infinite well is in the ground state with an energy of 1.26 eV. How much energy must be added to the particle to reach the second excited state ($n = 3$)? The third excited state ($n = 4$)? (Krane, P4, pg. 170)

10. An electron is trapped in a one-dimensional well of width 0.132 nm. The electron is in the $n = 10$ state. (a) What is the energy of the electron? (b) What is the uncertainty in its momentum? (c) What is the uncertainty in its position? How do these results change as $n \to \infty$? Is this consistent with classical behavior? (Krane, P9, pg. 170)

11. Consider a particle moving in a one-dimensional box with walls at $x = -L/2$ and $x = +L/2$. (a) Write the wave functions and probability densities for the states $n = 1$, $n = 2$, and $n = 3$. (b) Sketch the wave function and probability densities. (Hint: Make an analogy to the case of a particle in a box with walls at $x = 0$ and $x = L$) (Serway, M & M, P11, pg. 228)

12. A particle of mass m is placed in a one-dimensional box of length L. The box is so small that the particle's motion is relativistic, so that $E = p^2/2m$ is not valid. (*a*) Derive an expression for the energy levels of the particle using the relativistic energy- momentum relation and the quantization of momentum that derives from confinement. (*b*) If the particle is an electron in a box of length $L = 1.00\times10^{-12}$m, find its lowest possible kinetic energy. By what percent is the nonrelativistic formula for the energy in error? (Serway, M & M, P14, pg. 228)

ANS: (a) $K_n = \left[\left(\frac{nhc}{2L}\right)^2 + \left(mc^2\right)^2\right]^{1/2} - mc^2$; (b) 0.29 MeV, 29% too big

ZCT 104

MODERN PHYSICS

PAST YEAR QUESTIONS AND TUTORIAL PROBLEM SETS

(2003/04 – 2004/2005)

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:

$$p=\gamma m_0 u \rightarrow p'=\gamma' m_0 u'$$

$$\left(\frac{p'}{p}\right)^2=\left(\frac{u'}{u}\right)^2\left(\frac{\gamma'}{\gamma}\right)^2=\left(\frac{u'}{u}\right)^2\left[\frac{1-\left(\frac{u}{c}\right)^2}{1-\left(\frac{u'}{c}\right)^2}\right]=\left(\frac{u'}{u}\right)^2\frac{c^2-u^2}{c^2-u'^2}\Rightarrow\frac{p'}{p}=\left(\frac{u'}{u}\right)\sqrt{\frac{c^2-u^2}{c^2-u'^2}}$$

$$\text{Let } u'=2u\Rightarrow\frac{p'}{p}=\left(\frac{2u}{u}\right)\sqrt{\frac{c^2-u^2}{c^2-(2u)^2}}=2\sqrt{\frac{c^2-u^2}{c^2-4u^2}}$$

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.

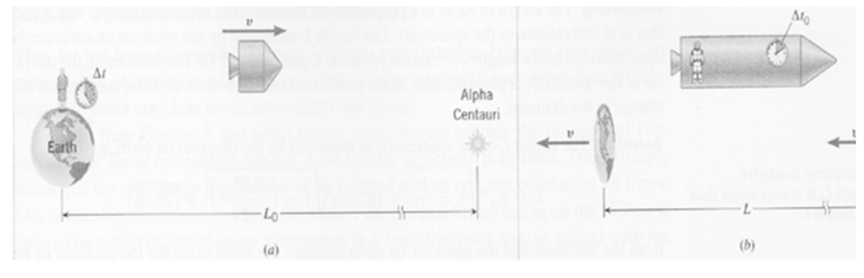


Figure: (a) As measured by an observer on the earth, the distance to Alpha Centauri is L_0, and the time required to make the trip is Δt. (b) According to the passenger on the spacecraft, the earth and Alpha Centauri move with speed v relative to the craft. The passenger measures the distance and time 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 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

$$E_0 = mc^2 = (0.046\ \text{kg})(3.0\times10^8\ \text{m/s})^2 = 4.1\times10^{15}\ \text{J}$$

(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

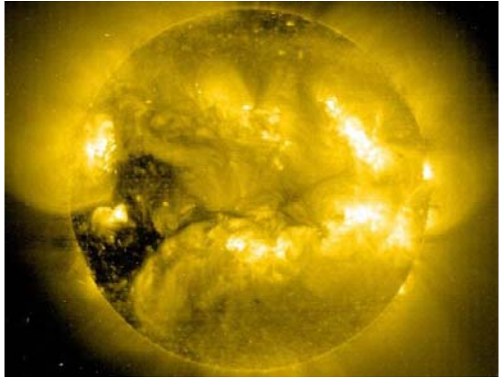
(a) $E_0 = mc^2 = 9.109\times10^{-31}\,kg\times(3\times10^8)^2\,m/s = 8.19\times10^{-14}\,J = 0.51MeV$

(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

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 $\Delta m = \Delta E_0/c^2 = 3.92\times10^{26}\ \text{J}/(3\times10^8\ \text{m/s})^2 = (4.36\times10^9)$ 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:

$$\Delta m/m = 1.0\times10^{19}\ \text{kg}/1.99\times10^{30}\ \text{kg} = 5.0\times10^{-12}$$

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} = +0.7*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?

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

$$u_x = \frac{u'_x + u}{1+\frac{u'_x u}{c^2}} \equiv v_{LS} = \frac{v_{LC}+v_{CS}}{1+\frac{v_{LC}v_{CS}}{c^2}} = \frac{(+c)+(+0.7c)}{1+\frac{(+c)(+0.7c)}{c^2}} = \frac{1.7c}{1.7c} = +c$$

, 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* - (+0.7*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.

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 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, $v\gamma = \dfrac{0.999999997c}{\sqrt{1-\dfrac{(0.999999997c)^2}{c^2}}} = 1.09989\times10^{13}$ 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

3.0×10^{20} eV. (a) What were the proton's Lorentz factor γ and speed v (both relative to the ground-based detector)?

Solution

$$\gamma = \frac{E}{m_0c^2} = \frac{m_0c^2 + K}{m_0c^2} = 1 + \frac{K}{m_0c^2} \Rightarrow \gamma = 1 + \frac{3.0\times10^{20}\,\mathrm{eV}}{938\times10^{6}\,\mathrm{eV}} \approx 3.2\times10^{11}$$

$$\gamma^{-1} = \sqrt{1-\left(\frac{v}{c}\right)^2} = \sqrt{\left(1-\frac{v}{c}\right)\left(1+\frac{v}{c}\right)}. \text{ But } 1+\frac{v}{c} \approx 2 \Rightarrow \gamma^{-2} \approx 2\left(1-\frac{v}{c}\right) = 9.766\times10^{-24}$$

$$\Rightarrow v \approx \left(1-5\times10^{-24}\right)c = 0.999999999999999999999995c$$

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.

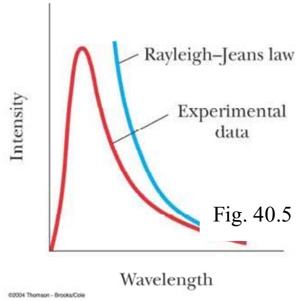


Fig. 40.5

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 $\sigma = 5.67\times10^{-8}\,\mathrm{W/m^2\cdot K^4}$. 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. $T \rightarrow 2T$, $I \rightarrow I'(2)^4 = 16I$, 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 $\lambda_{\max}$ 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 $\lambda_{\max}T = 2.898\times10^{-3}\,\mathrm{m\cdot K}$

   (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, $\lambda_{\max}T = 2.898\times10^{-3}\,\mathrm{m\cdot K}$
   $\lambda_{\max}$ = 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 = 2.898×10^{-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

$$\frac{T_2^4}{T_1^4}=\frac{4460^4}{293^4}=5.37\times 10^4$$

Be sure to notice the use of absolute (Kelvin) temperatures.

3. **Show that the spectral distribution derived by Planck, $I(\lambda,T)=\frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda k_BT}-1\right)}$ reduces to the Rayleigh-Jeans law, $I(\lambda,T)=\frac{2\pi ck_BT}{\lambda^4}$ in the long wavelength limit.**

ANS

In long wavelength limit, $hc \ll \lambda k_BT$, the exponential term is approximated to

$e^{hc/\lambda k_BT}=1+\frac{hc}{\lambda k_BT}+\frac{1}{2!}\left(\frac{hc}{\lambda k_BT}\right)^2+\ldots\approx 1+\frac{hc}{\lambda k_BT}$. Hence, substituting $e^{hc/\lambda k_BT}\approx 1+\frac{hc}{\lambda k_BT}$ into the Planck's distribution, we have

$$I(\lambda,T)=\frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda k_BT}-1\right)}\approx\frac{2\pi hc^2}{\lambda^5\left[\left(1+\frac{hc}{\lambda k_BT}\right)-1\right]}=\frac{2\pi hc^2}{\lambda^5\left[\frac{hc}{\lambda k_BT}\right]}=\frac{2\pi hc^2\lambda k_BT}{\lambda^5 hc}=\frac{2\pi ck_BT}{\lambda^4},$$

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 J/s/ (3.58×10^{-19} J/photon) = 3.6×10^{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, $E_P = hc/\lambda = 3.5\text{eV}$. 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 $n_e = (0.0050)n_p = 8.8\times10^{11}$ 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 $\mathring{A}$ 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),

$$\frac{hc}{\lambda} = 2m_e c^2 + K_+ + K_- = 2m_e c^2 + 3K_-$$

$$\frac{12.4\times10^{-3}\,\text{MeV}\cdot\mathring{A}}{0.0030\,\mathring{A}} = 2(0.511\text{MeV})\cdot 3K_-$$

$$K_- = 1.04\text{MeV};\; K_+ = 2K_- = 2.08\text{MeV}$$

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 = … 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 $v_p = \frac{c^2}{v} = \frac{c^2}{0.771c} = 1.29c$

   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/(9.1×10^{-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

5. **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.

$\Delta p \geq \dfrac{\hbar}{2\pi} = 9.9\times10^{-25}$ 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 $\Delta x \geq \dfrac{(1.054\times10^{-34} Js)(1.00s)}{2(1.672\times10^{-27} kg)(1.00\times10^{-11} m)} = 3.15\times10^3$ 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:

$$\lambda = 102.6\text{ nm}\,;\ \frac{1}{\lambda} = R\left(1-\frac{1}{n^2}\right) \Rightarrow n = \frac{R}{\left(R-\frac{1}{\lambda}\right)^{1/2}} = \frac{R}{\left(R-\frac{1}{102.6\times10^{-9}\text{ m}}\right)^{1/2}} = 2.99 \approx 3$$

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 $n_i = 4$, $\frac{1}{\lambda_{\max}} = R\left(\frac{1}{3^2}-\frac{1}{4^2}\right)$; $\lambda_{\max} = 1\,874.606\text{ nm}$. For minimum wavelength, $n_i \to \infty$, $\frac{1}{\lambda_{\min}} = R\left(\frac{1}{3^2}-\frac{1}{\infty}\right)$; $\lambda_{\min} = \frac{9}{R} = 820.140\text{ nm}$.

(b) $\frac{hc}{\lambda_{\min}} = \frac{\left(\frac{hc}{1\,874.606\text{ nm}}\right)}{1.6\times10^{-19}\ \text{J/eV}} = 0.662\,7\text{ nm}$, $\frac{hc}{\lambda_{\min}} = \frac{\left(\frac{hc}{820.140\text{ nm}}\right)}{1.6\times10^{-19}\ \text{J/eV}} = 1.515\text{ nm}$

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 $E_n = -\frac{13.6}{n^2}\text{eV}$, we have $E_n = -\frac{13.6}{434^2}\text{eV} = -0.000072$ eV. Such an atom would obviously be extremely fragile and be easily ionised (compared to the kinetic energy of the atom at temperature T, $kT \sim (1.38\times10^{-23}\text{ J/K})\times(300\text{ K}) = 0.03\text{ eV}$)

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, $v = h/2\pi m n r_0$.

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, $f = v/2\pi r = (h/2\pi m n r_0)/2\pi r = h/4\pi^2 m n^3 (r_0)^2$.

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 $m = \frac{m_0}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$. 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.

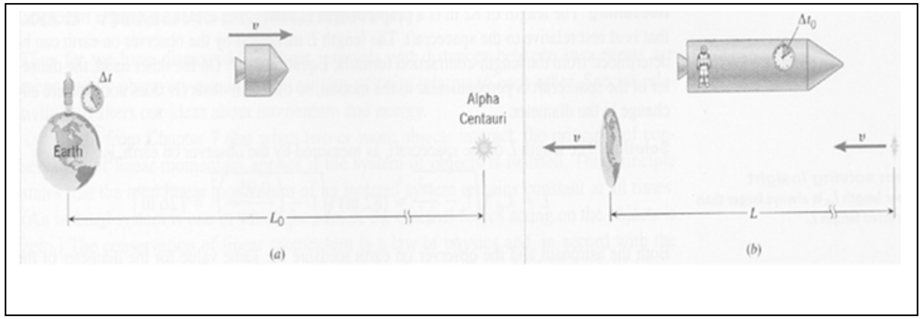


Figure: (a) As measured by an observer on the earth, the distance to Alpha Centauri is L_0*, and the time required to make the trip is* Δt*. (b) According to the passenger on the spacecraft, the earth and Alpha Centauri move with speed v relative to the craft. The passenger measures the distance and 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 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
$\Delta t_0 = \Delta t\sqrt{(1-v^2/c^2)} = 4.5 \text{ years } \sqrt{(1-0.95^2)} = 1.4$ 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 $L_0 = v\Delta t = (0.95c)(4.5 \text{ years}) = 4.3$ light-years. On the other hand, a passenger aboard the rocket finds the distance is only $L =$
$v\Delta t_0 = (0.95c)(1.4 \text{ years}) = 1.3$ 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, $v\gamma = \dfrac{0.999999997c}{\sqrt{1-\dfrac{(0.999999997c)^2}{c^2}}} = 1.09989\times10^{13}$ m/s. The relativistic momentum is greater than the non-relativistic momentum by a factor of $\gamma = \dfrac{1}{\sqrt{1-\dfrac{(0.999999997c)^2}{c^2}}} = 4\times10^4$.

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) $E_0 = mc^2 = 9.109\times10^{-31} kg \times (3\times10^8)^2 m/s = 8.19\times10^{-14} J = 0.51 MeV$

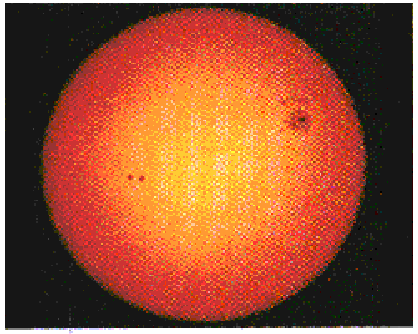
(b) Total energy of the traveling electron,

$$E = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{0.51MeV}{\sqrt{1-0.995^2}} = 16.2MeV$$

(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

$\Delta m = \Delta E_0/c^2 = 3.92\times10^{26}\ \mathrm{J}/(3\times10^8\ \mathrm{m/s})^2 = (4.36\times10^9)$ kg.

Over 4 billion kilograms of mass are lost by the sun during each second.

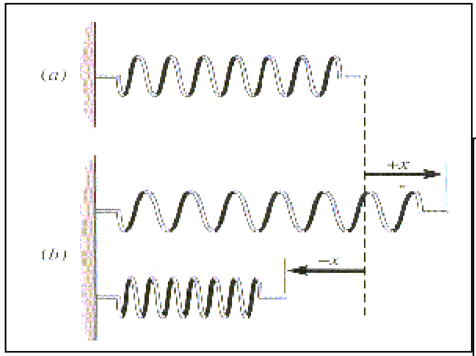
(b) The amount of mass lost by the sun in 75 years is

$\Delta m = (4.36\times10^9)\,\mathrm{kg} \times (3.16\times10^7\ \mathrm{s/year}) \times (75\ \mathrm{years}) = 1\times10^{19}$ kg

Although this is an enormous amount of mass, it represents only a tiny fraction of the sun's total mass:

$\Delta m/m = 1.0\times10^{19}\ \mathrm{kg}/1.99\times10^{30}\ \mathrm{kg} = 5.0\times10^{-12}$

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

$u_x = \dfrac{u'_x + u}{1 + \dfrac{u'_x u}{c^2}} \equiv v_{LS} = \dfrac{v_{LC} + v_{CS}}{1 + \dfrac{v_{LC} v_{CS}}{c^2}} = \dfrac{(+c) + (+0.7c)}{1 + \dfrac{(+c)(+0.7c)}{c^2}} = \dfrac{1.7c}{1.7c} = +c$, 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 × 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 $m_a = E'/c^2 = 5.98\text{x}10^{-10}$ J/$(3\text{x}10^8$ m/s$)^2 = 6.64\text{x}10^{-27}$ kg

In a similar manner, we find that the masses of particles b and c are

$$m_b = 6.64\text{x}10^{-27}\text{ kg},\ m_c = 33.2\text{x}10^{-27}\text{ kg},$$

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

$$KE_a = 2E' - E' = E' = 5.98\text{x}10^{-10}\text{ J}.$$

The kinetic energies of particles b and c can be determined in a similar fashion:

$$KE_b = 17.9\text{x}10^{-10}\text{ J},\ KE_c = 5.98\text{x}10^{-10}\text{ J}$$

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

$n_p = (E/t)/E_p = (E/A)(A)/E_p$

$= (1.00\ \mathrm{W/m^2})(1.00\times10^{-4}\ \mathrm{m^2})/5.68\times10^{-19}\ \mathrm{J}$

$= 1.76\times10^{14}$ 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,

$\lambda_{\max}T = 2.898\times10^{-3}\ \mathrm{m\cdot K}$

$\lambda_{\max} = 2.898\times10^{-3}\ \mathrm{m\cdot K}/\ 293\mathrm{K} = 9.89\ \mu\mathrm{m}$

(b) Taking the wavelength of red light to be =650 nm, we again use Wien's displacement law to find T:

$T = 2.898\times10^{-3}\ \mathrm{m\cdot K}/650\times10^{-9}\ \mathrm{m} = 4460\ \mathrm{K}$

(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

$\lambda_c = \frac{hc}{\phi} = \frac{1240\mathrm{eV\cdot nm}}{200\mathrm{nm}} = 274\mathrm{nm}$, 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 $K_{\max}$:

$$V_s = K_{\max}/e = \frac{1.68eV}{e} = 1.68\,\mathrm{V}$$

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

$\mathrm{KE}_{\max} = h(\nu - \nu') = hc(\frac{1}{\lambda} - \frac{1}{\lambda'}) = 40.8$ 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.

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:

$E = pc = \dfrac{hc}{\lambda} = \dfrac{1242eV\cdot nm}{10^{-6}nm} = 1.24$ 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

$$E_n = \frac{n^2\pi^2\hbar^2}{2mL^2} = 6.0\times10^{-18}n^2\text{ J} = 38n^2\text{ eV}.$$

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 $m = 1.0\times10^{-2}$ kg and $L = 1.0\times10^{-1}$ 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 $\Delta x = 5.3\times10^{-11}$ m.

$$\Delta p \geq \frac{\hbar}{2\pi} = 9.9\times10^{-25} \text{ Ns.}$$

An electron whose momentum is of this order of magnitude behaves like a classical particle, an its kinetic energy is $K = p^2/2m \geq (9.9\times10^{-25}\text{ Ns})^2/2\times9.110^{-31}\text{ kg} = 5.4\times10^{-19}$ 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 accruracy 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 $\psi_n(x) = \sqrt{\dfrac{2}{a}}\sin\dfrac{\pi x}{a}$.

$$\langle x\rangle = \int_{-\infty}^{\infty}\psi x\psi dx = \frac{2}{a}\int_0^a x\sin^2\frac{\pi x}{a}dx = \frac{2a}{\pi^2}\int_0^\pi y\sin^2 y dy$$

$$\int_0^\pi y\sin^2 y dy = \left.\frac{y^2}{4} - \frac{y\sin 2y}{4} - \frac{\cos 2y}{8}\right|_0^\pi = \frac{\pi^2}{4}$$

$\therefore \langle x\rangle = \dfrac{a}{2}$. Likewise,

$$\langle x^2\rangle = \int_{-\infty}^{\infty}\psi x^2\psi dx = \frac{2}{a}\int_0^a x^2\sin^2\frac{\pi x}{a}dx = \frac{2a^2}{\pi^3}\int_0^\pi y^2\sin^2 y dy$$

$$\int_0^\pi y^2\sin^2 y dy = \left.\frac{x^3}{6} - \frac{x\cos 2x}{4} + \frac{(1-2x^2)\sin 2x}{8}\right|_0^\pi = \frac{\pi^3}{6} - \frac{\pi}{4}$$

$$\therefore \langle x^2\rangle = \int_{-\infty}^{\infty}\psi x^2\psi dx = a^2\left(\frac{1}{3} - \frac{1}{2\pi^2}\right)$$

$\Delta x = <x^2> - <x>^2 = a^2\left(\dfrac{1}{3} - \dfrac{1}{2\pi^2}\right) - \dfrac{a^2}{4} = a^2\left(\dfrac{1}{12} - \dfrac{1}{2\pi^2}\right)$

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, $v = h/2\pi m n r_0$.

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, $f = v/2\pi r = (h/2\pi m n r_0)/2\pi r = h/4\pi^2 m n^3 (r_0)^2$.

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)
$$\nu = \frac{\Delta E}{h} = \frac{13.6eV}{h}\left(\frac{1}{1^2}-\frac{1}{2^2}\right) = \frac{3c}{4}\frac{13.6eV}{1242eV\cdot nm} = 0.00821\times(3\times10^8 m/s)/10^{-9} m =$$
2.463×10^{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

$\lambda=117.4\,\text{nm}$

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 $\overset{o}{A}$ strikes a crystal of *d*-spacing 4.4 $\overset{o}{A}$. 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

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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. $n^2\dfrac{\hbar^2}{8m\pi L^2}$ **B.** $n^2\dfrac{h^2}{8mL^2}$ **C.** $n^2\dfrac{\pi^2 h^2}{2mL^2}$ **D.** $n^2\dfrac{\hbar^2}{2mL^2}$
   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, $c = 3.00 \times 10^{8}$ 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

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

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

the Avogadro constant, $N_A = 6.02 \times 10^{23}$ 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}

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.** $\dfrac{cL_P / t}{\sqrt{c^2 + (L_P / t)^2}}$ **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.** $\dfrac{cL_P / t}{\sqrt{c^2 + (L_P / t)^2}}$ **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 $\mathrm{nm}\cdot\mathrm{eV}$
[Apakah nilai hc/e dalam unit $\mathrm{nm}\cdot\mathrm{eV}$ *?]*

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]

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. $0.000248\,\overset{\circ}{A}$

B. $2.48\,\overset{\circ}{A}$

C. $248\,\overset{\circ}{A}$

D. $0.248\,\overset{\circ}{A}$

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

[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 $L = 0.5\ \overset{\circ}{A}$
[Apakah tenaga titik-sifar bagi elektron yang terperangkap di dalam suatu telaga keupayaan infinit yang saiznya $L = 0.5\ \overset{\circ}{A}$*]*

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

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

(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

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

[2 marks]

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

[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, $E_n = -\dfrac{13.6}{n^2}\,\text{eV}$

Q4c(i)

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

[3 marks]

Q4c(ii)

$\lambda_{6\to 2} = hc/\Delta E_{6\to 2} = 1240\text{nm}\cdot\text{eV}/3.02\text{eV} =$ **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, $c = 3.00 \times 10^{8}$ 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
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
molar gas constant, = 8.31 J K^{-1} mol^{-1}
the Avogadro constant, $N_A = 6.02 \times 10^{23}$ 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]

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)]

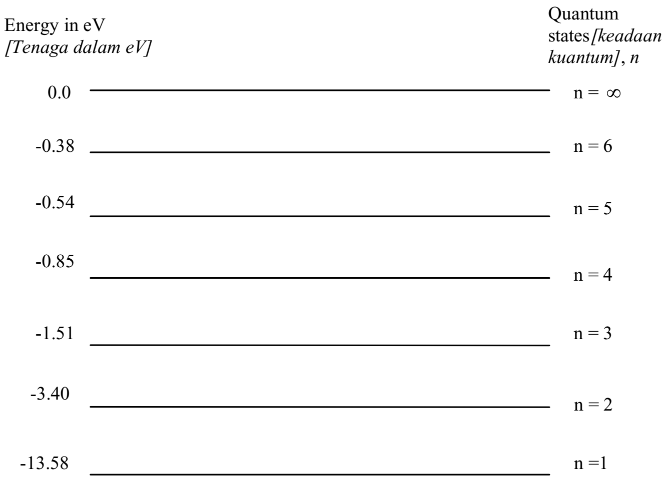


Figure 1 ***[Gambarajah 1]***

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)]

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?]

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:

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

$\Rightarrow v = 0.141\mathrm{c}$

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:

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

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) $m_p c^2 = 1.67 \text{ x } 10^{-27}\text{kg x } (3\times10^8\,\text{m/s})^2 = 1.503\times10^{-10}$ 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.

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

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

$9.1\times10^{-3}\ \overset{o}{\mathrm{A}}$

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

(b) Determine the cutoff wavelength in $\overset{o}{\mathrm{A}}$ of *x*-rays produced by a 50-keV electrons in a *x*-ray tube.
[Tentukan jarak gelombang penggal (dalam unit $\overset{o}{\mathrm{A}}$) sinar x yang dihasilkan oleh elektron 50 keV dalam suatu tiub sinar x.]
[5 marks]

Ans.

$$\lambda_{cutoff} = \frac{hc}{eV} = \frac{1240\text{eV}\cdot\text{nm}}{50\text{keV}} = 0.0248\text{nm} = 0.24\,\overset{o}{\mathrm{A}}$$

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 $\overset{o}{\mathrm{A}}$ and intensity 3×10^{-14} W/m^2.

[Tentukan fluks foton (dalam unit bilangan foton per unit masa per unit luas) yang bersepadanan dengan suatu bim cahaya monokromatik berjarak gelombang 3000 $\overset{o}{\mathrm{A}}$ 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 $r_0 = 0.5\ \overset{o}{\mathrm{A}}$, 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 $r_0 = 0.5\ \overset{o}{\mathrm{A}}$, 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 $R = 1.0967758 \times 10^{-3}\ \overset{o}{\mathrm{A}}^{-1}$, determine, in $\overset{o}{\mathrm{A}}$,

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

wavelengths of the Lyman series of hydrogen.

[Diberi bahawa pemalar Rydberg ialah $R = 1.0967758 \times 10^{-3}\ \overset{o}{\mathrm{A}}^{-1}$. Tentukan, dalam unit $\overset{o}{\mathrm{A}}$, 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 $n = 2$:

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

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

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

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

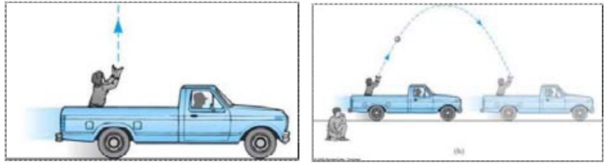
ANS:D, Serway, questions 1, 2, page 1313

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. $\frac{d}{c}$ **B.** $\frac{4d}{\sqrt{3}c}$ **C.** $\frac{2d}{\sqrt{3}c}$ **D.** $\frac{\sqrt{3}d}{c}$ **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').

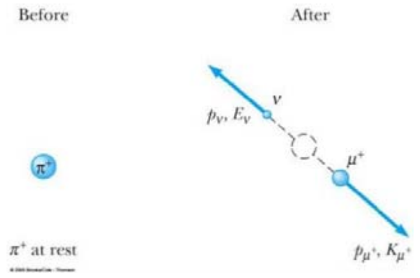
I $r = ct$ **II** $r' = ct'$ **III** $r' = r$ **IV** $r' = ut'$

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 $m_\mu = 106$ MeV/c^2, and the kinetic energy of the muon is measured to be $K_\mu = 4.6$ 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?

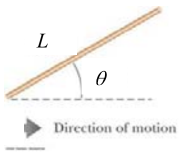
A. $m_e c$ **B.** c **C.** 0 **D.** Infinity **E. Non of the above**

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 $\theta = 45°$ with respect to the direction of motion, as shown in the figure below. The rod has a speed of $u = \frac{c}{\sqrt{2}}$.



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

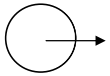
$$\gamma = \frac{1}{\sqrt{1-v^2/c^2}} = \frac{1}{\sqrt{1-\left(\frac{1}{\sqrt{2}}\right)^2}} = \sqrt{2}$$

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 $L_x = \frac{L'_x}{\gamma}$.

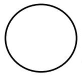
Therefore, $L'_x = \gamma L_x = \sqrt{2}\frac{L}{\sqrt{2}} = L$, and $L'_y = L_y = \frac{L}{\sqrt{2}}$. (Lengths perpendicular to the motion are unchanged). $\Rightarrow (L')^2 = (L'_y)^2 + (L'_x)^2 = \frac{L^2}{2} + L^2 = \frac{3L^2}{2} \Rightarrow L' = \sqrt{\frac{3}{2}}L$

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. $m_e c^2$ **B.** $0.511 m_e c^2$ **C.** $\frac{5}{36}m_e c^2$ **D.** $\frac{\sqrt{5}}{6}m_e c^2$ **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.

*[**Arahan**: 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.]*

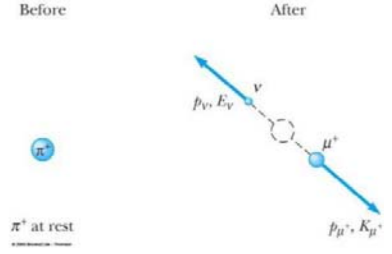
[Pelajar dibenarkan untuk menjawab samada dalam bahasa Malaysia atau bahasa Inggeris.]

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}

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 $m_\mu = 106$ MeV/c^2, and the kinetic energy of the muon is measured to be $K_\mu = 4.6$ 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 $m_\mu = 106$ MeV/c^2, dan tenaga kinetik muon yang terukur ialah $K_\mu = 46$ 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. $p_\mu c = \sqrt{\left(K_\mu + m_\mu c^2\right)^2 - m_\mu^2 c^4}$ **B.** $p_\mu = \sqrt{\left(K_\mu + m_\mu c^2\right)^2 - m_\mu^2 c^4}$
   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. $\sqrt{\left(K_\mu + m_\mu c^2\right)^2 - m_\mu^2 c^4}$ **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 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.]*

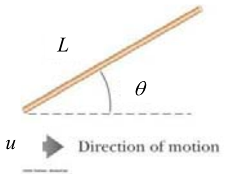
A. II,III **B. I, II,III** **C. II, III, IV** **D. I, II**

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

[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

[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?]*

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,

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 $m \rightarrow n$, where (m, n) is
[Limit siri bagi siri Balmer mewakili satu peralihan m → 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. $E \gg m_e c^2, m_p c^2$), 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) $\dfrac{m_p}{m_e}$ (B) $\sqrt{\dfrac{m_p}{m_e}}$ (C) $\sqrt{\dfrac{m_e}{m_p}}$ (D) $\dfrac{m_p}{m_e}$
(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. $R_{\mathrm{H}}=\dfrac{2\pi^2 m_e e^4}{h^2 c}\left(\dfrac{1}{4\pi\varepsilon_0}\right)^2$ **B.** $R_{\mathrm{H}}=\dfrac{2\pi^2 m_e e^4}{h^3 c}\left(\dfrac{1}{4\pi\varepsilon_0}\right)^2$

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

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

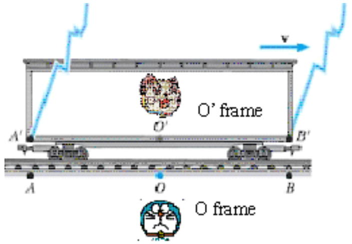
ANS (B), Cutnell and Johnson, pg. 910.

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 x 1.67e J / 9.11 x 10^{-31} kg)$^{1/2}$ = 7.66 x 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:
$\gamma = 1/\sqrt{1-0.95^2} = 3.20$
$p = m\gamma u = 9.1\times10^{-31}\times3.2\times(0.95\times3\times10^8)\mathrm{Ns}{=}8.3\times10^{-22}\,\mathrm{Ns}$

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

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

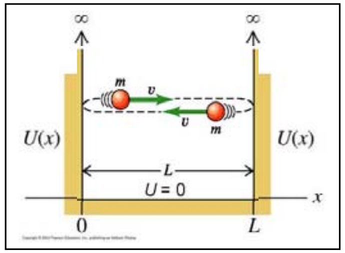
$$\Delta E_{\max} = \frac{hc}{\lambda} - \frac{hc}{\lambda_{\max}} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda + \Delta\lambda_{\max}}\right)$$

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

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 $\frac{\partial^2\psi(x)}{\partial x^2} = -B^2\psi(x)$:

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

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

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

(*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

$$B_n^2 = \frac{2mE_n}{\hbar^2} = \frac{n^2\pi^2}{L^2} \Rightarrow E_n = \frac{n^2\pi^2\hbar^2}{2mL^2}, n = 1,2,3\ldots$$ **[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. $\left(M_P+m_e\right)-\frac{E_k}{c^2}$ B. $\frac{E_k}{c^2}-\left(M_P+m_e\right)$ **C.** $M_P+m_e+\frac{E_k}{c^2}$

D. $\sqrt{\left(M_P+m_e\right)^2+\left(\frac{E_k}{c^2}\right)^2}$ **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]*

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 gelombang λ 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]

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·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·yr/(3.2·0.95c)= 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:

$$0.062\times 60\text{Watt}=2.325\times10^{19}\text{eV/s}$$

$$\text{energy of 1 photon}=\frac{hc}{\lambda}=\frac{1240}{580}\text{eV}=2.13\text{eV}$$

Let number of photon per second = N

$$\text{therefore } N\frac{hc}{\lambda}=2.325\times10^{19}\text{eV/s}$$

$$N=\frac{2.325\times10^{19}\text{eV/s}}{2.13\text{eV}}=1.09\times10^{19}/\text{s}$$

(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 eV – 1.8 eV)/e = 0.68 V
For Cs on W: stopping potential is (2.48 eV – 1.36 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 $\Delta\lambda_{\max}=\dfrac{2h}{m_e c}=2\times2.43\text{pm}=4.86\text{pm}$ when the scattering angle θ= 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, $f_1 = h/4\pi^2 m(r_0)^2 = 6.56\times10^{15}$ Hz.
For n = 2, $f_2 = h/4\pi^2 m(2)^3(r_0)^2 = 6.56\times10^{15}/8$ Hz $= 8.2\times10^{14}$.

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 E₀. 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

$$p = \frac{hc}{\lambda c} \sim \frac{1240\text{eV}\cdot\text{nm}}{\text{few}\left(0.1\text{nm}\right)\times c} = \frac{0.01124\text{MeV}}{\text{few}\times c}$$

$$\Rightarrow K = \frac{p^2}{2m_e} \sim \left(\frac{0.0124\text{MeV}/c}{\text{few}}\right)^2 \frac{1}{2\times 0.5\text{MeV}/c^2} = \frac{1.5\times10^{-4}}{\text{few}^2}\text{MeV}$$

(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

$$E = hf = mc^2 = \gamma m_0 c^2 = \frac{m_0 c^2}{\sqrt{1-\frac{v^2}{c^2}}} \Rightarrow f = \frac{m_0 c^2}{h\sqrt{1-\frac{v^2}{c^2}}}$$