SESSI 07/08/TEST1

ZCT 104/3E Modern Physics
Semester I, Sessi 2007/08
1. Test I (26 Jan 2008)

Name:____

Matrix Number:____

Class A / Class B

Instruction: Do all questions in Section A and Section B.

Duration : 1 Hour

Section A (Objective questions)

1. In the following, which statement(s) is (are) correct regarding two events, A and B, at the space-time coordinates (x_A,t_A) and (x_B,t_B)? Assume $x_A > x_B$, $t_B > t_A$.

    I. If $x_B - x_A > c(t_B - t_A)$, events A and B can never be causally related.
    II. If $x_B - x_A < c(t_B - t_A)$, events A and B could be causally related.
    III. If $x_B - x_A = c(t_B - t_A)$, events A and B must be causally related.
    IV. If $x_B - x_A = c(t_B - t_A)$, events A and B could be causally related.

A. I, II   B. II, IV   C. I, II, III   D. I, II, IV   E. None of A, B, C, D

ANS: D (I, II, IV true).

2. Referring to Question 1 above, the space-time interval of the events A and B, $c^2(t_B - t_A)^2 - (x_B - x_A)^2$, is

    A. always the same in all inertial frames of reference.
    B. unpredictable when measured in other frame of reference.
    C. always positive
    D. always negative
    E. None of A, B, C, D.

ANS: A

3. O' is running at a velocity of v towards O. O' throws out a ball towards O. The velocity of the ball as measured by O is u. What is the velocity of the ball as measured by O'? Assume the velocities are non-relativisitic.

    A. $u + v$ B. $u - v$ C. $v - u$ D. $\sqrt{|u^2 - v^2|}$

    E. (None of **A**, **B**, **C**)

    ANS: B

4. Reconsider Question 3 above. Which of the following statement(s) is (are) true?

    I. Galilean transformation of velocities can be used to calculate the correct relative velocities in Question 3.
    II. Lorentz transformation of velocities can be used to calculate the correct relative velocities in Question 3.
    III. Either Galilean or Lorentz transformation of velocities can be used to calculate the correct relative velocities in Question 3.
    IV. Only one of the Galillean or Lorentz transformations of velocities, BUT not both, can be used to calculate the correct relative velocities in Question 3.

FIZIK IV (MODERN PHYSICS)
ZCT 104
TEST 2
15 March 2008

Instruction: Answer both questions on blank paper. Explain your steps as clearly as possible.

1. In Compton scattering experiment, X-ray photons with frequency f are incident on a target. After collision with electrons which initially at rest, the scattered photons with frequency of f' are observed at angle θ while the recoiled electrons are observed at angle ϕ.
    (a) What is the kinetic energy of the recoiling electron in terms of the f and f'?
    (b) Show that the kinetic energy of the recoiling electron in the Compton scattering is give by the general formula:

$$KE_{recoil\ electron} = \frac{2\left(\frac{h}{m_e c}\right)\sin^2\left(\frac{\theta}{2}\right)}{\frac{c}{f} + 2\left(\frac{h}{m_e c}\right)\sin^2\left(\frac{\theta}{2}\right)} hf$$

    Where m_e = rest mass of electron
    h = Planck's constant
    c = speed of light
    θ = angle of the scattered-photon
    f = frequency of the incident photon

    [*Hint:* $\cos\theta = 1 - 2\sin^2\left(\frac{\theta}{2}\right)$.]

    (c) Show that the maximum kinetic energy of the recoiling electron in this Compton scattering experiment is given by

$$KE_{max}(recoiling\ electron) = hf\,\frac{\frac{2hf}{m_e c^2}}{1 + \frac{2hf}{m_e c^2}}$$

    (i) At what angles θ and ϕ does this occur?
    (ii) If we detect a scattered electron at ϕ = 0° of 100 keV, what energy photon was scattered?

[25 marks]

2. Being not prohibited by the uncertainty principle, a particle of mass m can be created spontaneously in vacuum, exists for a short period of lifetime, Δt, and then annihilate into vacuum again. **[25 marks]**

    (i) How long will this particle exist (i.e, what is Δt in terms of m)?

    (ii) If the particle travels at approximately the speed of light, approximately how far will it travel during its short existence?

    (iii) If such a spontaneous creation-annihilation happens within the nucleus, of a typical size of r ~ fm, estimate the mass of m in unit of MeV.

(iv) Estimate the lifetime of *m* of the mass as calculated in (iii), in unit of seconds.

Solution:

1.

(a) $$KE_{recoil\ electron} = hf - hf^{'} \qquad (1a)$$

(b) From the Compton scattering formula, we have

$$\lambda^{'} - \lambda = \frac{h}{m_e c}(1-\cos\theta) \qquad (1b)$$

By substituting

$$\lambda^{'} = \frac{c}{f^{'}} \quad \text{and} \quad \lambda = \frac{c}{f}$$

into Equation (1b) and after a bit of algebra, we find

$$f^{'} = \frac{f m_e c}{hf(1-\cos\theta) + m_e c} \qquad (1c)$$

By substituting Equation (1c) into 1(a) and after a bit algebra, the kinetic energy of the recoiling electrons given by

$$KE_{recoil\ electron} = \frac{2\left(\frac{h}{m_e c}\right)\sin^2\left(\frac{\theta}{2}\right)}{\frac{c}{f} + 2\left(\frac{h}{m_e c}\right)\sin^2\left(\frac{\theta}{2}\right)} hf \qquad (1d)$$

(c) From Equation (1d), the kinetic energy of the recoiling electron become maximum when $\sin^2\left(\frac{\theta}{2}\right)$ = 1. Consequently,

$$KE_{max}(recoiling\, electron) = \frac{2\left(\frac{h}{m_e c}\right)}{\frac{c}{f} + 2\left(\frac{h}{m_e c}\right)} hf \qquad (1e)$$

After a bit algebra, the maximum kinetic energy of the recoiling electron is

$$KE_{max}(recoiling\, electron) = hf \frac{\frac{2hf}{m_e c^2}}{1 + \frac{2hf}{m_e c^2}} \qquad (1f)$$

(c) (i)

From (c), the kinetic energy of the recoiling electron become maximum when

$\sin^2\left(\frac{\theta}{2}\right) = 1$ or θ = 0°, 180° and 360°

Therefore, the kinetic energy of the recoiling electron become maximum when

θ = 180° (head-on collision) because the shift in wavelength is zero at 0°.

and ϕ = 0°.

(c) (ii)

Here, $\phi = 0°$, θ = 180°, and KE_{max} (*recoiling electron*) = 100 keV.

By substituting these values into Equation 1(d) and solving the equation for *hf*, we obtain

hf = 0.2173 MeV

[*Hint*: In order to get this answer, you need to get the quadratic equation and then solves the equation by using:

$$x = \frac{-b \pm \sqrt{b^2 + 4ac}}{2a}\ .$$

]

Finally, replace the *hf* = 0.2173 MeV and KE_{max} (*recoiling electron*) = 100 keV into Equation (1a), we obtain

Energy of scattered photon $= hf'$

$= hf - KE_{recoil\ electron}$

¿$(0.2173 - 0.1)$ MeV

¿0.173 MeV

2. (i) $$\Delta t \sim \frac{\hbar}{2\Delta E} = \frac{\hbar}{2mc^2}$$

(ii) $$x = c\,\Delta t \sim \frac{\hbar}{2mc}$$

(iii) take *x* = *r*,

$$r \sim \frac{\hbar}{2mc} \Rightarrow mc^2 \sim \frac{\hbar c}{2r} = \frac{hc}{4\pi r} = \frac{1240\ \text{eV}\cdot 10^{-9} m}{4\pi \times 10^{-15} m} = \frac{1240\ \text{eV}\cdot 10^{-9} m}{4\pi \times 10^{-15} m} = 98.7\text{MeV} \sim 100\text{MeV}$$

(iv)

$$\Delta t \sim \frac{\hbar}{2\Delta E} = \frac{\hbar c}{2cmc^2} = \frac{hc}{4\pi cmc^2} = \frac{1240\ \text{eV}\cdot 10^{-9} m}{4\pi \times (3\times 10^8 \text{m/s})100\text{MeV}} = \frac{1240\ \text{eV}\cdot 10^{-9}}{4\pi \times (3\times 10^8)(100\times 10^6)\text{eV}} s$$

¿$$\frac{1240\, 10^{-9}}{4\pi \times (3\times 10^8)(100\times 10^6)} s \sim 10^{-24} s$$

A. I,II B. IV only C. I,II,IV D. I, IV E. None of A,B,C,D

ANS: E (I,II, III are true.)

5. Reconsider the similar scenario as in Question 3 above but with both *u*, *v relativistic*. Which of the following statements is true?

A. the speed of the ball as measured by O' would be smaller than that in Question 3.
B. the speed of the ball as measured by O' would be larger than that in Question 3.
C. the speed of the ball as measured by O' would be equal to that in Question 3.
D. the speed of the ball as measured by O' could be larger or smaller than that in Question 3.
E. None of A, B,C,D.
ANS: B

ANS: Let u be the velocity of the ball observed by O. O' is moving with a velocity v with respect to O. The Lorentz transformation for u,v and u', the velocity of the ball as measured by O', is simply

$u' = \dfrac{u-v}{1-\dfrac{uv}{c^2}}$. Since u,v has the same direction, $1-\dfrac{uv}{c^2}<1, \therefore |u'| = \left|\dfrac{u-v}{1-\dfrac{uv}{c^2}}\right| > |u-v|$

6. Given a species of fly has an average lifespan of τ. Let say you put many of them in a box and send them to a destination at some remote destination in deep space using a rocket that travel at speed v. The destination is located at a distance of L from Earth. Considering only special relativistic effect and assuming that none of the flies die of any cause other than aging, which of the following statements is (are) correct? (Lorentz factor is defined as $\gamma = [1-(v/c)^2]^{-1/2}$).

I. To the Earth observer, the time taken by the rocket to arrive at its destination is L/v.
II. To the flies, the time taken by the rocket to arrive at its destination is $(1/\gamma)(L/v)$.
III. Most of the flies would survive if $(1/\gamma)(L/v) < \tau$
IV. Most of the flies would survive if $(L/v) < \tau$

A. I,II B. I,II,III C. I,II,IV D. I, II,III,IV
E. None of A,B,C,D

ANS: D (ALL are true.)

7. Consider an object moving in a straight line with constant speed. Say in frame O, the momentum of the object is measured to be P. In a frame O′ moving with a non-zero relative constant velocity with respect to O, the momentum of the same object is measured to be P'. Which of the following statements are (is) true regarding P and P'?

I. In non-relativistic regime, P and P' have a same numerical value.
II. In relativistic regime, P and P' have a same numerical value.
III. P and P' have a same numerical value in the relativistic regime but not in the non-relativistic one.
IV. P and P' have a same numerical value in the non-relativistic regime but not in the relativisitic one.

A. I,II B. II,III C. I, IV D. III,IV
E. None of A, B, C,D

ANS: E (P,P' in general are different in different frames of reference, since momentum is not an invariant.)

8. Consider an object moving in a straight line with constant speed. Say in frame O, the kinetic energy of the object is measured to be K. In a frame O′ moving with a non-zero relative constant velocity with respect to O,

the kinetic energy of the same object is measured to be K'. Which of the following statements are (is) true regarding K and K'?

I. In non-relativistic regime, K and K' have a same numerical value.
II. In relativistic regime, K and K' have a same numerical value.
III. K and K' have a same numerical value in the relativistic regime but not in the non-relativistic one.
IV. K and K' have a same numerical value in the non-relativistic regime but not in the relativisitic one.

A. I,II B. II,III C. I, IV D. III,IV
E. None of A, B, C,D

ANS: E (K,K' in general are different in different frames of reference, since kinetic energy is not an invariant.)

9. A subatomic particle of rest mass of M, initially at rest, decays into two daughter subatomic particles with rest masses m_1 and m_2 respectively. Which statements in the following is (are) true?

I. $M = m_1 + m_2$
II. $(M - m_1 - m_2)c^2$ equals the sum of kinetic energy of the daughter subatomic particles.
III. The kinetic energy of the daughter subatomic particle with rest mass m_1 equals the kinetic energy of the daughter subatomic particle with rest mass m_2.
IV. The momentum of the daughter subatomic particle with rest mass m_1 equals the momentum of the daughter subatomic particle with rest mass m_2.

A. I,IV B. II,III, IV C. III, IV D. II,IV
E. None of A,B,C,D

ANS: D

10. A clock moving with a finite speed v is observed to run slow. If the speed of light were to be halved, you would observe the clock to be

A. Even slower.
B. Still slow but not as much
C. As slow as it was
D. To start to actually run fast.
E. None of A, B, C,D

ANS: A. The gamma-factor would be modified. The time dilation effect will be greater if c becomes $c/2$.

$$\gamma(c) \to \gamma(c/2) \equiv \gamma'(c)$$

$$\Rightarrow (\gamma')^2 = \frac{1}{1-\left(\frac{v}{c/2}\right)^2} = \frac{1}{1-4\left(\frac{v}{c}\right)^2} > \gamma^2 = \frac{1}{1-\left(\frac{v}{c}\right)^2}$$

Alternatively, in an ordinary world with speed of light c, the asymptote of the Lorentz factor γ is at $v=c$, whereas in a world with speed of light $c'=c/2$, the asymptote for γ' occurs at $v = c/2$. This intuitive argument leads to the conclusion that γ' is generally larger than γ at the same v.

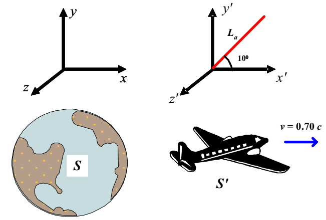
Section B (Structured questions)

1. A spacecraft antenna is at an angle of 10° relative to the axis of the spacecraft. If the spacecraft moves away from the earth at a speed of 0.70c, what is the angle of the antenna as seen from the earth? (biser, p.50) [Ans. 14°]

2. At what velocity does the KE of a particle equal its rest energy? [Ans. 2.6×10^{8} m s^{-1}] (Chand, p.25)

Solutions:

1. Let say the length of the antenna as measured by an observer on the spacecraft (system S') is L_a.



According to system S':

The projection of the antenna onto the spacecraft,

$$L_{a,x'} = L_a \cos(10°).$$

The projection of the antenna onto an axis perpendicular to the spacecraft's axis,

$$L_{a,y'} = L_a \sin(10°).$$

To an observer on the earth (system S):

The length in the direction of the spacecraft's axis will be contracted:

$$L_{a,x} = \frac{1}{\gamma} L'_{a,x'} = L'_{a,x'}\sqrt{1-\frac{v^2}{c^2}}$$

$$\therefore \qquad L_{a,x} = L_a \cos(10°)\sqrt{1-\left(\frac{0.70c}{c}\right)^2}. \qquad (1)$$

The length perpendicular to the spacecraft's motion will appear unchanged:

$$L_{a,y} = L_{a,y'} = L_a \sin(10°). \qquad (2)$$

The angle as seen from the earth will then be [Eq. (2) / Eq. (1)]:

$$\tan\theta = \frac{L_{a,y}}{L_{a,x}}$$

$$= \frac{L_a \sin(10°)}{L_a \cos(10°)\sqrt{1-\left(\frac{0.70c}{c}\right)^2}}$$

$$= \frac{\tan(10°)}{\sqrt{1-\left(\frac{0.70c}{c}\right)^2}}$$

$$\therefore \quad \theta = \arctan\left[\frac{\tan(10°)}{\sqrt{1-\left(\frac{0.70c}{c}\right)^2}}\right]$$

$$= 14°$$

2. If the kinetic energy KE = $E_0 = m_0c^2$, then the total energy will become

$$E = E_0 + KE = m_0c^2 + m_0c^2 = 2m_0c^2 \qquad (1)$$

Since,

$$E = mc^2 = \gamma m_0c^2 = \frac{1}{\sqrt{1-v^2/c^2}}m_0c^2 \qquad (2)$$

Therefore, Eq. (1) = Eq. (2)

$$\frac{1}{\sqrt{1-v^2/c^2}}m_0c^2 = 2m_0c^2$$

$$\therefore \quad \frac{1}{\sqrt{1-v^2/c^2}} = 2$$

Solving for v,

$$v = \frac{\sqrt{3}}{2}c = 2.60\times10^8 \text{ m s}^{-1}$$

FIZIK IV (MODERN PHYSICS)
ZCT 104
TEST
24 March 2008

Instruction: Two questions are prepared. Please answer both of them in this question sheet. Use extra blank paper if you need more space. Explain your steps as clearly as possible.

1. In Compton scattering experiment, X-ray photons with wavelength λ are incident on a target. After collision with electrons which initially at rest, the scattered photons are observed at angle θ while the recoiled electrons are observed at angle ϕ.
   (a) Show that the angle between the directions of the recoil electron and the incident photon is given by

$$\tan\phi = \frac{\sin\theta}{(1+\cos\theta)\left[\frac{h}{m_e c\lambda}+1\right]}.$$

Here h = Planck constant
λ = wavelength of incident photons
m_e = rest mass of electron
c = speed of light

   (b) If the wavelength of the X-rays is 1.5406Å and the scattered photons are observed at 120°, find
   (i) the wavelength of the scattered photons,
   (ii) the angle of the recoil electron, and
   (iii) the kinetic energy of the recoil electron (in keV).

[25 marks]

2. (a) Derive a non-relativistic formula that gives the de Broglie wavelength of a particle, of charge q and mass m, in terms of the potential difference V through which it has been accelerated.

(b) Derive the relativistic version for the de Broglie wavelength in (a).

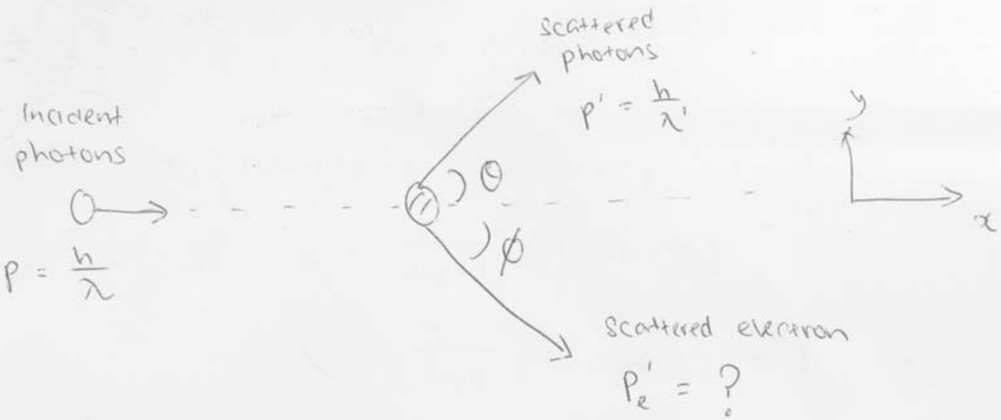
(c) Show that your formula in (b) reduces to that of (a) in the limit of $qV << mc^2$.

[25 marks]

Solution:

make-up test 0708

a) Let consider the conservation of momentum in 2-D



⇒ Based on the principle of conservation of momentum

Initial momentum = final momentum.

⇒ In x-direction:

$$p + 0 = p'\cos\theta + p_e'\cos\phi$$

$$p_e'\cos\phi = p - p'\cos\theta \quad (1)$$

⇒ In y-direction

$$0 + 0 = p'\sin\theta - p_e'\sin\phi$$

$$\therefore \quad p_e'\sin\phi = p'\sin\theta \quad (2)$$

⇒ $\frac{(2)}{(1)}$

$$\tan\phi = \frac{p'\sin\theta}{p - p'\cos\theta}$$

$$= \frac{\sin\theta}{p/p' - \cos\theta} \quad (3)$$

Since $p = \frac{h}{\lambda}$ & $p' = \frac{h}{\lambda'}$, we have

$$\tan\phi = \frac{\sin\theta}{\lambda'/\lambda - \cos\theta} \quad (4)$$

⇒ From the compton's scattering formula:

$$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

$$\lambda' = \frac{h}{m_e c}(1 - \cos\theta) + \lambda \quad (5)$$

⇒ ~~Replace (5)~~ By substituting (5) into (4)

$$\therefore \tan\phi = \frac{\sin\theta}{\frac{\left[\frac{h}{m_e c}(1-\cos\theta) + \lambda\right]}{\lambda} - \cos\theta}$$

$$= \frac{\sin\theta}{\left(\frac{h}{m_e c\lambda}(1-\cos\theta) + 1\right) - \cos\theta}$$

$$= \frac{\sin\theta}{(1-\cos\theta)\left[\frac{h}{m_e c\lambda} + 1\right]} \quad (6)$$

(shown)

make-up test 0708

b) Here $\lambda = 1.5406 \times 10^{-10}$ m, $\theta = 120^0$

i) $$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

$$\lambda = \frac{h}{m_e c}(1 - \cos\theta) + \lambda$$

$$= 2.43 \times 10^{-10}(1 - \cos 120) + 1.5406 \times 10^{-10} \text{ m}$$

$$= 1.5771 \times 10^{-10} \text{ m}$$

$$= 1.5771 \text{ Å}$$

ii) From Equation (6)

$$\tan\phi = \frac{\sin 120}{(1-\cos 120)\left[\frac{2.43\times10^{-12}}{1.5406\times10^{-10}} + 1\right]}$$

$$= \frac{0.866}{(1.5)(1.0158)}$$

$$= 0.5684$$

$$\phi = 29.61^0$$

iii) The kinetic energy of the recoil electron:

$$KE\,(\text{recoil electron}) = \frac{hc}{\lambda} - \frac{hc}{\lambda'}$$

$$= \frac{1240 \text{ eV.nm}}{0.15406\text{nm}} - \frac{1240 \text{ eV.nm}}{0.15771 \text{ nm}}$$

$$= 8.049 \text{ keV} - 7.863 \text{ keV}$$

∴ KE (recoil electron) = 0.186 keV

Solution:

Q2. Beiser, Ex. 12, pg 117.

(a) Non-relativistic scenario:

If the electron is non-relativistic, $K = p^2/2m$;

According to de Broglie's postulate, $p = h/\lambda$;

$K = qV$;

Hence,

$K = qV = p^2/2m = (h/\lambda)^2/2m$

$\Rightarrow qV = h^2/2m\lambda^2$

$\Rightarrow \lambda = h/\sqrt{(2mqV)}$.

(b) $K = qV$;

K is related to momentum p via $E^2 = (K + mc^2)^2 = p^2c^2 + m^2c^4 \Rightarrow K^2 + 2Kmc^2 = p^2c^2$

$$\Rightarrow K = \frac{-2mc^2 \pm \sqrt{4m^2c^4 + 4p^2c^2}}{2} = -mc^2 \pm c^2\sqrt{m^2 + p^2/c^2}$$

$$\Rightarrow K = c^2\left(\sqrt{m^2 + p^2/c^2} - m\right) = qV$$

$$p^2 = \left(\frac{qV}{c^2} + m\right)^2 c^2 - m^2c^2 = \frac{q^2V^2}{c^2} + 2mqV = \frac{h^2}{\lambda^2}$$

$$\Rightarrow \lambda = \frac{hc}{\sqrt{q^2V^2 + 2mc^2qV}}$$

(c) λ In non-relativistic limit:

$$\lambda = \frac{hc}{\sqrt{2qVmc^2}\sqrt{\frac{qV}{2mc^2} + 1}} = \frac{hc}{\sqrt{2qVmc^2}}\left(1 + \frac{qV}{2mc^2}\right)^{-1/2} = \frac{hc}{\sqrt{2qVmc^2}}\left(1 - \frac{qV}{4mc^2} + ...\right)$$

$$\Rightarrow \lim_{qV \ll mc^2} \lambda = \frac{hc}{\sqrt{2qVmc^2}} = \frac{h}{\sqrt{2qVm}}$$

Data

Speed of light in free space, $c = 3.00 \times 10^8$ m s^{-1}
Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
Permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
Elementary charge, $e = 1.60 \times 10^{-19}$ C
Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg
Molar gas constant, = 8.31 J K^{-1} mol^{-1}
Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}
Gravitational constant, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
Acceleration of free fall, $g = 9.81$ m s^{-2}

Section A: Objectives. [20 marks]
[Bahagian A: Soalan-soalan objektif]

Instruction: Answer all 20 objective questions in this Section.
[Arahan: Jawab kesemua 20 soalan objektif dalam Bahagian ini.]

1. How fast must a spacecraft travel relative to the earth for each day on the spacecraft to correspond to 2 day on the earth?
[Apakah kelajuan suatu kapal angkasa relatif kepada bumi supuya setiap hari dalam kapal angkasa setara dengan dua hari di bumi?]

A. $\sqrt{3}/2c$ B. $\sqrt{2}/3c$. C. $2/\sqrt{3}c$. D. $1/\sqrt{3}c$ E. c

2. Which of the following statement is true?
[Yang manakah kenyataan-kenyataan berikut adalah benar?]

A. It is possible for the electron beam in a television picture tube to move across the screen at a speed faster than the speed of light. This does not contradict special relativity.
[Adalah mungkin bagi bim elektron dalam tiub televisyen untuk bergerak merentasi skrin dengan laju yang lebih cepat daripada laju cahaya. Ini tidak bercanggah dengan kerelatifan khas.]

B. It is possible for the electron beam in a television picture tube to move across the screen at a speed faster than the speed of light despite this contradicts special relativity.
[Adalah mungkin bagi bim elektron dalam tiub televisyen untuk bergerak merentasi skrin dengan laju yang lebih cepat daripada laju cahaya walaupun ini bercanggah dengan kerelatifan khas.]

C. It is NOT possible for the electron beam in a television picture tube to move across the screen at a speed faster than the speed of light because this contradicts special relativity.
[Adalah TIDAK mungkin bagi bim elektron dalam tiub televisyen untuk bergerak merentasi skrin dengan laju yang lebih cepat daripada laju cahaya kerana ini bercanggah dengan kerelatifan khas.]

D. It is NOT possible for the electron beam in a television picture tube to move across the screen at a speed faster than the speed of light despite this does not contradict special relativity.
[Adalah TIDAK mungkin bagi bim elektron dalam tiub televisyen untuk bergerak merentasi skrin dengan laju yang lebih cepat daripada laju cahaya walaupun ini tidak bercanggah dengan kerelatifan khas.]

E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A,B,C,D]

3. A massless neutrino is measured to have a relativistic energy of 1 MeV. What is the order of magnitude of its momentum, in SI unit?
[Tenaga kerelatifan suatu neutrino yang berjisim sifar diukurkan dan bernilai 1 MeV. Apakah tertib magnitud momentumnya dalam unit SI?]

A. -19 B. -20 C. -21 D. -22 E. -23

4. Which of the following statements is (are) true?
[Yang manakah kenyataan-kenyataan berikut adalah benar?]

I. Heisenberg uncertainty principle is closely related to the particle attribute of things.
[Prinsip ketidakpastian Heisenberg adalah berkait rapat dengan tabii zarah jasad.]

II. Heisenberg uncertainty principle is closely related to the wave-particle duality of things.
[Prinsip ketidakpastian Heisenberg adalah berkait rapat dengan dualiti gelombang-zarah jasad.]

III. The ultimate accuracy of a simultaneous measurement on the position and linear momentum of a microscopic particle moving in one-dimension is constrained by the Heisenberg uncertainty principle.
[Kejituan muktamat ukuran serentak ke atas kedudukan dan momentum linear bagi zarah mikroscopik yang bergerak dalam satu dimensi adalah dikekang oleh prinsip ketidakpastian Heisenberg .]

IV. The ultimate accuracy of a simultaneous measurement on the x-coordinate and y-coordinate of a microscopic particle moving in two-dimension is constrained by the Heisenberg uncertainty principle.
[Kejituan muktamat ukuran serentak ke atas koordinat-x dan koordinat-y bagi zarah mikroscopik yang bergerak dalam dua dimensi adalah dikekang oleh prinsip ketidakpastian Heisenberg .]

A. I, III, IV
B. II, III
C. II, IV
D. I, II, IV
E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A,B,C,D]

5. Which of the following statements is (are) true regarding the spectrum of hydrogen atom, according to the Bohr model?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai spektrum atom hidrogen menurut model Bohr?]

I. The spectral line of the shortest wavelength in the Lyman series in the emission spectrum of a hydrogen atom is more energetic than the spectral line of the shortest wavelength in the Balmer series.
[Garis spektrum yang berjarak gelombang paling pendek dalam siri Lyman dalam spektrum pancaran suatu atom hidrogen adalah lebih bertenaga daripada garis spektrum yang berjarak gelombang paling pendek dalam siri Balmer.]

II. The spectral line of the longest wavelength in the Lyman series in the emission spectrum of a hydrogen atom is more energetic than the spectral line of the shortest wavelength in the Balmer series.
[Garis spektrum yang berjarak gelombang paling panjang dalam siri Lyman dalam spektrum pancaran suatu atom hidrogen adalah lebih bertenaga daripada garis spektrum yang berjarak gelombang paling pendek dalam siri Balmer.]

III. The spectral line of the shortest wavelength in the Lyman series in the emission spectrum of a hydrogen atom is more energetic than the spectral line of the longest wavelength in the Balmer series.
[Garis spektram yang berjarak gelombang paling pendek dalam siri Lyman dalam spektrum pancaran suatu atom hidrogen adalah lebih bertenaga daripada garis spektram yang berjarak gelombang paling panjang dalam siri Balmer.]

IV. The spectral line of the longest wavelength in the Lyman series in the emission spectrum of a hydrogen atom is more energetic than the spectral line of the longest wavelength in the Balmer series.
[Garis spektrum yang berjarak gelombang paling panjang dalam siri Lyman dalam spektrum pancaran suatu atom hidrogen adalah lebih bertenaga daripada garis spektrum yang berjarak gelombang paling panjang dalam siri Balmer.]

A. I, II, III, IV
B. I, II, III
C. II, IV
D. III, IV
E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A,B,C,D]

6. Which of the following statements is (are) true regarding the kinetic energy of an object?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tenaga kinetik suatu objek?]

I. The upper limit of the kinetic energy of an object is infinity.
[Limit atas tenaga kinetik suatu objek adalah infinit.]

II. The lower limit of the kinetic energy of an object is negative infinity.
[Limit bawah tenaga kinetik suatu objek adalah infiniti negatif.]

III. The kinetic energy of an object is equal to the increase in its relativistic mass times c^2.
[Tenaga kinetik suatu objek adalah bersamaan dengan pertambahan dalam jisim kerelatifannya darab c^2.]

IV. The decrease in the kinetic energy of an object is equal to the decrease in its relativistic mass times c^2.
[Pengurangan dalam tenaga kinetik suatu objek adalah bersamaan dengan pengurangan dalam jisim kerelatifannya darab c^2.]

A. I, II, III
B. II, IV
C. I, II, III, IV
D. I, III, IV
E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C,D]

7. Which of the following statements is (are) true regarding a blackbody?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai suatu jasad hitam?]

I. A perfect blackbody does not radiate electromagnetic radiation.
[Jasad hitam sempurna tidak memancarkan pancaran elektromagnet.]

II. A perfect blackbody radiates the whole spectrum of electromagnetic radiation.
[Jasad hitam sempurna tidak memancarkan pancaran elektromagnet.]

III. An approximate blackbody does not radiate electromagnetic radiation.
[Jasad hitam hampiran tidak memancarkan pancaran elektromagnet.]

IV. An approximate blackbody radiates electromagnetic radiation.
[Jasad hitam hampiran memancarkan pancaran elektromagnet.]

A. I, III
B. II,IV
C. I, IV
D. II,III
E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C,D]

8. The unit of Compton shift is that of:
[Unit bagi anjakan Compton adalah sama dengan unit bagi:]

A. energy *[tenaga]*
B. time *[masa]*
C. momentum *[momentum]*
D. length *[panjang]*
E. frequency *[frekuensi]*

9. In the Planck theory of blackbody radiation,
[Dalam teori Planck untuk pancaran jasad hitam,]

I. The smallest amount of energy carried by a single mode of oscillation in the electromagnetic radiation is proportional to the frequency of that mode.
[Jumlah tenaga yang paling kecil yang terbawa oleh suatu mod ayunan tertentu dalam pancaran elektromagnetik adalah berkadar terus dengan frekuensi mod tersebut.]

II. The smallest amount of energy carried by a single mode of oscillation of non-zero frequency in the electromagnetic radiation is non-zero.
[Jumlah tenaga yang paling kecil yang terbawa oleh suatu mod ayunan bukan sifar tertentu dalam pancaran elektromagnetik adalah bukan sifar.]

III. The smallest amount of energy carried by a single mode of oscillation in the electromagnetic radiation is proportional to the amplitude squared of the electromagnetic field of that mode.
[Jumlah tenaga yang paling kecil yang terbawa oleh suatu mod ayunan tertentu dalam pancaran elektromagnetik adalah berkadar terus dengan kuasadua amplitud medan elektromagnetik mod tersebut.]

IV. The smallest amount of energy carried by a single mode of oscillation in the electromagnetic radiation is zero.
[Jumlah tenaga yang paling kecil yang terbawa oleh suatu mod ayunan tertentu dalam pancaran elektromagnetik adalah sifar.]

A. II, III
B. I, II
C. I,II, III
D. I, III,IV
E. None of A, B, C, D [*Jawapan tiada dalam A, B, C, D*]

10. The light intensity incident on a metallic surface produces photoelectrons which could be stopped by a stopping potential of V_s. If the wavelength is halved, a stopping potential of V' is required to stop the photoelectrons. Which statement in the following correctly relates V_s to V' ?
[Keamatan cahaya yang menujui suatu permukaan logam menghasilkan fotoelektron yang dapat diberhentikan dengan keupayaan penghenti V_s. Jika jarak gelombang disetengahkan, keupayaan penghenti V' diperlukan untuk memberhentikan fotoelektron yang terhasil. Kenyataan berikut yang manakah dengan betulnya menghubungkaitkan V_s dengan V' ?]

A. $V' > 2V_s$
B. $V' < 2V_s$
C. $V' = 2V_s$
D. $V' < V_s$
E. V' could be larger or smaller than V_s
[V' mungkin lebih besar atau kecil daripada V_s]

11. Which of the following statements is (are) true about photon?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai foton?]

I. It is mandatory for photon in vacuum to travel at the speed of light *c*.
[Adalah mandatori bagi foton dalam vakum untuk bergerak dengan laju cahaya c.]

II. Photon does not gravitate since it has no mass.
[Foton tidak mengraviti kerana ia tidak berjisim.]

III. Photon gravitates since it has energy.
[Foton mengraviti kerana ia mempunyai tenaga.]

IV. Photon interacts with atoms.
[Foton berinteraksi dengan atom-atom.]

A. II, IV
B. I, II
C. I, III, IV
D. III, IV
E. None of A, B, C, D
[Jawapan tiada dalam A,B,C,D]

12. Which of the following statements is (are) true about the nature of X-ray?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tabii sinar X?]

I. X-ray is made up of neutral particles of non-zero mass.
[Sinar-X adalah terdiri daripada zarah-zarah bercas yang berjisim bukan sifar.]

II. X-ray is made up of charged particles.
[Sinar-X adalah terdiri daripada zarah-zarah bercas.]

III. X-ray can be produced by bombarding metal targets with electron at the energy of ~ eV.
[Sinar-X boleh dihasilkan dengan menghentum sasaran logam dengan elektron bertenaga ~eV.]

IV. A proton-antiproton pair will annihilates into a pair of X-ray photons.
[Pasangan proton-antiproton akan saling membinasa kepada pasangan foton sinar-X.]

A. II, III
B. I, IV
C. I, III
D. II, IV
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

13. Which of the following statements is (are) true regarding the energies of a hydrogen atom according to the Bohr model?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tenaga atom hidrogen menurut model Bohr?]

I. The total mechanical energy of a hydrogen atom is negative.
[Jumlah tenaga mekanik suatu atom hidrogen adalah negatif.]

II. The kinetic energy of an electron in a hydrogen atom is negative.
[Tenaga kinetik bagi suatu elektron dalam atom hidrogen adalah negatif.]

III. The potential energy of a hydrogen atom is negative.
[Tenaga keupayaan bagi suatu atom hidrogen adalah negatif.]

IV. The total mechanical energy of an ionized hydrogen atom is 0.
[Jumlah tenaga mekanik bagi suatu atom hidrogen terionkan adalah sifar.]

…10/-

A. I, II,IV
B. II,IV
C. I, III,IV
D. I, III
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

14. Which of the following statements is (are) true regarding photoelectric effect?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai kesan fotoelektrik?]

I. In a photoelectric effect experiment, the intensity of photoelectron detected will keep increasing when the incident wavelength keep decreasing, while other parameters are fixed.
[Dalam eksperimen kesan fotoelektrik, keamatan fotoelektron yang diukur akan terus meningkat bila jarak gelombang tuju terus berkurang, dengan parameter-parameter lain ditetapkan.]

II. Photoelectric effect can be explained in terms of classical electromagnetic theories.
[Kesan fotoelektrik boleh diterangkan dengan teori elektromagnetik klasik.]

III. The cutoff frequency in a photoelectric effect experiment is a measure of the maximal kinetic of the photoelectron.
[Frekuensi penggal dalam eksperimen fotoelektrik merupakan suatu ukuran bagi tenaga kinetik maksimum fotoelektron.]

IV. The stopping potential in a photoelectric effect experiment is a measure of the work function of the target material.
[Keupayaan penghenti dalam eksperimen fotoelektrik merupakan suatu ukuran bagi fungsi kerja bahan sasaran.]

A. I only
B. I, II, III, IV
C. I, II
D. III, IV
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

…11/-

15. Which of the following statements is (are) true?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. Gamma rays will undergo spontaneous electron-positron pair production in vacuum.
[Sinar gamma boleh menjalani penghasilan pasangan elektron-positron secara spontan dalam vakum.]

II. The probability of a photon to undergo a Compton scattering with the free electron in a metallic target generally drops when the photon energy increases beyond ~ MeV.
[Kebarangkalian suatu foton menjalani serakan Compton dengan elektron bebas dalam suatu sasaran logam secara amnya akan berkurangan jika energy foton bertambah melebihi MeV.]

III. The larger the atomic number of the target material, the larger the probability of an incident X-ray photon to undergo Compton scattering in that target.
[Lebih besar nombor atom bahan sasaran, lebih besar kebarangkalian suatu foton sinar X tuju menjalani serakan Compton dalam sasaran tersebut.]

IV. The larger the atomic number of the target material, the larger the probability of an incident gamma-ray photon of energy $>2m_ec^2$ to undergo electron-positron pair-production in that sample.
[Lebih besar nombor atom bahan sasaran, lebih besar kebarangkalian suatu foton sinar gamma tuju bertenaga $>2m_ec^2$ menjalani penghasilan pasangan elektron-positron dalam sasaran tersebut.]

A. II, III
B. I, IV
C. I, III
D. II, IV
E. None of A, B, C, D [*Jawapan tiada dalam A,B,C,D*]

16. A relativistic electron has a de Broglie wavelength of λ. Find its total relativistic energy.
[Jarak gelombang de Broglie suatu elektron kerelatifan ialah λ. Hitungkan jumlah tenaga kerelatifannya.]

A. $c\sqrt{\frac{\lambda^2}{h^2}+m_e^2c^2}$
B. $c\sqrt{\frac{h^2}{\lambda^2}+m_e^2c^2}$
C. $\sqrt{\frac{h^2}{\lambda^2}+m_e^2c^2}.$
D $\frac{hc}{\lambda}+m_ec^2$
E. None of the above
[Jawapan tiada dalam A, B, C, D]

17. Consider the photoelectric effect experiment. According to classical electromagnetic theory,
[Pertimbangkan eksperimen kesan fotoelektrik. Menurut teori elektromagnet klasikal,]

I. the photoelectron is expected to be ejected from the atom immediately.
[fotoelektron dijangka akan ditendang keluar dari atom dengan serta-merta.]

II. some time interval is required for the atom to absorb enough energy from the electromagnetic radiation before the photoelectron can be ejected from the atom.
[suatu selang masa adalah diperlukan untuk atom menyerap cukup tenaga daripada pancaran electromagnet sebelum fotoelektron dapat ditendang keluar dari atom.]

III. the atom will never absorb any electromagnetic energy from the incident light.
[atom tidak akan menyerap apa-apa tenaga elektromagnetik daripada pancaran cahaya tuju.]

IV. the atom will absorb the electromagnetic energy from the incident light at a rate proportional to the intensity of the incident light.
[atom akan menyerap tenaga elektromagnetik daripada cahaya tuju pada kadar yang berkadaran dengan keamatan cahaya tuju.]

A. II, IV
B. I, IV
C. III only
D. I, II,IV
E. None of A, B, C, D
[Jawapan tiada dalam A,B,C,D]

18. Which of the following statements is (are) true?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. $\lambda_e = h/m_e c$ characterises the length scale of the Compton effect between the incident photon and free electron in a sample target.
[$\lambda_e = h/m_e c$ mencirikan skala panjang kesan Compton di antara foton tuju dan elektron bebas dalam suatu sampel sasaran.]

II. The velocity of electron in the ground state of hydrogen atom ~ αc, where α is the fine structure constant, $\alpha = \frac{e^2}{4\pi\varepsilon_0\hbar c}$.
[Halaju elektron dalam keadaan dasar atom hidrogen adalah ~ αc, di mana α pemalar struktur halus, $\alpha = \frac{e^2}{4\pi\varepsilon_0\hbar c}$.

III. Planck's constant gives a measure of the scale at which quantum effects are observed.
[Pemalar Planck merupakan ukuran bagi skala di mana kesan kuantum dicerap.]

IV. The energy scale characterizing pair creation of proton-antiproton is ~ MeV.
[Skala tenaga yang mencirikan penghasilan pasangan proton-antiproton ialah ~ MeV]

A. I, III
B. I, II, III
C. II, III
D. I, II, III, V
E. None of A, B, C, D [*Jawapan tiada dalam A, B, C, D*]

19. Which of the following statements is (are) true regarding Bohr's hydrogen model?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai model hidrogen Bohr?]

I. The kinetic energy of the electron in the higher orbits is much larger than $m_e c^2$.
[Tenaga kinetik elektron dalam orbit tinggi adalah jauh lebih besar daripada $m_e c^2$.]

II. The kinetic energy of the electron in the lower orbits is much less than $m_e c^2$.
[Tenaga kinetik elektron dalam orbit rendah adalah jauh lebih kecil daripada $m_e c^2$.]

III. The emission line spectrum of hydrogen atom is well explained by the Bohr model.
[Spektrum garisan pancaran atom hidrogen dapat dijelaskan oleh model Bohr.]

IV. The absorption line spectrum of hydrogen atom is well explained by the Bohr model.
[Spektrum garisan serapan atom hidrogen dapat dijelaskan oleh model Bohr.]

A. I, II
B. I, III, IV
C. II, III, IV
D. III, IV
E. None of A, B, C, D [*Jawapan tiada dalam A, B, C, D*]

20. Which of the following statements is (are) true regarding the duality of an electron?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai dualiti suatu elektron?]

I. Electron behaves like wave in a Young double-slit experiment.
[Elektron berlagak seperti gelombang dalam suatu eksperimen dwi-celah Young.]

II. Electron behaves like particle in the TV cathode-ray tube.
[Elektron berlagak seperti zarah dalam tiub sinar katod TV.]

III. Electron behaves like wave in the Compton scattering effect experiment.
[Elektron berlagak seperti gelombang dalam eksperimen kesan Compton.]

IV. Electron behaves like particle in the photoelectric effect experiment.
[Elektron berlagak seperti zarah dalam eksperimen kesan fotoelektrik.]

A. I, II
B. I, III, IV
C. I, II, IV
D. III, IV
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

Section B: Structural questions.
[*Bahagian B: Soalan-soalan strutur.***]**

Instruction: Answer ALL questions. Each question carries 10 marks.
[Arahan: Jawab semua soalan. Setiap soalan membawa 10 markah.]

1. An observer in rocket *A* finds that rockets *C* and *B* are approaching him from opposite direction at speeds of 0.9*c* and 0.8*c*, respectively. Determine the speed of rocket *C* as measured by *B* using Galilean approach and special relativity approach. Please state clearly all the symbols used in your working.
[Seorang pemerhati di dalam roket A mendapati bahawa roket-roket C dan B sedang menuju kepadanya dari arah yang bertentangan dengan laju masing-masing 0.9c dan 0.8c. Tentukan laju roket C seperti yang diukur oleh B dengan menggunakan pendekatan Galileo dan pendekatan teori kerelatifan khas. Sila nyatakan dengan jelas simbol-simbol yang digunakan dalam kerja anda.]
[10 marks (*markah)*]

2. A certain metal has a threshold wavelength of 600 nm. Find the stopping potentials when the metal is irradiated with:
[Suatu logam tertentu mempunyai jarak gelombang ambang 600 nm. Cari keupayaan penghenti apabila logam itu disinari dengan]

(a) monochromatic light of wavelength 400 nm,
[cahaya monokromatik yang berjarak gelombang 400 nm]
[4 marks *(markah)*]

(b) light having twice the frequency of that in (a), and
[cahaya yang berfrekuensi dua kali ganda daripada cahaya dalam (a), dan]
[4 marks *(markah)*]

(c) light having three times the intensity of that in (a).
[cahaya yang berkeamatan tiga kali ganda daripada cahaya dalam (a).]
[2 marks *(markah)*]

3. X-ray photons of wavelength 0.0248 nm are incident on a target and the Compton scattered photons are observed at 90°.
[Foton-foton X-ray yang berjarak gelombang 0.0248 nm ditujukan ke atas satu sasaran dan foton-foton yang mengalami serakan Compton dapat diperhatikan pada sudut 90°.]

(a) What is the wavelength of the scattered photons?
[Apakah jarak gelombang bagi foton-foton yang terserak?]
[2 marks *(markah)*]

(b) What is the momentum of the incident and the scattered photons?
[Apakah momentum bagi foton tuju dan foton yang terserak?]
[4 marks *(markah)*]

(c) What is the momentum (magnitude and direction) of the scattered electrons?
[Apakah momentum (magnitud dan arah) bagi elektron-elektron yang terserak?]
[4 marks *(markah)*]

4. Suppose that the momentum of a certain particle can be measured to an accuracy of 0.1%. Determine the minimum uncertainty in the position of the particle if the particle is
[Andaikan bahawa momentum suatu zarah tertentu dapat diukur dengan kejituan 0.1%. Tentukan ketakpastian minimum bagi kedudukan zarah jika zarah itu ialah]

(a) a 46 gm golf ball moving with speed of 2 m s^{-1}, and
[sebiji bola golf yang berjisim 46 gm bergerak dengan laju 2 m s^{-1}, dan]
[5 marks *(markah)*]

(b) an electron moving with a speed of 2.4×10^{8} m s^{-1}.
[suatu elektron yang bergerak dengan laju 2.4×10^{8} m s^{-1}]
[5 marks *(markah)*]

5. (a) If the Rydberg constant is 1.097×10^{7} m^{-1}, determine the longest and the shortest wavelengths of the Paschen series for hydrogen?
[Jika pemalar Rydberg ialah 1.097×10^{7} m^{-1}, tentukan jarak gelombang yang paling panjang dan paling pendek dalam siri Paschen hidrogen?]
[5 marks *(markah)*]

(b) Find the value of initial energy state, n_i in the series that gives rise to the line in the hydrogen spectrum at 4861 Å (angstrom)? Given that the final energy state, n_f in this series transitions is $n_f = 2$.
[Cari nilai keadaan tenaga awal, n_i yang peralihannya mengakibatkan garis pada 4861 Å (angstrom) di dalam spectrum hidrogen? Diberi bahawa keadaan tenaga akhir, n_f bagi peralihan ini ialah $n_f = 2$.]
[5 marks *(markah)*]

6. (a) K^0, an unstable, neutral meson, is produced in high energy accelerators. It will decay into a pair of oppositely charged pions via $K^0 \rightarrow \pi^- \pi^+$. The rest masses of the charged pions, π^-, π^+ are 139.6 MeV/c^2. In an experiment, the momentum of the charged pions is measured to be 206.0 MeV/c, calculate the mass of K^0. Assume K^0 is at rest before the decay. Express you answer in terms of MeV/c^2.
[5 marks *(markah)*]

(b) Explain with sufficient clarity why is it not possible for a microscopic particle of rest mass M to decay into a photon with the same energy, Mc^2.
[Terangkan dengan jelasnya mengapa adalah tidak mungkin bagi suatu zarah mikroskopik berjisim rehat M mereput menjadi suatu foton yang tanaganya Mc^2.]
[5 marks *(markah)*]

7. A photon of energy E is scattered by a particle of rest energy E_0. Find the maximum kinetic energy of the recoiling particle in terms of E and E_0.
[Suatu foton bertenaga E diserakkan oleh suatu zarah yang bertenaga rehat E_0. Dapatkan tenaga kinetik maksimum zarah yang tersentak itu dalam sebutan E_0 dan E.]
[10 makrs *(markah)*]

8. By what percentage will a nonrelativistic calculation of the de Broglie wavelength of an electron with kinetic energy100 keV be in error?
[Apakah peratusan ralat suatu pengiraan tak-kerelatifan jarak gelombang de Broglie bagi elektron bertenaga kinetik 100 keV?]
[10 marks *(markah)*]

- ooo O ooo -

Solution

Section A (objective)

1. A (Beiser, pg 49, Ex. 7)
2. A (Beiser, pg 49, Ex. 2)
3. C
   Energy can be measured in terms of MeV. Momentum can be measured in terms of MeV/c. A particle with energy of 1 MeV has a momentum of 1 MeV/c. The SI equivalent of 1 MeV/c is simply
   $$\frac{10^6 \cdot 1.6\times10^{-19}\,\mathrm{J}}{3\times10^8\,\mathrm{m/s}} \sim 10^{-21}\,\mathrm{Ns}.$$
   Hence, 1 MeV/c has an order of magnitude of -21 in SI unit.

4. B
5. A.
   32 = longest wavelength in Balmer series;
   3∞ = shortest wavelength in Balmer series;
   21 = longest wavelength in Lyman series;
   ∞1 = shortest wavelength in Lyman series;
   $E_{32} < E_{3\infty} < E_{21} < E_{\infty 1}$;
   All of the spectral lines in the Lyman series is more energetic than the lines in the Balmer series.

6. D. I, III, IV are true, according to $\Delta K = (\Delta m)c^2$.

7. B

8. D (trivial)

9. B (I,II are true)

10. A.
    $K_{\max} = hc/\lambda - W_0 = eV_s$. If $\lambda \rightarrow \lambda/2$, $\Rightarrow 2hc/\lambda - W_0 = eV'$. Expressing V' in terms of V_s, we have $eV' = 2hc/\lambda - W_0 = 2(eV_s + W_0) = 2eV_s + 2W_0$.

11. C

12. E. None is true. IV is false since a pair of gamma-ray with energy ~ GeV is produced, not X-ray.

13. C

14. E, none is true.

15. D

16. B

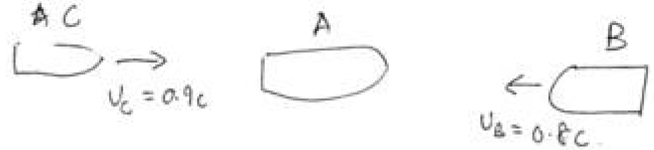
17. A

18. B

19. C

20. C

(1)



→ Assume that the direction to the right-hand side is positif

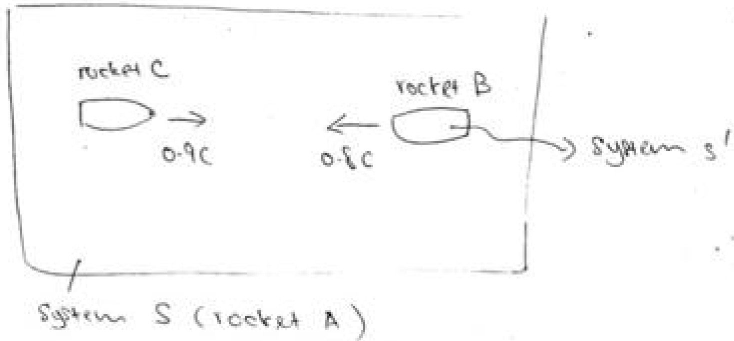
→ With respect to the rocket A,

→ the speed of rocket B, $U_B = -0.8c$

→ the speed of rocket C, $U_C = 0.9c$.

→ the speed of rocket C as measured by B :

→ Now, we may assume that the rocket B is a moving system (system S').



→ Here, $V = -0.8c$, $V_x (V_c) = 0.9c$ and we need to determine V_x' (speed of rocket c as measured by B)

(1) By Galileo approach

$$V_x' = V_x - V$$

$$= 0.9c - (-0.8c) = 1.7c$$

By Special relativity approach:

$$V_x' = \frac{V_x - V}{1 - \left(\frac{V}{c^2}\right)V_x}$$

$$= \frac{0.9c - (-0.8c)}{1 - \left(\frac{-0.8c}{c^2}\right)(0.9c)}$$

$$= \frac{1.7c}{1 + 0.72}$$

$$= \frac{1.7c}{1.72}$$

$$= 0.9884c$$

(3) Given that the threshold wavelength (or cut-off wavelength) of the metal is

$$\lambda_{cutoff} = 600\ nm.$$

→ The work function of this metal is given by

$$W_0 = \frac{hc}{\lambda_{cutoff}} \quad (1)$$

or

$$W_0 = hf_{cutoff} \quad (2)$$

where h = Planck constant

f_{cutoff} = Cut-off or threshold frequency $= \frac{c}{\lambda_{cutoff}}$

→ From (1), Hence.

$$W_0 = \frac{1240\ eV \cdot nm}{600\ nm} = 2.067\ eV$$

→ The photoelectric (PE) formula is given by

$$eV_s = hf - W_0 \quad (3)$$

or

$$eV_s = \frac{hc}{\lambda} - W_0 \quad (4)$$

where e = charge of an electron

V_s = stopping potential

or $K_{max} = eV_s$

$\therefore K_{max} = hf - W_0$.

2 (a) Given that $\lambda = 400nm$.

→ By using Eq. (3).

$$\therefore \quad eV_s = \frac{1240 \text{ eV.nm}}{400} - 2.067 \text{ eV}$$

$$= 3.100 \text{ eV} - 2.067 \text{ eV}$$

$$= 1.033 \text{ eV}$$

$$\therefore \quad V_s = 1.033 \text{ V}$$

2 b) Assume that the light frequency in 2(a) is $f_1 = f = \frac{c}{\lambda}$

Now, the light frequency is, $f_2 = 2f = \frac{2c}{\lambda}$

→ By replacing $f_2 = \frac{2c}{\lambda}$ into Eq. (3), hence.

$$eV_s = \frac{2hc}{\lambda} - W_0$$

$$= 2\left(\frac{1240 \text{ eV.nm}}{400}\right) - 2.067 \text{ eV}$$

$$= 2(3.100 \text{ eV}) - 2.067 \text{ eV}$$

$$= 6.200 \text{ eV} - 2.067 \text{ eV}$$

$$= 4.133 \text{ eV}$$

$$\therefore \quad V_s = 4.133 \text{ V}$$

2(c) → the stopping potential V_s is independent of the intensity of light.

→ Hence, the V_s remain the same as in 2(a)

$$\therefore \quad V_s = 1.033 \text{ V}$$

3.

→ The Compton shift relationship is given by

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_o c}(1-\cos\theta) \quad (1)$$

or

$$\lambda' - \lambda = \lambda_e(1-\cos\theta)$$

where
λ = wavelength of the incident photon
λ' = wavelength of the scattered photon.
m_o = rest mass of electron.
θ = angle of the scattered photon.
λ_e = Compton wavelength = 2.43×10^{-3} nm.

3(a) Here, $\lambda = 0.0248$ nm, $\theta = 90°$, $\lambda' = ?$

→ From Eq. (1),

$$\lambda' - \lambda = \frac{h}{m_o c}(1-\cos\theta)$$

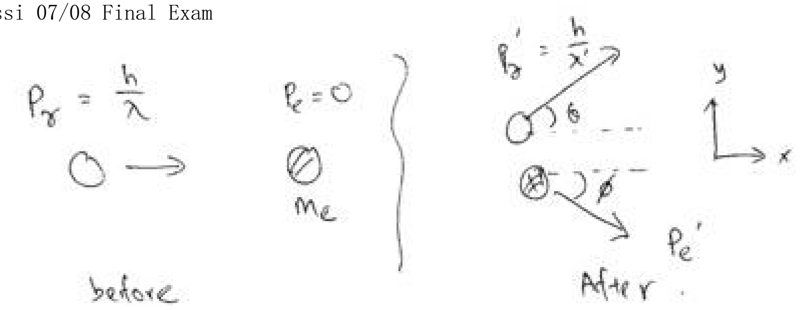
$$\lambda' = 2.43\times10^{-3}\left[1-\cos(90)\right] + \lambda$$

$$= 2.43\times10^{-3}\text{ nm} + 0.0248\text{ nm}$$

$$= 0.02723\text{ nm}$$

$$= 2.723\times10^{-2}\text{ nm}$$ #

3 b)



– Momentum of the incident photon

$$p_\gamma = \frac{h}{\lambda} = \frac{6.63\times10^{-34}\text{ Js}}{0.0248\text{ nm}}$$

$$= \frac{6.63\times10^{-34}\text{ Js}}{2.48\times10^{-11}\text{ m}}$$

$$= 2.673\times10^{-23}\text{ kg ms}^{-1}$$ #

– Momentum of the scattered photons.

$$p_\gamma' = \frac{h}{\lambda'}$$

$$= \frac{6.63\times10^{-34}\text{ Js}}{2.723\times10^{-2}\text{ nm}}$$

$$= \frac{6.63\times10^{-34}\text{ Js}}{2.723\times10^{-11}\text{ m}}$$

$$= 2.435\times10^{-23}\text{ kg ms}^{-1}$$ #

or

$$|p_\gamma'| = \sqrt{(p_\gamma'\sin\theta)^2 + (p_\gamma'\cos\theta)^2}$$

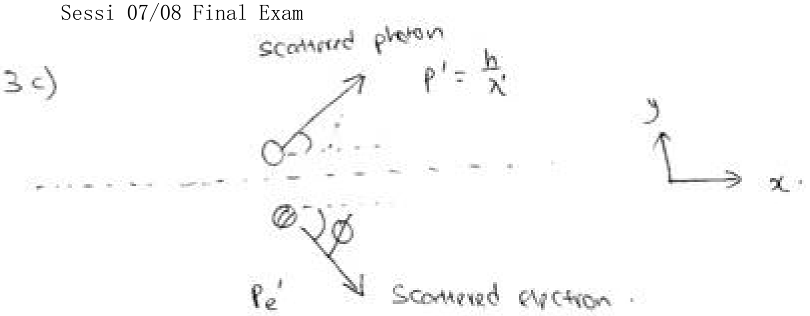
$$= \sqrt{p_\gamma'^2}$$

$$= p_\gamma'$$

$$= \frac{h}{\lambda'}$$

$$= 2.435\times10^{-23}\text{ kgms}^{-1}$$

3 c)



After collision

- Use the conservation of linear momentum in x- and y- directions.

Total momentum before = Total momentum after.

$$\therefore \quad p + p_e = p' + p_e' \quad (1)$$

→ In x- direction

$$p + 0 = p'\cos\theta + p_e'\cos\phi$$

$$\therefore \quad p_e'\cos\phi = p - p'\cos\theta \quad (2)$$

→ In y- direction

$$0 = p'\sin\theta - p_e'\sin\phi$$

$$\therefore \quad p_e'\sin\phi = p'\sin\theta \quad (3)$$

3 c) $\frac{(3)}{(2)}$

$$\frac{p_e'\sin\phi}{p_e'\cos\phi} = \frac{p'\sin\theta}{p - p'\cos\theta}$$

$$\therefore \quad \tan\phi = \frac{\sin\theta}{p/p' - \cos\theta} \quad (4)$$

- magnitude of the momentum of the scattered electron can be calculated using ~~Eq~~ Eq. (1).

$$p = p' + p_e'$$

$$\therefore \quad p_e' = p - p'$$

$$= 2.673 \times 10^{-23}\ \text{kg m s}^{-1} - 2.435 \times 10^{-23}\ \text{kg m s}^{-1}$$

$$= 0.238 \times 10^{-23}\ \text{kg m s}^{-1}$$

$$= 2.38 \times 10^{-24}\ \text{kg m s}^{-1}$$

→ the direction of the momentum of the scattered electron can be determined by using Eq. (4)

$$\therefore \quad \tan\phi = \frac{\sin\theta}{p/p' - \cos\theta}$$

$$= \frac{\sin(90^\circ)}{\left(\frac{2.673\times10^{-23}}{2.435\times10^{-23}}\right) - \cos(90^\circ)} = \frac{1}{1.0977} = 0.911$$

$$\phi = 42.33^\circ.$$

(4.) a)

→ Heisenberg's uncertainty principle is given by

$$\Delta x \, \Delta p \geq \frac{\hbar}{2} \qquad \text{where } \hbar = \frac{h}{2\pi}$$

$$\therefore \; \Delta x \geq \frac{\hbar}{2} \cdot \frac{1}{\Delta p}$$

→ The minimum uncertainty in the position is then

$$\Delta x = \frac{\hbar}{2} \cdot \frac{1}{\Delta p} \qquad (1)$$

→ Given that $m = 46 \text{ gm} = 46 \times 10^{-3} \text{ kg}$.

$v = 2 \text{ ms}^{-1}$.

→ then, the momentum of the golf ball is

$$p_g = mv = (46 \times 10^{-3} \text{ kg}) \times (2 \text{ ms}^{-1})$$

$$= 9.2 \times 10^{-2} \text{ kg ms}^{-1} \; *$$

→ Given that the accuracy of the momentum = 0.1%

$$\therefore \; \Delta p_g = 0.1\% \times p_g = \frac{0.1}{100} \times 9.2 \times 10^{-2} \text{ kgms}^{-1}$$

$$= 9.2 \times 10^{-5} \text{ kg m s}^{-1}$$

→ From Eq. (1), then

$$\Delta x = \frac{\hbar}{2} \cdot \frac{1}{\Delta p}$$

$$= \frac{6.63 \times 10^{-34}}{4\pi (9.2 \times 10^{-5})} = 5.735 \times 10^{-31} \text{ m.} \; *$$

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(4.) a)

→ Heisenberg's uncertainty principle is given by

$$\Delta x \, \Delta p \geq \frac{\hbar}{2} \qquad \text{where } \hbar = \frac{h}{2\pi}$$

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4 b) Here, $m_0 = 9.1 \times 10^{-31}$ kg, $V = 2.4 \times 10^8$ ms^{-1}

- In the case, we must treat the problem relativistically, namely,

$$P_e = \gamma m_0 V$$

where $\gamma = \frac{1}{\sqrt{1 - \frac{V}{C}}} = \frac{1}{\sqrt{1 - \frac{2.4 \times 10^8}{3.0 \times 10^8}}} = 2.236$

$\therefore \; P_e = 2.236 \, (9.1 \times 10^{-31})(2.4 \times 10^8) = 4.883 \times 10^{-22}$ kgms^{-1}

→ Given that the uncertainty of momentum = 0.1%

$\therefore \; \Delta P_e = 0.1\% \times P_e$

$= \frac{0.1}{100} \times 4.883 \times 10^{-22} = 4.883 \times 10^{-25}$ kgms^{-1}

→ From Eq (1), then

$$\Delta x = \frac{\hbar}{2} \cdot \frac{1}{\Delta P_e}$$

$$= \frac{6.63 \times 10^{-34}}{4\pi \, (4.883 \times 10^{-25})}$$

$$= 1.080 \times 10^{-10} \text{ m.}$$

(5) a)

→ The Paschen series for hydrogen is given by

$$\frac{1}{\lambda} = R_H \left[\frac{1}{3^2} - \frac{1}{n_i^2} \right] \quad (1)$$

where R_H = Rydberg constant $= 1.097 \times 10^7$ m^{-1}

$n_i = 4, 5, 6, \ldots$

→ the longest wavelength of the Paschen series for hydrogen corresponds to

$$n_i = \infty$$

$\therefore \; \frac{1}{\lambda} = R_H \left[\frac{1}{3^2} - \frac{1}{\infty^2} \right]$

$= 1.097 \times 10^7 \left(\frac{1}{9} - 0 \right)$

$= 1.2189 \times 10^6$ m^{-1}

$\therefore \; \lambda = 8.204 \times 10^{-7}$ m

#

5 b)

→ The shortest wavelength of the Paschen series for hydrogen is corresponds to

$n_i = n_f + 1$

$= 3 + 1$

$= 4$

$\therefore \frac{1}{\lambda} = R_H \left[\frac{1}{3^2} - \frac{1}{4^2} \right]$

$= 1.097 \times 10^7 \left[\frac{1}{9} - \frac{1}{16} \right]$

$= 5.333 \times 10^5 \ m^{-1}$

$\therefore \lambda = 1.875 \times 10^{-6} \ m$ #

5. b)

→ The general formula of the spectral line series for hydrogen is given by

$$\frac{1}{\lambda} = R_H \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right].$$

→ Given that $\lambda = 4861 \text{ Å} = 4861 \times 10^{-10} \ m$ and $n_f = 2$.

→ from 5(a), $R_H = 1.097 \times 10^7 \ m^{-1}$.

$$\therefore \frac{1}{4861 \times 10^{-10}} = 1.097 \times 10^7 \left[\frac{1}{2^2} - \frac{1}{n_i^2} \right].$$

$$\frac{1}{(4861 \times 10^{-10})(1.097 \times 10^7)} = \left(\frac{1}{4} - \frac{1}{n_i^2} \right)$$

$$0.1875 = 0.25 - \frac{1}{n_i^2}$$

$$\frac{1}{n_i^2} = 0.25 - 0.1875$$

$$\frac{1}{n_i^2} = 0.0625$$

$$n_i^2 = \frac{1}{0.0625}$$

$$n_i^2 = 16$$

$$n_i = 4 \ \#$$

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Section B (structured question)

6(a) ANS:
近代物理学，北京大学教材。Pg. 54.
Use conservation of energy and momentum:

$$E_K^2 = (E_{\pi^+} + E_{\pi^-})^2 = 4E_\pi^2 \qquad \because E_{\pi^+} = E_{\pi^-} = E_\pi, |p_{\pi^-}| = |p_{\pi^+}|.$$

$$m_K^2 c^4 = 4\left(c^2 p_\pi^2 + m_\pi^2 c^4\right) = 4\left(206^2\,\text{MeV}^2 + 139^2\,\text{MeV}^2\right) = 247028\,\text{MeV}^2$$

$$\Rightarrow m_K = 497.0\,\text{MeV}/c^2$$

(b)
In the rest frame of the particle *M*, the total momentum before any decay is zero. If *M* decays into a single photon, which must necessarily has a non-zero momentum in all frames of reference due to the invariance of the speed of light, it is impossible to keep the conservation of momentum in the rest frame of *M*. Hence, such a single photon decay mode is forbidden to preserve conservation of momentum.

7 **ANS: Beiser, Exercise 38, pg 91.**

Denote the corresponding Compton wavelength of the scattering (recoiling) particle as $\lambda_C^* = hc/E_0$. The recoil particle will have the maximum kinetic energy when the scattering angle is 180°, and so $\lambda' = \lambda + 2\lambda_C^*$, and the maximum kinetic energy will be

$$K_{\max} = E - \frac{hc}{\lambda'} = E - \frac{hc}{(hc/E) + 2\lambda_C^*} = E\left(1 - \frac{E_0}{E_0 + 2E}\right) = E\left(\frac{E_0}{2E} + 1\right)^{-1}$$

ANS: 8 Beiser, Exercise 5, pg 117.

3-5: Becasue the de Broglie wavelength depends only on the electron's momentum, the percentage error in the wavelength will be the same as the percentage error in the reciprocal of the momentum, with the nonrelativistic calculation giving the higher wavelength due to a lower calculated momentum. The nonrelativistic momentum is

$$p_{\text{nr}} = \sqrt{2\,m\,\text{KE}} = \sqrt{2\ (9.1095 \times 10^{-31}\ \text{kg})\,(100 \times 10^3\ \text{eV})\ (1.602 \times 10^{-19}\ \text{J/eV})}$$
$$= 1.708 \times 10^{-22}\ \text{kg}\cdot\text{m/s},$$

and the relativistic momentum is

$$p_{\text{r}} = \frac{1}{c}\sqrt{(\text{KE} + mc^2)^2 - (mc^2)^2} = \sqrt{(0.100 + 0.511)^2 - (0.511)^2}\ \text{MeV}/c$$
$$= 1.790 \times 10^{-22}\ \text{kg}\cdot\text{m/s},$$

keeping extra figures in the intermediate calculations. The percentage error in the computed de Broglie wavelength is then

$$\frac{(h/p_{\text{nr}}) - (h/p_{\text{r}})}{(h/p_{\text{r}})} = \frac{p_{\text{r}} - p_{\text{nr}}}{p_{\text{nr}}} = \frac{1.790 - 1.708}{1.708} = 4.8\%.$$