UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2006/2007

April 2007

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

Duration: 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains **TWENTY THREE** pages before you begin the examination.

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

Instruction: Answer **ALL** questions in Section A and Section B.

Please answer the objective questions from Section A in the objective answer sheet provided. Please submit the objective answer sheet and the answers to the structured questions separately.

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

*[**Arahan**: Jawab **SEMUA** soalan dalam Bahagian A dan Bahagian B.*

Sila jawab soalan-soalan objektif daripada bahagian A dalam kertas jawapan objektif yang dibekalkan. Sila serahkan kertas jawapan objektif dan jawapan kepada soalan-soalan struktur berasingan.

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

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Data

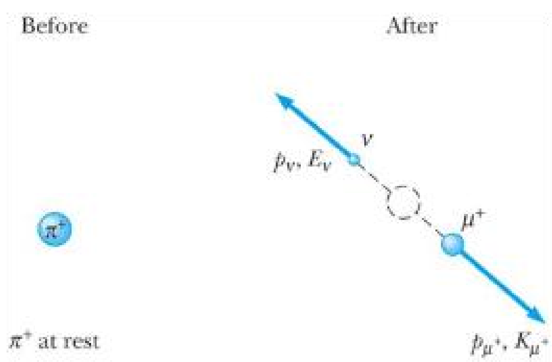
Speed of light in free space, $c = 3.00 \times 10^{8}$ m s^{-1}
Permeability of free space, $m_0 = 4\pi \times 10^{-7}$ H m^{-1}
Permittivity of free space, $e_0 = 8.85 \times 10^{-12}$ F m^{-1}
Elementary charge, $e = 1.60$ x 10^{-19} C
Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg
Molar gas constant, = 8.31 J K^{-1} mol^{-1}
Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}
Gravitational constant, $G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
Acceleration of free fall, $g = 9.81$ m s^{-2}

Section A: Objectives. [40 marks]
[Bahagian A: Soalan-soalan objektif]

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

Question 1 - 3 are based on the decay of a π meson into a muon and a massless neutrino shown in the figure below. The rest mass of the muon is m_m, and the kinetic energy of the muon is measured to be K_m. p_m denotes the momentum of the muon. m_p denotes the rest mass of π meson.

[Soalan 1-3 adalah berdasarkan pereputan satu meson p kepada satu muon dan satu neutrino tanpa jisim, sepertimana ditunjukkan dalam gambarajah di bawah. Diketahui jisim rehat muon ialah m_m, dan tenaga kinetik muon yang terukur ialah K_m. p_m menandakan momentum muon. m_p menandakan jisim rehat meson π.]



1. How is the energy of the muon E_μ related to the momentum of the muon?
[Bagaimanakah tenage muon E_m dikaitkan dengan momentum muon?]

A. $E_m^2 = p_m^2c^2 - m_m^2c^4$

B. $E_m = p_m c + m_m c^2$

C. $E_m = p_m c$

D. $E_m^2 = p_m^2c^2 + m_m^2c^4$

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

2. What is the kinetic energy of the π meson?
[Apakah tenaga kinetik meson π ?]

A. $K_m + m_m c^2$

B. 0

C. K_m

D. $m_p c^2$

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

3. What is the momentum of the neutrino?
[Apakah momentum neutrino?]

A. $p_n = \frac{1}{c}\sqrt{K_m\left(2m_m c^2 + K_m\right)}$

B. $p_n = \frac{1}{c}\sqrt{\left(2m_m^2c^4 + K_m^2\right)}$

C. $p_n = K_m / c$

D. 0

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

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

I. The Lyman series emission spectrum of a hydrogen atom lies in the visible region of the electromagnetic spectrum.
[Spektrum pancaran siri Lyman atom hidrogen terletak dalam rantau nampak spektrum elektromagnetik.]

II. The Balmer series emission spectrum of a hydrogen atom lies in the ultraviolet region of the electromagnetic spectrum.
[Spektrum pancaran siri Balmer atom hidrogen terletak dalam rantau ultraungu spektrum elektromagnetik.]

III. The Paschen series emission spectrum of a hydrogen atom lies in the ultraviolet region of the electromagnetic spectrum.
[Spektrum pancaran siri Paschen atom hidrogen terletak dalam rantau ultra ungu spektrum elektromagnetik.]

IV. Not all of the emission spectrum of a hydrogen atom lies in the visible region of the electromagnetic spectrum.
[Bukan kesemua spektrum pancaran siri atom hidrogen terletak dalam rantau nampak spektrum elektromagnetik.]

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

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

I. The kinetic energy of an object is the energy associated with the motion of the object.
[Tenaga kinetik suatu objek adalah tenaga yang berkaitan dengan pergerakan objek.]

II. The kinetic energy of an object cannot be larger than its total energy.
[Tenaga kinetik suatu objek tidak boleh melebihi jumlah tenaganya.]

III. The relativistic expression of momentum reduces to that of the classical theory of machanics in the limit $v << c$.
[Ungkapan momentum keretatifan terturun kepada ungkapan mekanik teori klasik dalam limit $v<<c$.]

IV. The classical expression of kinetic energy has to be supplanted by that of the special theory of relativity when v approaches c from below.
[Ungkapan tenaga kinetik klasik harus digantikan oleh ungkapan kerelatifan jika v menokok ke c dari bawah.]

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

6. Consider a proton and an electron, both moving at a common momentum, p. Let K_p and K_e denote the proton and electron kinetic energies respectively. Which of the following statements is (are) true?
[Pertimbangkan suatu proton dan suatu elektron, kedua-duanya bergerak dengan momentum yang sama, p. Biar K_p *dan* K_e *masing-masing menandakan tenaga kinetik proton dan elektron. Yang manakah kenyataan(-kenyataan) berikut adalah benar?]*

I. $K_p = K_e$ for $v < c$. *[*$K_p = K_e$ *untuk* $v < c$.*]*
II. $K_p \neq K_e$ in general. *[*$K_p \neq K_e$ *pada amnya.]*
III. $K_p > K_e$ for all values of $v < c$. *[*$K_p > K_e$ *untuk semua nilai* $v < c$.*]*
IV. $K_e > K_p$ for $v << c$. *[*$K_e > K_p$ *untuk* $v << c$.*]*

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

7. Which of the following statements is (are) true according to the special theory of relativity?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar menurut teori kerelatifan?]

I. A massless particle can travel at the speed lower than the speed of light.
[Suatu zarah tanpa jisim mungkin bergerak dengan laju yang kurang daripada laju cahaya.]

II. A particle with non-zero mass does not necessarily travel at the speed smaller than that of light.
[Suatu zarah dengan jisim bukan sifar tidak semestinya bergerak dengan laju yang kurang daripada laju cahaya.]

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III. The rest mass of a moving object changes when it is moving.
[Jisim rehat suatu objek berubah bila ia bergerak.]

IV. It requires an infinite amount of energy to accelerate a massive object to the speed of light.
[Tenaga yang infinit diperlukan untuk memecutkan suatu zarah kepada laju cahaya.]

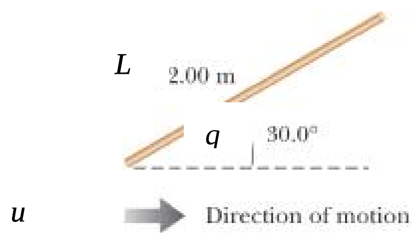
A. I, III, IV
B. I, II, III, IV
C. I, II, III
D. IV only *[IV sahaja]*
E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]

8. When two particles collide relativistically,
[Bila dua zarah berlanggar secara kerelatifan,]

I. the total momentum is conserved.
[jumlah momentum adalah terabadikan.]
II. the total kinetic is conserved.
[jumlah tenaga kinetik adalah terabadikan.]
III. the total kinetic energy is an invariant.
[jumlah tenaga kinetik adalah tak varian.]
IV. the total rest mass is conserved.
[jumlah jisim rehat adalah terabadikan.]

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

9. In its rest frame, a rod has a proper length of L and is orientated at an angle of $q = 45°$ with the x-axis. The rod then move at a speed of $u = c/2$ in the x-direction.
[Dalam rangka rehatnya, suatu rod dengan panjang lazim L diorientasikan pada suatu sudut $q = 45°$ merujuk kepada paksi-x. Ia kemudian bergerak pada laju $u = c/2$ dalam arah x.]



What is the length of the rod as observed in the improper frame?
[Apakah panjang rod tersebut dalam rangka tak lazim?]

A. L

B. $\frac{\sqrt{7}}{4}L$

C. $\frac{3}{4}L$

D. $\sqrt{\frac{7}{8}}L$

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

10. In Question 9, what is the inclination angle of the rod with respect to the *x*-axis as observed in the improper frame?
[Dalam solaan 9, apakah sudut di antara rod dengan paksi-x dalam rangka tak lazim?]

A. $\tan^{-1}\left(\frac{\sqrt{7}}{8}\right)$

B. $\tan^{-1}\left(\frac{\sqrt{3}}{2}\right)$

C. $\tan^{-1}(1)$

D. $\tan^{-1}\left(\frac{2}{\sqrt{3}}\right)$

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

11. What measurement(s) do two observers in relative motion always agree on?
[Apakah ukuran(-ukuran) yang sentiasa disetujui oleh dua orang pemerhati yang berada dalam pergerakan relatif?]

I The speed of an electron moving in medium water.
[Laju suatu elektron dalam medium air.]

II The time interval between two events.
[Selang masa antara dua kejadian.]

III The number of particles.
[bilangan zarah.]

IV The density of an object. *[Ketumpatan suatu objek]*

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

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

12. The units of the work function are those of:
[Unit bagi fungsi kerja adalah sama dengan unit bagi …]

A. energy
[tenaga]
B. power
[kuasa]
C. momentum
[momentum]
D. angular momentum
[momentum sudut]
E. frequency
[frekuensi]

13. The S.I. units of 1-D wavefunction are those of:
[Unit bagi fungsi gelombang 1D adalah sama dengan unit bagi …]

A. $1/\sqrt{\text{length}}$

B. $1/\sqrt{\text{energy}}$

C. $1/\sqrt{\text{momentum}}$

D. $1/\sqrt{\text{frequency}}$

E. $1/\sqrt{\text{mass}}$

14. The light intensity incident on a metallic surface produces photoelectrons with a maximum kinetic energy of 2 eV. The light intensity is doubled. Determine the maximum kinetic energy of the photoelectrons (in eV).
[*Keamatan cahaya yang menujui suatu permukaan logam menghasilkan fotoelektron dengan tenaga kinetik maksimum 2 eV. Keamatan cahaya digandaduakan. Tentukan tenaga kinetik maksimum fotoelektron terhasil (dalam eV).*]

A. 4
B. 2
C. $\sqrt{2}$
D. 3
E. 16

15. Microscopes are inherently limited by the wavelength of the light used. How much smaller (in order of magnitude) can we "see" using an electron microscope whose electrons have been accelerated through a potential difference of 10 000 V than using red light (400 nm)?
[Secara tabiinya mikroskop dihadkan oleh jarak gelombang cahaya yang digunakan. Berbanding dengan penggunaan cahaya merah (400 nm), betapa kecilkah (dalam magnitud tertib) yang boleh kita 'nampak' dengan menggunakan mikroskop elektron yang elektronnya dipecutkan melalui suatu beza keupayaan 10 000 V?]

A. 3
B. 4
C. 5
D. 6
E. 14

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

I. In photoelectric effect , a photon will either be totally absorbed or not at all. *[Dalam kesan fotoelektrik suatu foton akan samada terserap sepenuhnya atau langsung tidak]*.
II. Photons have mass.
[foton mempunyai jisim.]
III. Photons have electric charge.
[foton mempunyai cas elektrik.]
IV. Photons can be accelerated via an electric field.
[foton boleh dipecutkan oleh suatu medan elektrik.]

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

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17. Which of the following statements is (are) true about the nature of light?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tabii cahaya?]

I. Effects due to the photon nature of light are generally more important at the low-frequency end of the electromagnetic spectrum (radio waves).
[Kesan-kesan disebabkan oleh tabii foton dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi rendah spektrum elektromagnet (gelombang radio)].

II. Effects due to the photon nature of light are generally more important at the high-frequency end of the electromagnetic spectrum (X-ray and gamma ray).
[Kesan-kesan disebabkan oleh tabii foton dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi tinggi spektrum elektromagnet (sinaran-X dan sinaran gamma).]

III. Effects due to the wave nature of light are generally more important at the low-frequency end of the electromagnetic spectrum (radio waves).
[Kesan-kesan disebabkan oleh tabii gelombang dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi rendah spektrum elektromagnet (gelombang radio)].

IV. Effects due to the wave nature of light are generally more important at the high-frequency end of the electromagnetic spectrum (Xray and gamma ray).
[Kesan-kesan disebabkan oleh tabii gelombang dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi tinggi spektrum elektromagnet (sinaran-X dan sinaran gamma).]

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]

18. The total energy (kinetic plus potential) of the hydrogen atom is negative. What significance does this have?
[Jumlah tenaga (kinetik serta keupayaan) atom hidrogen adalah negatif. Apakah kepentingannya?]

A. The hydrogen atom is ionized.
[Atom higrogen diionkan.]
B. The angular momentum of the electron is quantized.
[Momentum sudut elektron terkuantumkan.]
C. The electron is bonded by the hydrogen atom's electric field.
[Elektron adalah terikat oleh medan elektrik atom hidrogen.]
D. The hydrogen atom is a free particle.
[Atom hidrogen adalah zarah bebas.]
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

19. A double ionized lithium atom (Li^{++}) is one that has had two of its three electrons removed. The ground state energy of the Li^{++} is _____ times the ground state energy of the hydrogen atom.
[Suatu atom lithium yang berganda terionkan ialah atom yang dua daripada tiga elektronnya disingkirkan. Keadaan dasar Li^{++} *adalah ______kali tenaga dasar hidrogen.*]

A. 2
B. 4
C. 8
D. 9
E. 32

20. In photoelectric effect experiment, which of the following will increase the maximum kinetic energy of the photoelectron? [*Dalam eksperimen kesan fotoelektrik, yang manakah berikut akan menambahkan tenaga kinetik maksmum fotoelektron?*]

I. Use the light of greater intensity.
[Guna cahaya yang keamatannya lebih tinggi].

II. Use the light of greater frequency.
[Guna cahaya yang frekuensinya lebih tinggi].

III. Use the light of greater wavelength.
[Guna cahaya yang jarak gelombangnya lebih tinggi].

IV. Use metal surface with a smaller work function.
[Guna permukaan logam yang fungsi kerjanya lebih rendah].

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]

21. Which of the following associations with experiments is (are) true?
[Yang manakah perhubungan-perhubungan dengan eksperimen berikut adalah benar?]

I. The Davisson-Gremer experiment shows that electrons do behave like waves.
[Eksperimen Davisson-Germer menunjukkan bahawa elektron berlagak seperti gelombang.]

II. The Frank-Hertz experiment shows that atoms do behave like waves.
[Eksperimen Frank-Hertz menunjukkan bahawa atom-atom berlagak seperti gelombang.]

III. The Compton scattering experiment show that electrons behave like waves.
[Eksperimen Compton menunjukkan bahawa elektron berlagak seperti gelombang.]

IV. The Young double slit experiment using electron as the source shows that electrons do behave like waves.
[Eksperimen dwi-celah Young yang menggunakan elektron sebagai punca menunjukkan bahawa elektron berlagak seperti gelombang.]

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

22. Say a beam of light has an intensity of I (i.e. the total energy per unit area per unit time) and frequency n. What is the photon density, n (i.e. the number of photon per unit volume), of the light beam?
[Katakan keamatan satu alur cahaya ialah I (iaitu jumlah tenaga per unit permukaan per unit masa) dan frekuensinya ialah n. Apakah ketumpatan foton n (iaitu bilangan foton per unit isipadu) dalam alur cahaya tersebut?]

A. $(hcn)^2/I^2$
B. hcn/I
C. $I/(hcn)$
D. $I^2/(hcn)^2$
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

23. A particle of mass m is confined to a one-dimensional box of width L and infinite height. The particle's wavelength at state n is given by
[Suatu zarah yang terperangkap dalam suatu kotak satu dimensi dengan lebar L dan ketinggian infiniti. Jarak gelombang zarah tersebut pada keadaan n ialah]

A. $2L/n$
B. $n/2L$
C. $2L/n\mathbf{h}$
D. $n\mathbf{h}/2L$
E. None of the above
[Jawapan tiada di atas]

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24. The kinetic energy of the particle in Question 23 is given by
[Tenaga kinetik zarah dalam Soalan 23 ialah]

A. $n^2 \frac{\mathbf{h}^2}{8mpL^2}$

B. $n^2 \frac{h^2}{8mL^2}$

C. $n^2 \frac{p^2 h^2}{2mL^2}$

D. $n^2 \frac{\mathbf{h}^2}{2mL^2}$

E. None of the above
[Jawapan tiada di atas]

25. If the infinitely high potential box in Question 23 is replaced by one with a finite height, how would the wavelength of the particle at a given state ***n*** be modified as compared to the answer in Question 23?
[Jika keupayaan kotak yang infinit dalam Soalan 23 digantikan dengan kotak yang tinggi keupayaannya finit, bagaimanakah jarak gelombang zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 23?]

A. The wavelength would be longer than that in Question 23.
[Jarak gelombang akan menjadi lebih panjang daripada jarak gelombang dalam Soalan 23.]

B. The wavelength would be shorter than that in Question 23.
[Jarak gelombang akan menjadi lebih pendek daripada jarak gelombang dalam Soalan 23.]

C. The wavelength would be the same as that in Question 23.
[Jarak gelombang adalah sama seperti jarak gelombang dalam Soalan 23.]

D. The wavelength could be longer or shorter than that in Question 23, depending on n.
[Jarak gelombang akan menjadi lebih panjang atau lebih pendek daripada jarak gelombang dalam Soalan 23, bergantung kepada n.]

E. None of the above.
[Jawapan tiada di atas]

26. Following Question 25, how would the kinetic energy of the particle at a given state ***n*** be modified as compared to the answer in Question 24?
[Menurut Soalan 25, bagaimanakah tenaga kinetik zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 24?]

A. The kinetic energy would be larger than that in Question 24.

B. The kinetic energy would be smaller than that in Question 24.

C. The kinetic energy would be the same as that in Question 24.

D. The kinetic energy could be larger or smaller than that in Question 24, depending on ***n***.

E. None of the above.
[Jawapan tiada di atas]

27. If the finite potential box in Question 25 is in turn replaced by one with a width larger than *L*, how would the wavelength of the particle at a given state ***n*** be modified as compared to the answer in Question 25?
[Jika kotak yang berkeupayaan finit dalam Soalan 25 digantikan dengan kotak yang lebarnya lebih besar daripada L, bagaimanakah jarak gelombang zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 25?]

A. The wavelength would be longer than that in Question 25.

B. The wavelength would be shorter than that in Question 25.

C. The wavelength would be the same as that in Question 25.

D. The wavelength could be longer or shorter than that in Question 25, depending on ***n***.

E. None of the above
[Jawapan tiada di atas]

28. Following Question 27, how would the kinetic energy of the particle at a given state ***n*** be modified as compared to the answer in Question 26?
[*Menurut Soalan 27, bagaimanakah tenaga kinetik zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 26?]*

A. The kinetic energy would be larger than that in Question 26.

B. The kinetic energy would be smaller than that in Question 26.

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C. The kinetic energy would be the same as that in Question 26.

D. The kinetic energy could be larger or smaller than that in Question 26, depending on *n*.

E. None of the above
[Jawapan tiada di atas]

29. What are the features of a X-ray curve as produced from a X-ray tube?
[Apakah ciri-ciri bagi suatu lengkung sinaran-X yang dihasilkan oleh tiub sinaran-X]

I. The spectrum is continuous.
[*Spektrumnya adalah selanjar.*]

II. The existence of a minimum wavelength for a given accelerating potential *V*, below which no x-ray is observed.
[*Wujudnya suatu jarak gelombang minimum bagi suatu keupayaan pecutan V yang diberikan. Kurang daripada jarak gelombang minimum tersebut, tiada sinaran-X akan tercerap.*]

III. Increasing *V* decreases the minimum wavelength.
[*Menambahkan V menyebabkan jarak gelombang minimum dikurangkan.*]

IV. There exists an upper limit in the wavelength of the X-ray produced.
[*Wujudnya limit atas untuk jarak gelombang sinaran-X yang dihasilkan.*]

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

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

I. In photoelectricity the whole photon is directly absorbed by the free electron in the metal surface.
[Dalam kesan fotoelektrik keseluruh foton diserap secera terus oleh elektron bebas dalam permukaan logam.]

II**.** In photoelectricity the whole photon is first absorbed by the atom in the metal surface.
[Dalam kesan fotoelektrik keseluruh foton terdahulunya diserap oleh atom dalam permukaan logam.]

III. In X-ray production by electron bombardment on a metal target, the kinetic energy of the bombarding electron is converted to the continuous X-ray photon energy via Bremsstrahlung.
[Dalam penghasilan sinaran-X oleh penghentaman elektron ke atas sasaran logam, tenaga kinetik elektron yang menghentam ditukarkan kepada tenaga foton selanjar sinaran-X melalui Bremsstrahlung.]

IV. In the X-ray production using the X-ray tube, the energy of the X-ray photon is converted to the kinetic energy of the electron via Bremsstrahlung.
[Dalam penghasilan sinaran-X dalam tiub sinaran-X, tenaga foton ditukarkan kepada tenaga kinetik elektron melalui Bremsstrahlung.]

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

31. Which of the following statements is (are) true?

[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. A photon can materialize into an electron plus a positron in the absence of any external field.
[Suatu foton boleh bertukar menjadi jirim satu elektron serta satu positron dalam ketidakhadiran sebarang medan luar.]

II. A photon can materialize into either a single electron OR a single positron in the presence of a strong electric field.
[Suatu foton boleh bertukar menjadi jirim satu elektron tunggal atau satu positron tunggal dalam kehadiran medan elektrik kuat.]

III. An electron-positron pair can annihilate into a single photon.
*[Suatu pasangan elektron-positron boleh menghabisbinasa menjadi satu foton tunggal.] [*F*]*

IV. An electron-positron pair can annihilate into two photons.
[*Suatu pasangan elektron-positron boleh menghabisbinasa menjadi dua foton.*]

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

…17/-

32. Which of the following statements is (are) true regarding the interactions between photons with matter?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai interaksi foton dengan jirim?]

I. The probability (cross section) of a photon undergoes a given channel of interaction with matter depends on the photon energy.
[Kebarangkalian (keratan rentas) suatu foton menjalani mana-mana saluran interaksi dengan jirim bergantung kepada tenaga foton.]

II. The probability (cross section) of a photon undergoes a given channel of interaction with matter depends on the atomic number of the absorbing material.
[Kebarangkalian (keratan rentas) suatu foton menjalani mana-mana saluran interaksi dengan jirim bergantung kepada nombor atom bahan penyerap.]

III For a fixed atomic number, the photon-material interactions at low energy are dominated by photoelectric effect.
[Pada suatu nombor atom yang tertentu, interaksi di antara foton dengan jirim pada tenaga rendah dikuasai oleh kesan fotoelektrik.]

IV. Electron-positron Pair production begins to show up when the photon energy approaches, but not yet exceed, the value of 1.02 MeV.
[Penghasilan pasangan electron-positron mula muncul semasa tenaga foton menhampiri, tapi belum melebihi, nilai 1.02 MeV.]

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

33. A relativistic electron has a de Broglie wavelength of l. Find its kinetic energy.
[Jarak gelombang de Broglie suatu elektron kerelatifan ialah l. Dapatkan tenaga kinetiknya.]

A. $K = ((hc/\lambda)^2 - m_e^2c^4)^{½} + m_ec^2$.
B. $K = ((hc/\lambda)^2 + m_e^2c^4)^{½} + m_ec^2$.
C. $K = ((\lambda/hc)^2 + m_e^2c^4)^{½} - m_ec^2$.
D. $K = ((hc/\lambda)^2 + m_e^2c^4)^{½} - m_ec^2$.
E. None of the above
[Jawapan tiada dalam A, B, C, D]

34. In the Davisson-Gremer experiment, the electron is accelerated via an electric potential of V. The wavelength of the electron, l, in terms of V is given by the expression
[Dalam eksperimen Davisson-Gremer, elektron dipecutkan oleh keupayaan elektrik V. Jarak gelombang elektron, l, dalam ungkapan V, adalah diberikan oleh]

A. $l = (2eVm_e)^{1/2}/h$
B. $l = h^{1/2}/(2eVm_e)$
C. $l = h/(2eVm_e)$
D. $l = h/(2eVm_e)^{1/2}$
E. None of the above
[Jawapan tiada dalam A, B, C, D]

Questions 35 - 37 are based on Figure 1.
[Soalan 35 -37 adalah berdasarkan Gambarajah 1.]

35. Figure 1 shows three group waves. Which of the group waves has the largest spatial spread, Δx?
[Gambarajah 1 menunjukkan 3 gelombang kumpulan. Yang mana satukah mempunyai sebaran ruagan Δx yang terbesar?]

36. Which of the group waves has the largest spread in wavelength, $\Delta\lambda$?
[Yang mana satukah mempunyai sebaran jarak gelombang $\Delta\lambda$ yang terbesar?]

37. Which of the group waves has the largest spread in wave number, Δk?
[Yang mana satukah mempunyai sebaran nombor gelombang Δk yang terbesar?]

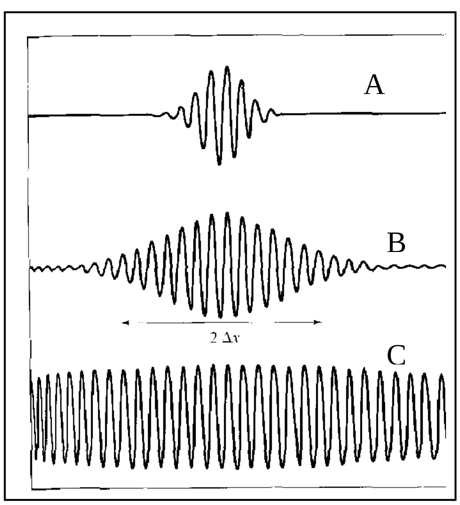


Figure 1

38. Assume that the uncertainty in the position of a particle is equal to two times its de Broglie wavelength. What is the minimal uncertainty in its velocity?
[Anggap bahawa ketidakpastian dalam kedudukan suatu zarah adalah bersamaan 2 kali jarak gelombang de Broglienya. Apakah ketidakpastian mimimum dalam halajunya?]

A. $v_x/4\pi$
B. B. $v_x/2\pi$
C. $v_x/8\pi$
D. v_x/π
E. $v_x/16\pi$

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

I. The length scale characterizing atomic physics is ~ Å
[Skala panjang yang mencirikan fizik atom ialah ~ Å*]*

II. The velocity scale characterizing special relativistic effect is ~ *c*.
[*Skala halaju yang mencirikan kesan kerelatifan khas ialah ~ c]*

III. The length scale characterizing Compton scattering is ~ pm.
[*Skala panjang yang mencirikan serakan Compton ialah* ~ pm]

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

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

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

I. The velocity of the electron in the lower orbits is relativistic.
[Halaju elektron dalam orbit rendah adalah kerelatifan.]

II. The kinetic energy of the electron in the lower orbits is relativistic.
[Tenaga kinetik elektron dalam orbit rendah adalah kerelatifan.]

III. The model does not take into account the effect of Heisenberg uncertainty principle.

[Model tersebut tidak mengambil kira kesan prinsip ketidakpastian Heisenberg]

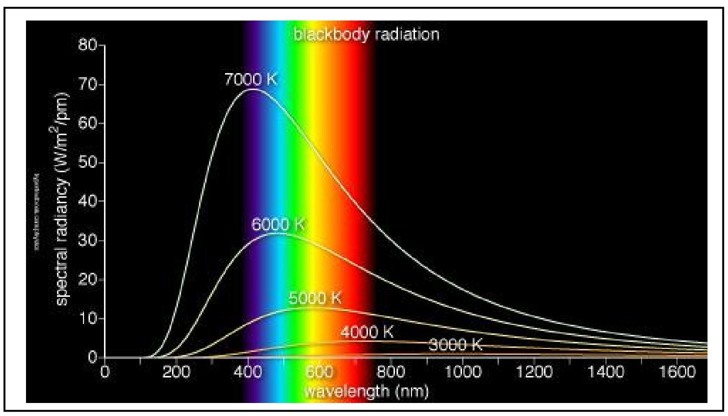
IV. The energy scale characterizing the transition is ~ keV.
[Skala tenaga yang mencirikan peralihan ialah ~ keV]

A. III Only
B. I, II, IV
C. I, II
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 20 marks.
[Arahan: Jawab semua soalan. Setiap soalan membawa 20 markah.]

1. (a) A typical spectral distribution of radiation energy of a black body for several temperatures is as shown.
[Terpapar adalah suatu taburan spektrum yang tipikal bagi tenaga pancaran suatu jasad hitam untuk beberapa suhu.]



The shift of the peak of the curve was found to obey the empirical Wein's displacement law,
[Anjakan puncak lengkungan didapati mematuhi hukum sesaran Wein,]

$$l_p T = \text{constant},$$
$$[\ l_p T = \text{pemalar},]$$

where the symbol l_p refers to the value of the wavelength corresponding to the peak of the curve.

[dengan l_p mewakili nilai jarak gelombang pada puncak lengkungan.]

The *total power radiated per unit area* of a blackbody is found to be empirically related to its absolute temperature by the *the Stefan-Boltzman law*
[Jumlah kuasa pancaran per unit permukaan suatu jasad hitam didapati berkait secara empirikal kepada suhu mutlak oleh hukum Stefan-Boltzman, $I(T) = s\,T^4$,]

$$I(T) = s\,T^4,$$

where s is the Stefan constant. The radiance, $R(l,T)$ and $I(T)$ are related by the integral $I(T) = \int_0^\infty R(l,T)\,\mathrm{d}l$.

[dengan s pemalar Stefan. Radians, $R(l,T)$ dikaitkan dengan $I(T)$ oleh kamiran $I(T) = \int_0^\infty R(l,T)\,\mathrm{d}l$.]

Wein proposed an empirical form for the radiance $R(l,T)$ by constructing a mathematical function to fit the experimental blackbody curve, known as the *Wein's law*:
[Wein menyarankan suatu bentuk empirikal bagi $R(l,T)$ dengan membinakan suatu fungsi matematik untuk memadankan lengkungan eksperimen jasad hitam. Ia dikenali sebagai hukum Wein:]

$$R(l,T) = \frac{a e^{-b/lT}}{l^5} \quad \text{(Wein's law)}$$

The quantities ***a*** and ***b*** are not derived but are simply curve-fitting parameters.
[Kuantiti a dan b bukannya diterbitkan tapi sekadar merupakan parameter-parameter untuk memadankan lengkungan.]

On the theoretically front, Planck derives his famous blackbody radiation law by assuming that the energies emitted from the oscillators are quantized. In his theory, the radiance is given by the theoretical expression
[Dalam garis depan teori, Planck menerbitkan hukum jasad hitamnya yang masyur dengan anggapan bahawa tenaga terpancar daripada pengayun adalah terkuantumkan. Dalam teorinya, radians diberikan oleh]

$$R(l,T) = \frac{2p\,hc^2}{l^5\left(e^{hc/lkT} - 1\right)} \quad \text{(Planck's law)}$$

Using Planck's law as given above,
[Dengan menggunakan hukum Planck,]

(i) show that it reduces to Wein's law in the short wavelength limit.
[tunjukkan bahawa ia terturun kepada hukum Wein dalam limit jarak gelombang pendek.]

(ii) Evaluate *a* and *b* in terms of the natural constants (i.e. *k, c, h, p*).
[Nilaikan a dan b dalam sebutan pamalar semulajadi, iaitu k, c, h, p)]

(iii) Evaluate the Stefan constant.
[Nilaikan pemalar Stefan.] [2+(2+2)+4=10]

(b) If the photocurrent of a photocell is cut off by a retarding potential of 0.92 V for monochromatic radiation of 2500Å what is the work function of the material?
[Jika fotoarus suatu fotosel dipengal oleh keupayaan rencatan 0.92 V untuk pancaran monokromatik 2500 Å *, apakan funsi kerja bahan tersebut?]*

[4]

(c) (i) What is the frequency of a X-ray photon with momentum 1.1×10^{-23} kg·m/s
[Apakah frekuensi suatu foton sinaran-X dengan momentum 1.1×10^{-23} kg·m/s *?]*

(ii) What is the momentum of (c)(*i*) in unit of eV/*c*?
[Apakah memomtum di (c)(*i*) *dalam unit eV/c?]*

[3 + 3 = 6]

2. (a) Derive the Compton scattering formula $l' - l = \frac{h}{mc}(1-\cos q)$, where l and l' are the wavelengths of the incident and scattered photon respectively, q the scattered angle of the photon, *m* the mass of target particle.
[Terbitkan formula serakan Compton $l' - l = \frac{h}{mc}(1-\cos q)$ *.]*

[10]

(b) Determine the wavelength of a photon that is emitted when an atom hydrogen makes a transition from state *n* = 10 to the ground state.
[Tebtukan jarak gelombang foton yang dipancarkan apabila suatu atom hydrogen beralih dari keadaan n = 10 ke keadaan asas.]

[5]

(c) Given the wave function of a particle in an infinite box $y_n(x) = \sqrt{\frac{2}{L}}\sin\frac{np x}{L}$, where *L* is the width of the box. Find the probability that the particle can be found between *x* = 0 and *x* = *L/n* when it is in the *n*th state.

[Diberikan fungsi gelombang zarah dalam kotak infini $\psi_n(x) = \sqrt{\frac{2}{L}} \sin \frac{n\pi x}{L}$, *di mana L ialah lebar kotak tersebut. Carikan kebarangkalian untuk mencarikan zarah di antara x=0 dan x=L/n bila ia berada dalam keadaan n.]*

[5]

3. (a) Consider three inertial frames that are moving along a common direction. The relative velocity of S′ with respect to S is b_1c, whereas the relative velocity of S″ with respect to S′ is b_2c. Find the velocity of S″ with respect to S, bc, in terms of b_1c, and b_2c.
[Pertimbangkan tiga rangka inersia yang bergerak sepanjang arah yang sama. Halaju relatif S' terhadap S ialah b_1c*, manakala halaju relatif S'' terhadap S' ialah* b_2c*. Carikan halaju S'' terhadap S,* bc*, dalam sebutan* b_1c *dan* b_2c.]

[10]

(b) The kinetic energy, K, of a fast-moving alpha particle (with rest mass M_α) is measured in the laboratory. [*Tenaka kinetik, K, bagi suatu zarah alfa (dengan jisim rehat* M_α*) diukurkan dalam makmal.*]

(i) What is its total energy E?
[Apakah jumlah tenaganya?]

(ii) What is its momentum p?
[Apakah momentumnya?]

(iii) What's the increase in its mass (as compared to its mass when at rest), ΔM_α?
[Apakah pertambahan dalam jisimnya (berbanding dengan jisimnya semasa ia berehat)?]

(iv) Based on the answer of (*ii*) above, show that the expression of the kinetic energy K reduces to the classical one in the limit $v << c$, where v is the velocity of the alpha particle.
[Berdasarkan jawapan dalam (ii) di atas, tunjukkan bahawa sebutan tenaga kinetik K terturun kepada sebutan tenaga kinetik klasikal dalam limit v<<c, dengan v halaju zarah alfa.]

[2+3+2+3]

SOLUTIONS

1. **ANS:D**
2. **ANS:B.**
3. **ANS:A.**
4. ANS: E (Only IV is true)
5. **ANS: C [My own question.]**
6. **ANS: D**
7. **ANS: D [My own question.]** Note: In the limit $v<<c$,
$$\frac{K_P}{K_e} = \frac{p^2/2m_P}{p^2/2m_e} \Rightarrow \frac{K_P}{K_e} = \frac{m_e}{m_P} \Rightarrow K_P = \frac{m_e}{m_P} K_e < K_e$$
8. **ANS: B.**

9. ANS:D

$$g^2 = 1/\left[1-\left(v^2/c^2\right)\right] = 1/\left(1-\frac{1}{4}\right) = \frac{4}{3};$$

$$\left(L'\right)^2 = \left(L\sin 45^{\circ}\right)^2 + \left(\frac{L\sin 45^{\circ}}{g}\right)^2 = L^2\left(\frac{1}{2}+\frac{1}{2}\cdot\frac{3}{4}\right) = L^2\left(\frac{1}{2}+\frac{3}{8}\right) = L^2\left(\frac{7}{8}\right)$$

$$L' = L\sqrt{\frac{7}{8}}$$

10. ANS:D
11. Solution: E. only III is true
12. Solution: A
13. Solution: A
14. Solution: B
15. Solution: B

$$eV = \frac{p^2}{2m} = \frac{\left(h/l_e\right)^2}{2m}$$

$$\Rightarrow l_e = \frac{h}{\sqrt{2m_e eV}} = \frac{hc}{\sqrt{2m_e c^2 eV}} = \frac{hc}{\sqrt{2m_e c^2 eV}} = \frac{1240\text{nm}\cdot\text{eV}}{\sqrt{1\text{MeV}\cdot e\cdot 10000\text{V}}} =$$

$$\frac{1240\text{nm}\cdot\text{eV}}{\sqrt{1\times10^{10}\text{eV}^2}} = \frac{1240\text{nm}}{\sqrt{10^{10}}} : \frac{10^3\text{nm}}{10^5} = 10^{-2}\text{nm}$$

$$\frac{l_e}{l} \sim \frac{10^{-2}\text{nm}}{10^2\text{nm}} = 10^{-4}$$

Hence, with λ_e we can see 4 orders smaller.

16. Solution: E, Only I is true. Young and Freeman, pg. 1485, Q38
17. Solution: A
18. Solution: C
19. Solution: D. Note: $E_n = -\frac{Z^2}{n^2}E_0$
20. Solution: D
21. ANS: B
22. ANS: C
23. ANS: A
24. ANS: B
25. ANS: A
26. ANS: B
27. ANS: A
28. ANS: B
29. ANS: C
30. ANS: C
31. ANS: E (Only IV is true)
32. ANS: D
33. ANS: D
34. ANS: D
35. (ANS: C)
36. (ANS: A)
37. (ANS: A)
38. ANS: C

$$l = \frac{h}{p_x}$$

$$\Delta x = 2l = \frac{2h}{p_x}$$

$$\Delta x \Delta p_x \geq \frac{\mathbf{h}}{2} \Rightarrow \frac{2h}{p_x}\Delta p_x \geq \frac{\mathbf{h}}{2} \Rightarrow \frac{\Delta p_x}{p_x} \geq \frac{\mathbf{h}}{4h} = \frac{1}{8p}$$

$$\frac{\Delta p_x}{p_x} = \frac{m\Delta v_x}{mv_x} \geq \frac{1}{8p} \Rightarrow \Delta v_x \geq \frac{v_x}{8p}$$

39. ANS: D
40. ANS: A

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

1(A) ANS
Elmer Anderson, pg49, problem 2-6.

(i) For short wavelength, the exponential term in Planck's law, $e^{hc/\lambda kT}$, becomes very large compared to the value 1, $e^{hc/\lambda kT}$ >>1, hence the term in the bracket in the denominator of the Planck's law reduces to $e^{hc/\lambda kT}$, i.e.

$$\lim_{\lambda \to 0} \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT}-1\right)} = \frac{2\pi hc^2}{\lambda^5} e^{-hc/\lambda kT}. \qquad \text{Eq. (1)}$$

Comparing Eq. (1) and the Wein's law, we find that both have the same form of λ–dependence,

$$\frac{2\pi hc^2}{\lambda^5} e^{-hc/\lambda kT} \equiv \frac{ae^{-b/\lambda T}}{\lambda^5}.$$

[*satisfactory argument:* 2 MARKS]

(ii) Comparing both equation, we identify the constants a and b to be

$a \equiv 2\pi hc^2$ **[2 MARKS]**
$b \equiv hc/k$ **[2 MARKS]**

(iii)
Stafan-Boltzman law: $I(T) = \sigma T^4$

Substitute Planck's law, $R(\lambda,T) = \dfrac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}$, into the definition of $I(T) = \int_0^\infty R(\lambda,T)\mathrm{d}\lambda$, we get

$$I(T) = \int_0^\infty R(\lambda,T)\mathrm{d}\lambda = \int_0^\infty \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}\mathrm{d}\lambda = 2\pi hc^2 \int_0^\infty \frac{1}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}\mathrm{d}\lambda .$$

Define $x = \dfrac{hc}{\lambda kT} \Rightarrow \mathrm{d}x = -\dfrac{hc}{kT}\dfrac{1}{\lambda^2}\mathrm{d}\lambda$

$$I(T) = 2\pi hc^2 \int_0^\infty \frac{1}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}\mathrm{d}\lambda = 2\pi hc^2 \int_0^\infty \frac{1}{\lambda^3\left(e^x-1\right)}\frac{\mathrm{d}\lambda}{\lambda^2}$$

$$= -\frac{2\pi k^4T^4}{h^3c^2}\int_\infty^0 \frac{x^3}{e^x-1}\mathrm{d}x = \frac{2\pi k^4T^4}{h^3c^2}\int_0^\infty \frac{x^3}{e^x-1}\mathrm{d}x = \frac{2\pi k^4T^4}{h^3c^2}\frac{\pi^4}{15} = \frac{2\pi^5k^4T^4}{15h^3c^2}$$

Hence, the Stefan constant is $\sigma = \dfrac{2\pi^5k^4}{15h^3c^2}$.**[4 marks]**

Mark will not be deduced if candidate leaves the σ expression as $\dfrac{2\pi k^4T^4}{h^3c^2}\int_0^\infty \dfrac{x^3}{e^x-1}\mathrm{d}x$ without evaluating it.

IF candidate integrate over the wavelength using the Wein's law instead of the Planck's law, i.e. $I(T) = \int_0^\infty \frac{ae^{-b/kT}}{l^5} \mathrm{d}l = \frac{-aT^4}{b^4}\int_0^\infty y^3 e^{-y} \mathrm{d}y = \frac{-aT^4}{b^4}\cdot(-6) = \frac{6aT^4}{b^4} \equiv s\,T^4$ to identify $s \equiv \frac{12p\,k^4}{h^3c^2}$ instead of the correct answer, $s = \frac{2p^5k^4}{15h^3c^2}$, a maximum of **3** marks will be given.

1(B) ANS: 4.04 eV
E. Anderson, pg. 57, Problem 2-16. **[4 marks]**
Retarding potential measures the maximal kinetic energy = 0.92 eV. Cutoff wavelength l_{cut} is related to the maximum kinetic energy and the work function Φ via

$$K_{\max} = \frac{hc}{l} - \Phi .$$

Hence $\Phi = \frac{hc}{l} - K_{\max} = \frac{1240\ \text{nm}\cdot\text{eV}}{250\ \text{nm}} - 0.92\ \text{eV} = 4.04\,\text{eV}.$

1(C)(i) ANS: [3 marks]

$$E = pc = hf$$

$$\Rightarrow f = pc/h = \frac{\left(1.1\times10^{-23}\ \text{kg}\cdot\text{m/s}\right)\left(3\times10^{8}\,\text{m/s}\right)}{\left(6.63\times10^{-34}\ \text{Js}\right)} = 5\times10^{18}\,/\text{s} = 5\times10^{18}\,\text{Hz}$$

1(C)(ii) ANS: [3 marks]

$$E = pc = hf$$

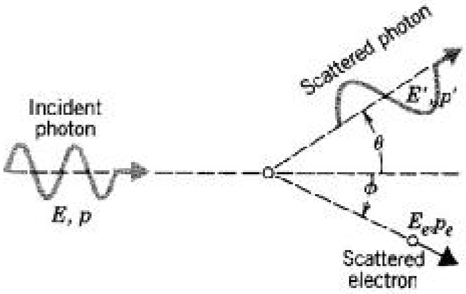
$$\Rightarrow p = E/c = hf/c = \frac{hc}{c}\left(\frac{f}{c}\right) = \frac{1240\ \text{nm}\cdot\text{eV}}{c}\left(\frac{5\times10^{18}/\text{s}}{3\times10^{8}\ \text{m/s}}\right) = \frac{1240\ \text{nm}\cdot\text{eV}}{c}\left(\frac{5\times10^{18}}{3\times10^{8}\cdot10^{9}\ \text{nm}}\right) = \frac{20667\ \text{eV}}{c}$$

or

$$l = c/f = 0.06\ \text{nm}$$

$$p = \frac{h}{l} = \frac{hc}{l\,c} = \frac{1240\ \text{nm}\cdot\text{eV}}{l\,c} = \frac{1240\ \text{nm}\cdot\text{eV}}{c\,(0.06\text{nm})} = 20667\,\frac{\text{eV}}{c}$$

2(A) ANS Elmer E. Anderson, pg. 66 (BM version). **[10 marks]**



Conservation of total relativistic energy:

$$E_i = E_f$$

$$pc + mc^2 = p'c + E_e \qquad \text{Eq. (1)}$$

Conservation of momentum in direction x and y direction:

Mom conservation in y: $p'\sin q = p_e \sin f$ Eq. (PY)

Mom conservation in x: $p = p'\cos q + p_e \cos f$ Eq. (PX)

Squaring Eq. (PY) + Squaring Eq. (PX):

$$p'^2 \sin^2 q = p_e{}^2 \sin^2 f$$

$$\left(p - p'\cos q\right)^2 = p_e{}^2 \cos^2 f$$

$$p'^2 \sin^2 q + \left(p^2 + p'^2 \cos^2 q - 2pp'\cos q\right) = p_e{}^2\left(\cos^2 f + \cos^2 f\right) = p_e{}^2$$

$$\Rightarrow c^2 p'^2 + c^2 p^2 - 2c^2 pp'\cos q = c^2 p_e{}^2 \qquad \text{Eq. (2)}$$

For the electron, $E_e^2 = c_e^2 p_e^2 + m^2c^4 \Rightarrow c_e^2 p_e^2 = E_e^2 - m^2c^4$. Eq. (3)

Plug Eq. (3) into Eq. (2),

$$c^2 p'^2 + c^2 p^2 - 2c^2 pp'\cos q = E_e{}^2 - m^2c^4 \qquad \text{Eq. (4)}$$

From Eq. (1), $E_e = pc + mc^2 - p'c$ Eq. (5)

Plug Eq. (5) into Eq. (4),

$c^2 p'^2 + c^2 p^2 - 2c^2 pp'\cos q = \left(pc + mc^2 - p'c\right)^2 - m^2c^4 = p^2c^2 + p'^2c^2 - 2p'pc^2 + 2mc^2\left(pc - p'c\right)$ Simp lifying the above equation, we arrive at

$$mc\left(p - p'\right) = p'p\left(1 - \cos q\right)$$

$$mc\left(\frac{h}{l} - \frac{h}{l'}\right) = \frac{h^2}{l'l}\left(1 - \cos q\right)$$

$$mc\left(\frac{l' - l}{l'l}\right) = \frac{h}{l'l}\left(1 - \cos q\right)$$

$$\Delta l = \frac{h}{mc}\left(1 - \cos q\right)$$

[10 marks]

2(B) ANS: (Beiser, BM version, pg 161, Soalan 3) [5 marks]

Solution:

The energy of electron in the *n* state is given by $E_n = \dfrac{-13.6\ \text{eV}}{n^2}$.

Energy emitted when electron makes transition from the *n*=10 state to *n* = 1 state (the ground state) is

$\Delta E = E_{10} - E_4 = \left(\dfrac{-13.6\ \text{eV}}{10^2}\right) - \left(\dfrac{-13.6\ \text{eV}}{1^2}\right) = 13.6\ \text{eV}\left(1 - \dfrac{1}{100}\right) = 13.6\ \text{eV}\left(\dfrac{99}{100}\right) = 13.5\ \text{eV}$ The energy is emitted in form of photon, which energy is related to the wavelength via

$$\frac{hc}{l} = \Delta E$$

Hence,

$$l = \frac{hc}{\Delta E} = \frac{1240\ \text{nm}\cdot\text{eV}}{13.5\ \text{eV}} = 92\text{nm}.$$

(Alternative calculation that makes used of $\dfrac{1}{l} = R_H\left(\dfrac{1}{n_f^2} - \dfrac{1}{n_i^2}\right)$ is also acceptable).

2(C) ANS (Beiser, Ex. 19, pg. 198)

The probability density is given by $p_n(x) = y_n(x) y_n^*(x)$, where the wave function of a particle in a box is

$y_n(x) = \sqrt{\dfrac{2}{L}} \sin\dfrac{np\,x}{L}$; The probability to find the particle between x_2 and x_1 within the box is

$P_n(x_2, x_1) = \int_{x_1}^{x_2} y_n(x) y_n^*(x) dx = \dfrac{2}{L}\int_{x_1}^{x_2} \sin^2\dfrac{np\,x}{L} dx = \left(\dfrac{x}{L} - \dfrac{x}{2np}\sin\dfrac{2p\,nx}{L}\right)\Bigg|_{x_1}^{x_2}$. Here, set $x_2 = L/n$, $x_1 = 0$,

$$P(L/n, 0) = \left(\frac{x}{L} - \frac{x}{2p}\sin\frac{2p\,x}{L}\right)\Bigg|_0^{L/n} = \left(\frac{1}{n} - \frac{L}{2p\,n}\sin 2p\,n\right) - (0 - 0) = \frac{1}{n}$$

[5 marks]

3(A) ANS

Elmer E. Anderson, pg. 19 (BM version), problem 1-10.

Take S′ to be the 'rest frame'. S′′ is moving with respect to S′ with a velocity of $u_x = b_2 c$. Take S as the "moving frame", moving at a velocity of $v = -\, b_1 c$ with respect to the frame S′. Hence, the velocity of S′′ with respect to S, u'_x, is related to both u_x and v via the formula

$$u'_x = \frac{u_x - v}{1 - \frac{u_x v}{c^2}} = \frac{b_2 c - (-b_1 c)}{1 - \frac{(b_2 c)(-b_1 c)}{c^2}} = \frac{(b_2 + b_1)c}{1 + b_2 b_1}$$

Note: one can check the correctness of the above result by considering two limiting cases:

i. When $b_2 \to 0$, S′′ becomes S′, hence, we should recover $u'_x \to b_1 c$.

ii. When $b_1 \to 0$, S becomes S′, hence, we should recover $u'_x \to b_2 c$.

[10 marks]

3(B) ANS (My own question)

(i) Total energy $E = K + M_\alpha c^2$ **[2 marks]**

(ii) $E = K + M_\alpha c^2 \Rightarrow E^2 = (K + M_\alpha c^2)^2$
Energy-momentum invariance: $E^2 = p^2c^2 + M_\alpha^2 c^4$
Eliminating E in the above equations, $p = \sqrt{(K^2/c^2 + 2KM_\alpha)}$. **[3 marks]**

(iii) Let M be the relativistic mass of the alpha particle. Its total energy is then related to this mass as per $E = Mc^2$. But $E = K + M_\alpha c^2$, hence, the increase in mass $\times c^2$,
$\Delta M_\alpha c^2 = Mc^2 - M_\alpha c^2 = (K + M_\alpha c^2) - M_\alpha c = K$
$\Rightarrow \Delta M_\alpha c^2 = K$ **[2 marks]**

(iv) In the limit of $v << c$, the relativistic expression for the momentum reduces to classical one, i.e. $p_{SR} = gM_\alpha v \to p_{Classical} = M_\alpha v$. Hence, from (*ii*), as $v<<c$, $p = M_\alpha v = \sqrt{(K^2/c^2 + 2KM_\alpha)}$.
Squaring, $K^2/c^2 + 2KM_\alpha = M_\alpha^2 v^2$. Solving the quadratic equation in K:
$K^2 + 2KM_\alpha c^2 - M_\alpha^2 v^2 c^2 = 0$
The positive root is given by
$K = [-2M_\alpha c^2 + \sqrt{(4M_\alpha^2 c^4 + 4M_\alpha^2 v^2 c^2)}]/2 = -M_\alpha c^2 + \sqrt{(M_\alpha^2 c^4 + M_\alpha^2 v^2 c^2)}$
$= -M_\alpha c^2 + M_\alpha c^2 (1 + v^2/c^2)^{1/2} = -M_\alpha c^2 + M_\alpha c^2 (1 + v^2/2c^2 + \ldots)$ (Binomial expansion)
$= M_\alpha v^2/2$ (retaining the term up to order of v^2/c^2) **[3 marks]**

UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2006/2007

April 2007

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

Duration: 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains **TWENTY THREE** pages before you begin the examination.

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

Instruction: Answer **ALL** questions in Section A and Section B.

Please answer the objective questions from Section A in the objective answer sheet provided. Please submit the objective answer sheet and the answers to the structured questions separately.

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

*[**Arahan**: Jawab **SEMUA** soalan dalam Bahagian A dan Bahagian B.*

Sila jawab soalan-soalan objektif daripada bahagian A dalam kertas jawapan objektif yang dibekalkan. Sila serahkan kertas jawapan objektif dan jawapan kepada soalan-soalan struktur berasingan.

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

Data

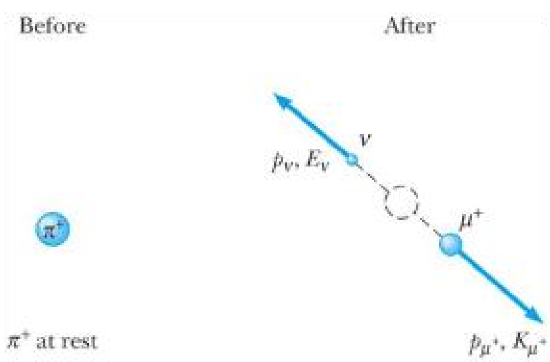
Speed of light in free space, $c = 3.00 \times 10^{8}$ m s^{-1}
Permeability of free space, $m_0 = 4\pi \times 10^{-7}$ H m^{-1}
Permittivity of free space, $e_0 = 8.85 \times 10^{-12}$ F m^{-1}
Elementary charge, $e = 1.60$ x 10^{-19} C
Planck constant, $h = 6.63 \times 10^{-34}$ J s
Unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg
Rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg
Molar gas constant, = 8.31 J K^{-1} mol^{-1}
Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}
Gravitational constant, $G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
Acceleration of free fall, $g = 9.81$ m s^{-2}

Section A: Objectives. [40 marks]
[Bahagian A: Soalan-soalan objektif]

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

Question 1 - 3 are based on the decay of a π meson into a muon and a massless neutrino shown in the figure below. The rest mass of the muon is m_m, and the kinetic energy of the muon is measured to be K_m. p_m denotes the momentum of the muon. m_p denotes the rest mass of π meson.

[Soalan 1-3 adalah berdasarkan pereputan satu meson p kepada satu muon dan satu neutrino tanpa jisim, sepertimana ditunjukkan dalam gambarajah di bawah. Diketahui jisim rehat muon ialah m_m, dan tenaga kinetik muon yang terukur ialah K_m. p_m menandakan momentum muon. m_p menandakan jisim rehat meson π.]



…3/-
[ZCT 104]

1. How is the energy of the muon E_μ related to the momentum of the muon?
[Bagaimanakah tenage muon E_m dikaitkan dengan momentum muon?]

A. $E_m^2 = p_m^2 c^2 - m_m^2 c^4$

B. $E_m = p_m c + m_m c^2$

C. $E_m = p_m c$

D. $E_m^2 = p_m^2 c^2 + m_m^2 c^4$

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

2. What is the kinetic energy of the π meson?
[Apakah tenaga kinetik meson π ?]

A. $K_m + m_m c^2$

B. 0

C. K_m

D. $m_p c^2$

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

3. What is the momentum of the neutrino?
[Apakah momentum neutrino?]

A. $p_n = \frac{1}{c}\sqrt{K_m\left(2m_m c^2 + K_m\right)}$

B. $p_n = \frac{1}{c}\sqrt{\left(2m_m^2 c^4 + K_m^2\right)}$

C. $p_n = K_m / c$

D. 0

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

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

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I. The Lyman series emission spectrum of a hydrogen atom lies in the visible region of the electromagnetic spectrum.
[Spektrum pancaran siri Lyman atom hidrogen terletak dalam rantau nampak spektrum elektromagnetik.]

II. The Balmer series emission spectrum of a hydrogen atom lies in the ultraviolet region of the electromagnetic spectrum.
[Spektrum pancaran siri Balmer atom hidrogen terletak dalam rantau ultraungu spektrum elektromagnetik.]

III. The Paschen series emission spectrum of a hydrogen atom lies in the ultraviolet region of the electromagnetic spectrum.
[Spektrum pancaran siri Paschen atom hidrogen terletak dalam rantau ultra ungu spektrum elektromagnetik.]

IV. Not all of the emission spectrum of a hydrogen atom lies in the visible region of the electromagnetic spectrum.
[Bukan kesemua spektrum pancaran siri atom hidrogen terletak dalam rantau nampak spektrum elektromagnetik.]

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

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

I. The kinetic energy of an object is the energy associated with the motion of the object.
[Tenaga kinetik suatu objek adalah tenaga yang berkaitan dengan pergerakan objek.]

II. The kinetic energy of an object cannot be larger than its total energy.
[Tenaga kinetik suatu objek tidak boleh melebihi jumlah tenaganya.]

III. The relativistic expression of momentum reduces to that of the classical theory of machanics in the limit $v << c$.
[Ungkapan momentum keretatifan terturun kepada ungkapan mekanik teori klasik dalam limit $v<<c$.]

IV. The classical expression of kinetic energy has to be supplanted by that of the special theory of relativity when v approaches c from below.
[Ungkapan tenaga kinetik klasik harus digantikan oleh ungkapan kerelatifan jika v menokok ke c dari bawah.]

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

6. Consider a proton and an electron, both moving at a common momentum, p. Let K_p and K_e denote the proton and electron kinetic energies respectively. Which of the following statements is (are) true?
[Pertimbangkan suatu proton dan suatu elektron, kedua-duanya bergerak dengan momentum yang sama, p. Biar K_p dan K_e masing-masing menandakan tenaga kinetik proton dan elektron. Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. $K_p = K_e$ for $v < c$. *[$K_p = K_e$ untuk $v < c$.]*
II. $K_p \neq K_e$ in general. *[$K_p \neq K_e$ pada amnya.]*
III. $K_p > K_e$ for all values of $v < c$. *[$K_p > K_e$ untuk semua nilai $v < c$.]*
IV. $K_e > K_p$ for $v << c$. *[$K_e > K_p$ untuk $v << c$.]*

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

7. Which of the following statements is (are) true according to the special theory of relativity?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar menurut teori kerelatifan?]

I. A massless particle can travel at the speed lower than the speed of light.
[Suatu zarah tanpa jisim mungkin bergerak dengan laju yang kurang daripada laju cahaya.]

II. A particle with non-zero mass does not necessarily travel at the speed smaller than that of light.
[Suatu zarah dengan jisim bukan sifar tidak semestinya bergerak dengan laju yang kurang daripada laju cahaya.]

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III. The rest mass of a moving object changes when it is moving.
[Jisim rehat suatu objek berubah bila ia bergerak.]

IV. It requires an infinite amount of energy to accelerate a massive object to the speed of light.
[Tenaga yang infinit diperlukan untuk memecutkan suatu zarah kepada laju cahaya.]

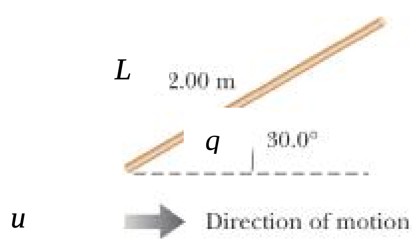
A. I, III, IV
B. I, II, III, IV
C. I, II, III
D. IV only *[IV sahaja]*
E. None of A, B, C, D
[Jawapan tidak terdapat dalam pilihan-pilihan A, B, C]

8. When two particles collide relativistically,
[Bila dua zarah berlanggar secara kerelatifan,]

I. the total momentum is conserved.
[jumlah momentum adalah terabadikan.]
II. the total kinetic is conserved.
[jumlah tenaga kinetik adalah terabadikan.]
III. the total kinetic energy is an invariant.
[jumlah tenaga kinetik adalah tak varian.]
IV. the total rest mass is conserved.
[jumlah jisim rehat adalah terabadikan.]

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

9. In its rest frame, a rod has a proper length of L and is orientated at an angle of $q = 45°$ with the x-axis. The rod then move at a speed of $u = c/2$ in the x-direction.
[Dalam rangka rehatnya, suatu rod dengan panjang lazim L diorientasikan pada suatu sudut $q = 45°$ merujuk kepada paksi-x. Ia kemudian bergerak pada laju $u = c/2$ dalam arah x.]



What is the length of the rod as observed in the improper frame?
[Apakah panjang rod tersebut dalam rangka tak lazim?]

A. L

B. $\frac{\sqrt{7}}{4}L$

C. $\frac{3}{4}L$

D. $\sqrt{\frac{7}{8}}L$

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

10. In Question 9, what is the inclination angle of the rod with respect to the x-axis as observed in the improper frame?
[Dalam solaan 9, apakah sudut di antara rod dengan paksi-x dalam rangka tak lazim?]

A. $\tan^{-1}\left(\frac{\sqrt{7}}{8}\right)$

B. $\tan^{-1}\left(\frac{\sqrt{3}}{2}\right)$

C. $\tan^{-1}(1)$

D. $\tan^{-1}\left(\frac{2}{\sqrt{3}}\right)$

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

11. What measurement(s) do two observers in relative motion always agree on?
[Apakah ukuran(-ukuran) yang sentiasa disetujui oleh dua orang pemerhati yang berada dalam pergerakan relatif?]

I The speed of an electron moving in medium water.
[Laju suatu elektron dalam medium air.]

II The time interval between two events.
[Selang masa antara dua kejadian.]

III The number of particles.
[bilangan zarah.]

IV The density of an object. *[Ketumpatan suatu objek]*

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

E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

12. The units of the work function are those of:
[Unit bagi fungsi kerja adalah sama dengan unit bagi …]

A. energy
[tenaga]
B. power
[kuasa]
C. momentum
[momentum]
D. angular momentum
[momentum sudut]
E. frequency
[frekuensi]

13. The S.I. units of 1-D wavefunction are those of:
[Unit bagi fungsi gelombang 1D adalah sama dengan unit bagi …]

A. $1/\sqrt{\text{length}}$

B. $1/\sqrt{\text{energy}}$

C. $1/\sqrt{\text{momentum}}$

D. $1/\sqrt{\text{frequency}}$

E. $1/\sqrt{\text{mass}}$

14. The light intensity incident on a metallic surface produces photoelectrons with a maximum kinetic energy of 2 eV. The light intensity is doubled. Determine the maximum kinetic energy of the photoelectrons (in eV).
[*Keamatan cahaya yang menujui suatu permukaan logam menghasilkan fotoelektron dengan tenaga kinetik maksimum 2 eV. Keamatan cahaya digandaduakan. Tentukan tenaga kinetik maksimum fotoelektron terhasil (dalam eV).*]

A. 4
B. 2
C. $\sqrt{2}$
D. 3
E. 16

15. Microscopes are inherently limited by the wavelength of the light used. How much smaller (in order of magnitude) can we "see" using an electron microscope whose electrons have been accelerated through a potential difference of 10 000 V than using red light (400 nm)?
[Secara tabiinya mikroskop dihadkan oleh jarak gelombang cahaya yang digunakan. Berbanding dengan penggunaan cahaya merah (400 nm), betapa kecilkah (dalam magnitud tertib) yang boleh kita 'nampak' dengan menggunakan mikroskop elektron yang elektronnya dipecutkan melalui suatu beza keupayaan 10 000 V?]

A. 3
B. 4
C. 5
D. 6
E. 14

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

I. In photoelectric effect , a photon will either be totally absorbed or not at all. *[Dalam kesan fotoelektrik suatu foton akan samada terserap sepenuhnya atau langsung tidak].*
II. Photons have mass.
[foton mempunyai jisim.]
III. Photons have electric charge.
[foton mempunyai cas elektrik.]
IV. Photons can be accelerated via an electric field.
[foton boleh dipecutkan oleh suatu medan elektrik.]

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

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17. Which of the following statements is (are) true about the nature of light?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai tabii cahaya?]

I. Effects due to the photon nature of light are generally more important at the low-frequency end of the electromagnetic spectrum (radio waves).
[Kesan-kesan disebabkan oleh tabii foton dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi rendah spektrum elektromagnet (gelombang radio)].

II. Effects due to the photon nature of light are generally more important at the high-frequency end of the electromagnetic spectrum (X-ray and gamma ray).
[Kesan-kesan disebabkan oleh tabii foton dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi tinggi spektrum elektromagnet (sinaran-X dan sinaran gamma).]

III. Effects due to the wave nature of light are generally more important at the low-frequency end of the electromagnetic spectrum (radio waves).
[Kesan-kesan disebabkan oleh tabii gelombang dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi rendah spektrum elektromagnet (gelombang radio)].

IV. Effects due to the wave nature of light are generally more important at the high-frequency end of the electromagnetic spectrum (Xray and gamma ray).
[Kesan-kesan disebabkan oleh tabii gelombang dalam cahaya secara amnya adalah lebih penting pada hujung frekuensi tinggi spektrum elektromagnet (sinaran-X dan sinaran gamma).]

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]

18. The total energy (kinetic plus potential) of the hydrogen atom is negative. What significance does this have?
[Jumlah tenaga (kinetik serta keupayaan) atom hidrogen adalah negatif. Apakah kepentingannya?]

A. The hydrogen atom is ionized.
[Atom higrogen diionkan.]
B. The angular momentum of the electron is quantized.
[Momentum sudut elektron terkuantumkan.]
C. The electron is bonded by the hydrogen atom's electric field.
[Elektron adalah terikat oleh medan elektrik atom hidrogen.]
D. The hydrogen atom is a free particle.
[Atom hidrogen adalah zarah bebas.]
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

19. A double ionized lithium atom (Li^{++}) is one that has had two of its three electrons removed. The ground state energy of the Li^{++} is _____ times the ground state energy of the hydrogen atom.
[Suatu atom lithium yang berganda terionkan ialah atom yang dua daripada tiga elektronnya disingkirkan. Keadaan dasar Li^{++} *adalah ______kali tenaga dasar hidrogen.*]

A. 2
B. 4
C. 8
D. 9
E. 32

20. In photoelectric effect experiment, which of the following will increase the maximum kinetic energy of the photoelectron? [*Dalam eksperimen kesan fotoelektrik, yang manakah berikut akan menambahkan tenaga kinetik maksmum fotoelektron?*]

I. Use the light of greater intensity.
[Guna cahaya yang keamatannya lebih tinggi].

II. Use the light of greater frequency.
[Guna cahaya yang frekuensinya lebih tinggi].

III. Use the light of greater wavelength.
[Guna cahaya yang jarak gelombangnya lebih tinggi].

IV. Use metal surface with a smaller work function.
[Guna permukaan logam yang fungsi kerjanya lebih rendah].

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]

21. Which of the following associations with experiments is (are) true?
[Yang manakah perhubungan-perhubungan dengan eksperimen berikut adalah benar?]

I. The Davisson-Gremer experiment shows that electrons do behave like waves.
[Eksperimen Davisson-Germer menunjukkan bahawa elektron berlagak seperti gelombang.]

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II. The Frank-Hertz experiment shows that atoms do behave like waves.
[Eksperimen Frank-Hertz menunjukkan bahawa atom-atom berlagak seperti gelombang.]

III. The Compton scattering experiment show that electrons behave like waves.
[Eksperimen Compton menunjukkan bahawa elektron berlagak seperti gelombang.]

IV. The Young double slit experiment using electron as the source shows that electrons do behave like waves.
[Eksperimen dwi-celah Young yang menggunakan elektron sebagai punca menunjukkan bahawa elektron berlagak seperti gelombang.]

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

22. Say a beam of light has an intensity of I (i.e. the total energy per unit area per unit time) and frequency n. What is the photon density, n (i.e. the number of photon per unit volume), of the light beam?
[Katakan keamatan satu alur cahaya ialah I (iaitu jumlah tenaga per unit permukaan per unit masa) dan frekuensinya ialah n. Apakah ketumpatan foton n (iaitu bilangan foton per unit isipadu) dalam alur cahaya tersebut?]

A. $(hcn)^2/I^2$
B. hcn/I
C. $I/(hcn)$
D. $I^2/(hcn)^2$
E. None of A, B, C, D
[Jawapan tiada dalam A, B, C, D]

23. A particle of mass m is confined to a one-dimensional box of width L and infinite height. The particle's wavelength at state n is given by
[Suatu zarah yang terperangkap dalam suatu kotak satu dimensi dengan lebar L dan ketinggian infiniti. Jarak gelombang zarah tersebut pada keadaan n ialah]

A. $2L/n$
B. $n/2L$
C. $2L/n\mathbf{h}$
D. $n\mathbf{h}/2L$
E. None of the above
[Jawapan tiada di atas]

24. The kinetic energy of the particle in Question 23 is given by
[Tenaga kinetik zarah dalam Soalan 23 ialah]

A. $n^2 \dfrac{\mathbf{h}^2}{8mpL^2}$

B. $n^2 \dfrac{h^2}{8mL^2}$

C. $n^2 \dfrac{p^2 h^2}{2mL^2}$

D. $n^2 \dfrac{\mathbf{h}^2}{2mL^2}$

E. None of the above
[Jawapan tiada di atas]

25. If the infinitely high potential box in Question 23 is replaced by one with a finite height, how would the wavelength of the particle at a given state ***n*** be modified as compared to the answer in Question 23?
[Jika keupayaan kotak yang infinit dalam Soalan 23 digantikan dengan kotak yang tinggi keupayaannya finit, bagaimanakah jarak gelombang zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 23?]

A. The wavelength would be longer than that in Question 23.
[Jarak gelombang akan menjadi lebih panjang daripada jarak gelombang dalam Soalan 23.]

B. The wavelength would be shorter than that in Question 23.
[Jarak gelombang akan menjadi lebih pendek daripada jarak gelombang dalam Soalan 23.]

C. The wavelength would be the same as that in Question 23.
[Jarak gelombang adalah sama seperti jarak gelombang dalam Soalan 23.]

D. The wavelength could be longer or shorter than that in Question 23, depending on n.
[Jarak gelombang akan menjadi lebih panjang atau lebih pendek daripada jarak gelombang dalam Soalan 23, bergantung kepada n.]

E. None of the above.
[Jawapan tiada di atas]

…14/-

26. Following Question 25, how would the kinetic energy of the particle at a given state ***n*** be modified as compared to the answer in Question 24?
[Menurut Soalan 25, bagaimanakah tenaga kinetik zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 24?]

A. The kinetic energy would be larger than that in Question 24.

B. The kinetic energy would be smaller than that in Question 24.

C. The kinetic energy would be the same as that in Question 24.

D. The kinetic energy could be larger or smaller than that in Question 24, depending on ***n***.

E. None of the above.
[Jawapan tiada di atas]

27. If the finite potential box in Question 25 is in turn replaced by one with a width larger than *L*, how would the wavelength of the particle at a given state ***n*** be modified as compared to the answer in Question 25?
[Jika kotak yang berkeupayaan finit dalam Soalan 25 digantikan dengan kotak yang lebarnya lebih besar daripada L, bagaimanakah jarak gelombang zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 25?]

A. The wavelength would be longer than that in Question 25.

B. The wavelength would be shorter than that in Question 25.

C. The wavelength would be the same as that in Question 25.

D. The wavelength could be longer or shorter than that in Question 25, depending on ***n***.

E. None of the above
[Jawapan tiada di atas]

28. Following Question 27, how would the kinetic energy of the particle at a given state ***n*** be modified as compared to the answer in Question 26?
[*Menurut Soalan 27, bagaimanakah tenaga kinetik zarah pada suatu keadaan n akan dimodifikasikan bila berbanding dengan jawapan untuk Soalan 26?]*

A. The kinetic energy would be larger than that in Question 26.

B. The kinetic energy would be smaller than that in Question 26.

C. The kinetic energy would be the same as that in Question 26.

D. The kinetic energy could be larger or smaller than that in Question 26, depending on ***n***.

E. None of the above
[Jawapan tiada di atas]

29. What are the features of a X-ray curve as produced from a X-ray tube?
[Apakah ciri-ciri bagi suatu lengkung sinaran-X yang dihasilkan oleh tiub sinaran-X]

I. The spectrum is continuous.
[*Spektrumnya adalah selanjar.*]

II. The existence of a minimum wavelength for a given accelerating potential *V*, below which no x-ray is observed.
[*Wujudnya suatu jarak gelombang minimum bagi suatu keupayaan pecutan V yang diberikan. Kurang daripada jarak gelombang minimum tersebut, tiada sinaran-X akan tercerap.*]

III. Increasing *V* decreases the minimum wavelength.
[*Menambahkan V menyebabkan jarak gelombang minimum dikurangkan.*]

IV. There exists an upper limit in the wavelength of the X-ray produced.
[*Wujudnya limit atas untuk jarak gelombang sinaran-X yang dihasilkan.*]

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

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

I. In photoelectricity the whole photon is directly absorbed by the free electron in the metal surface.
[Dalam kesan fotoelektrik keseluruh foton diserap secera terus oleh elektron bebas dalam permukaan logam.]

II**.** In photoelectricity the whole photon is first absorbed by the atom in the metal surface.
[Dalam kesan fotoelektrik keseluruh foton terdahulunya diserap oleh atom dalam permukaan logam.]

III. In X-ray production by electron bombardment on a metal target, the kinetic energy of the bombarding electron is converted to the continuous X-ray photon energy via Bremsstrahlung.
[Dalam penghasilan sinaran-X oleh penghentaman elektron ke atas sasaran logam, tenaga kinetik elektron yang menghentam ditukarkan kepada tenaga foton selanjar sinaran-X melalui Bremsstrahlung.]

IV. In the X-ray production using the X-ray tube, the energy of the X-ray photon is converted to the kinetic energy of the electron via Bremsstrahlung.
[Dalam penghasilan sinaran-X dalam tiub sinaran-X, tenaga foton ditukarkan kepada tenaga kinetik elektron melalui Bremsstrahlung.]

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

31. Which of the following statements is (are) true?

[Yang manakah kenyataan(-kenyataan) berikut adalah benar?]

I. A photon can materialize into an electron plus a positron in the absence of any external field.
[Suatu foton boleh bertukar menjadi jirim satu elektron serta satu positron dalam ketidakhadiran sebarang medan luar.]

II. A photon can materialize into either a single electron OR a single positron in the presence of a strong electric field.
[Suatu foton boleh bertukar menjadi jirim satu elektron tunggal atau satu positron tunggal dalam kehadiran medan elektrik kuat.]

III**.** An electron-positron pair can annihilate into a single photon.
*[Suatu pasangan elektron-positron boleh menghabisbinasa menjadi satu foton tunggal.] [*F*]*

IV**.** An electron-positron pair can annihilate into two photons.
[*Suatu pasangan elektron-positron boleh menghabisbinasa menjadi dua foton.*]

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

…17/-

32. Which of the following statements is (are) true regarding the interactions between photons with matter?
[Yang manakah kenyataan(-kenyataan) berikut adalah benar mengenai interaksi foton dengan jirim?]

I. The probability (cross section) of a photon undergoes a given channel of interaction with matter depends on the photon energy.
[Kebarangkalian (keratan rentas) suatu foton menjalani mana-mana saluran interaksi dengan jirim bergantung kepada tenaga foton.]

II. The probability (cross section) of a photon undergoes a given channel of interaction with matter depends on the atomic number of the absorbing material.
[Kebarangkalian (keratan rentas) suatu foton menjalani mana-mana saluran interaksi dengan jirim bergantung kepada nombor atom bahan penyerap.]

III For a fixed atomic number, the photon-material interactions at low energy are dominated by photoelectric effect.
[Pada suatu nombor atom yang tertentu, interaksi di antara foton dengan jirim pada tenaga rendah dikuasai oleh kesan fotoelektrik.]

IV. Electron-positron Pair production begins to show up when the photon energy approaches, but not yet exceed, the value of 1.02 MeV.
[Penghasilan pasangan electron-positron mula muncul semasa tenaga foton menhampiri, tapi belum melebihi, nilai 1.02 MeV.]

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

33. A relativistic electron has a de Broglie wavelength of l. Find its kinetic energy.
[Jarak gelombang de Broglie suatu elektron kerelatifan ialah l. Dapatkan tenaga kinetiknya.]

A. $K = ((hc/\lambda)^2 - m_e^2c^4)^{½} + m_ec^2$.
B. $K = ((hc/\lambda)^2 + m_e^2c^4)^{½} + m_ec^2$.
C. $K = ((\lambda/hc)^2 + m_e^2c^4)^{½} - m_ec^2$.
D. $K = ((hc/\lambda)^2 + m_e^2c^4)^{½} - m_ec^2$.
E. None of the above
[Jawapan tiada dalam A, B, C, D]

34. In the Davisson-Gremer experiment, the electron is accelerated via an electric potential of *V*. The wavelength of the electron, l, in terms of *V* is given by the expression
[Dalam eksperimen Davisson-Gremer, elektron dipecutkan oleh keupayaan elektrik V. Jarak gelombang elektron, l, dalam ungkapan V, adalah diberikan oleh]

A. $l = (2eVm_e)^{1/2}/h$
B. $l = h^{1/2}/(2eVm_e)$
C. $l = h/(2eVm_e)$
D. $l = h/(2eVm_e)^{1/2}$
E. None of the above
[Jawapan tiada dalam A, B, C, D]

Questions 35 - 37 are based on Figure 1.
[Soalan 35 -37 adalah berdasarkan Gambarajah 1.]

35. Figure 1 shows three group waves. Which of the group waves has the largest spatial spread, Δx?
[Gambarajah 1 menunjukkan 3 gelombang kumpulan. Yang mana satukah mempunyai sebaran ruagan Δx yang terbesar?]

36. Which of the group waves has the largest spread in wavelength, $\Delta\lambda$?
[Yang mana satukah mempunyai sebaran jarak gelombang $\Delta\lambda$ yang terbesar?]

37. Which of the group waves has the largest spread in wave number, Δk?
[Yang mana satukah mempunyai sebaran nombor gelombang Δk yang terbesar?]

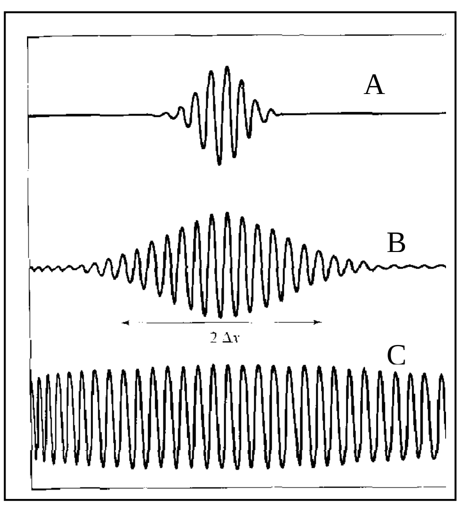


Figure 1

…19/-
[ZCT 104]

38. Assume that the uncertainty in the position of a particle is equal to two times its de Broglie wavelength. What is the minimal uncertainty in its velocity?
[Anggap bahawa ketidakpastian dalam kedudukan suatu zarah adalah bersamaan 2 kali jarak gelombang de Broglienya. Apakah ketidakpastian mimimum dalam halajunya?]

A. $v_x/4\pi$
B. B. $v_x/2\pi$
C. $v_x/8\pi$
D. v_x/π
E. $v_x/16\pi$

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

I. The length scale characterizing atomic physics is ~ Å
[Skala panjang yang mencirikan fizik atom ialah ~ Å*]*

II. The velocity scale characterizing special relativistic effect is ~ *c*.
[*Skala halaju yang mencirikan kesan kerelatifan khas ialah* ~ *c]*

III. The length scale characterizing Compton scattering is ~ pm.
[*Skala panjang yang mencirikan serakan Compton ialah* ~ pm]

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

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

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

I. The velocity of the electron in the lower orbits is relativistic.
[Halaju elektron dalam orbit rendah adalah kerelatifan.]

II. The kinetic energy of the electron in the lower orbits is relativistic.
[Tenaga kinetik elektron dalam orbit rendah adalah kerelatifan.]

…20/-

III. The model does not take into account the effect of Heisenberg uncertainty principle.

[Model tersebut tidak mengambil kira kesan prinsip ketidakpastian Heisenberg]

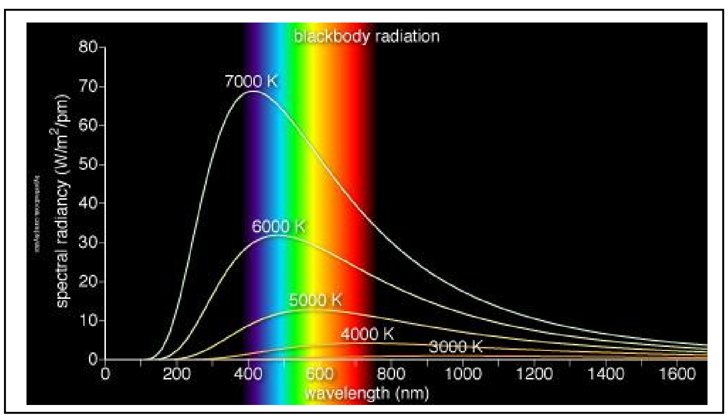
IV. The energy scale characterizing the transition is ~ keV.
[Skala tenaga yang mencirikan peralihan ialah ~ keV]

A. III Only
B. I, II, IV
C. I, II
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 20 marks.
[Arahan: Jawab semua soalan. Setiap soalan membawa 20 markah.]

1. (a) A typical spectral distribution of radiation energy of a black body for several temperatures is as shown.
[Terpapar adalah suatu taburan spektrum yang tipikal bagi tenaga pancaran suatu jasad hitam untuk beberapa suhu.]



The shift of the peak of the curve was found to obey the empirical Wein's displacement law,
[Anjakan puncak lengkungan didapati mematuhi hukum sesaran Wein,]

$$l_p T = \text{constant},$$
$$[\ l_p T = \text{pemalar},]$$

…21
[ZCT 104]

where the symbol l_p refers to the value of the wavelength corresponding to the peak of the curve.

[dengan l_p mewakili nilai jarak gelombang pada puncak lengkungan.]

The ***total power radiated per unit area*** of a blackbody is found to be empirically related to its absolute temperature by the *the Stefan-Boltzman law*
[Jumlah kuasa pancaran per unit permukaan suatu jasad hitam didapati berkait secara empirikal kepada suhu mutlak oleh hukum Stefan-Boltzman, $I(T) = s T^4$,]

$$I(T) = s T^4,$$

where s is the Stefan constant. The radiance, $R(l, T)$ and $I(T)$ are related by the integral $I(T) = \int_0^\infty R(l, T) \mathrm{d}l$.
[dengan s pemalar Stefan. Radians, $R(l, T)$ dikaitkan dengan $I(T)$ oleh kamiran $I(T) = \int_0^\infty R(l, T) \mathrm{d}l$.]

Wein proposed an empirical form for the radiance $R(l, T)$ by constructing a mathematical function to fit the experimental blackbody curve, known as the *Wein's law*:
[Wein menyarankan suatu bentuk empirikal bagi $R(l, T)$ dengan membinakan suatu fungsi matematik untuk memadankan lengkungan eksperimen jasad hitam. Ia dikenali sebagai hukum Wein:]

$$R(l, T) = \frac{a e^{-b/lT}}{l^5} \quad \text{(Wein's law)}$$

The quantities ***a*** and ***b*** are not derived but are simply curve-fitting parameters.
[Kuantiti a dan b bukannya diterbitkan tapi sekadar merupakan parameter-parameter untuk memadankan lengkungan.]

On the theoretically front, Planck derives his famous blackbody radiation law by assuming that the energies emitted from the oscillators are quantized. In his theory, the radiance is given by the theoretical expression
[Dalam garis depan teori, Planck menerbitkan hukum jasad hitamnya yang masyur dengan anggapan bahawa tenaga terpancar daripada pengayun adalah terkuantumkan. Dalam teorinya, radians diberikan oleh]

$$R(l, T) = \frac{2p hc^2}{l^5 \left(e^{hc/lkT} - 1\right)} \quad \text{(Planck's law)}$$

Using Planck's law as given above,
[Dengan menggunakan hukum Planck,]

(i) show that it reduces to Wein's law in the short wavelength limit.
[tunjukkan bahawa ia terturun kepada hukum Wein dalam limit jarak gelombang pendek.]

(ii) Evaluate *a* and *b* in terms of the natural constants (i.e. *k, c, h, p*).
[Nilaikan a dan b dalam sebutan pamalar semulajadi, iaitu k, c, h, p)]

(iii) Evaluate the Stefan constant.
[Nilaikan pemalar Stefan.] [2+(2+2)+4=10]

(b) If the photocurrent of a photocell is cut off by a retarding potential of 0.92 V for monochromatic radiation of 2500Å what is the work function of the material?
[Jika fotoarus suatu fotosel dipengal oleh keupayaan rencatan 0.92 V untuk pancaran monokromatik 2500 Å *, apakan funsi kerja bahan tersebut?]*

[4]

(c) (i) What is the frequency of a X-ray photon with momentum 1.1×10^{-23} kg·m/s
[Apakah frekuensi suatu foton sinaran-X dengan momentum 1.1×10^{-23} kg·m/s *?]*

(ii) What is the momentum of (c)(*i*) in unit of eV/*c*?
[Apakah memomtum di (c)(*i*) *dalam unit eV/c?]*

[3 + 3 = 6]

2. (a) Derive the Compton scattering formula $l' - l = \frac{h}{mc}(1-\cos q)$, where l and l' are the wavelengths of the incident and scattered photon respectively, q the scattered angle of the photon, *m* the mass of target particle.
[Terbitkan formula serakan Compton $l' - l = \frac{h}{mc}(1-\cos q)$ *.]*

[10]

(b) Determine the wavelength of a photon that is emitted when an atom hydrogen makes a transition from state *n* = 10 to the ground state.
[Tebtukan jarak gelombang foton yang dipancarkan apabila suatu atom hydrogen beralih dari keadaan n = 10 ke keadaan asas.]

[5]

…23/-

(c) Given the wave function of a particle in an infinite box $y_n(x) = \sqrt{\frac{2}{L}}\sin\frac{np\,x}{L}$, where *L* is the width of the box. Find the probability that the particle can be found between *x* = 0 and *x* = *L/n* when it is in the *n*th state.

[Diberikan fungsi gelombang zarah dalam kotak infini $\psi_n(x) = \sqrt{\frac{2}{L}} \sin \frac{n\pi x}{L}$ *, di mana L ialah lebar kotak tersebut. Carikan kebarangkalian untuk mencarikan zarah di antara x=0 dan x=L/n bila ia berada dalam keadaan n.]*

[5]

3. (a) Consider three inertial frames that are moving along a common direction. The relative velocity of S′ with respect to S is b_1c, whereas the relative velocity of S″ with respect to S′ is b_2c. Find the velocity of S″ with respect to S, *bc*, in terms of b_1c, and b_2c.
[Pertimbangkan tiga rangka inersia yang bergerak sepanjang arah yang sama. Halaju relatif S' terhadap S ialah b_1c*, manakala halaju relatif S'' terhadap S' ialah* b_2c*. Carikan halaju S'' terhadap S, bc, dalam sebutan* b_1c *dan* b_2c.]

[10]

(b) The kinetic energy, *K*, of a fast-moving alpha particle (with rest mass M_α) is measured in the laboratory. [*Tenaka kinetik, K, bagi suatu zarah alfa (dengan jisim rehat* M_α*) diukurkan dalam makmal.*]

(i) What is its total energy *E*?
[Apakah jumlah tenaganya?]

(ii) What is its momentum *p*?
[Apakah momentumnya?]

(iii) What's the increase in its mass (as compared to its mass when at rest), ΔM_α?
[Apakah pertambahan dalam jisimnya (berbanding dengan jisimnya semasa ia berehat)?]

(iv) Based on the answer of (*ii*) above, show that the expression of the kinetic energy *K* reduces to the classical one in the limit $v \ll c$, where *v* is the velocity of the alpha particle.
[Berdasarkan jawapan dalam (ii) di atas, tunjukkan bahawa sebutan tenaga kinetik K terturun kepada sebutan tenaga kinetik klasikal dalam limit v<<c, dengan v halaju zarah alfa.]

[2+3+2+3]

SOLUTIONS

1. **ANS:D**
2. **ANS:B.**
3. **ANS:A.**
4. ANS: E (Only IV is true)
5. **ANS: C [My own question.]**
6. **ANS: D**
7. **ANS: D [My own question.]** Note: In the limit *v<<c*,
$$\frac{K_P}{K_e} = \frac{p^2/2m_P}{p^2/2m_e} \Rightarrow \frac{K_P}{K_e} = \frac{m_e}{m_P} \Rightarrow K_P = \frac{m_e}{m_P} K_e < K_e$$
8. **ANS: B.**

9. ANS:D

$$g^2 = 1/\left[1-\left(v^2/c^2\right)\right] = 1/\left(1-\frac{1}{4}\right) = \frac{4}{3};$$

$$\left(L'\right)^2 = \left(L\sin 45^{\circ}\right)^2 + \left(\frac{L\sin 45^{\circ}}{g}\right)^2 = L^2\left(\frac{1}{2}+\frac{1}{2}\cdot\frac{3}{4}\right) = L^2\left(\frac{1}{2}+\frac{3}{8}\right) = L^2\left(\frac{7}{8}\right)$$

$$L' = L\sqrt{\frac{7}{8}}$$

10. ANS:D
11. Solution: E. only III is true
12. Solution: A
13. Solution: A
14. Solution: B
15. Solution: B

$$eV = \frac{p^2}{2m} = \frac{\left(h/l_e\right)^2}{2m}$$

$$\Rightarrow l_e = \frac{h}{\sqrt{2m_e eV}} = \frac{hc}{\sqrt{2m_e c^2 eV}} = \frac{hc}{\sqrt{2m_e c^2 eV}} = \frac{1240\text{nm}\cdot\text{eV}}{\sqrt{1\text{MeV}\cdot e\cdot 10000\text{V}}} =$$

$$\frac{1240\text{nm}\cdot\text{eV}}{\sqrt{1\times 10^{10}\text{eV}^2}} = \frac{1240\text{nm}}{\sqrt{10^{10}}} : \frac{10^3\text{nm}}{10^5} = 10^{-2}\text{nm}$$

$$\frac{l_e}{l} \sim \frac{10^{-2}\text{nm}}{10^2\text{nm}} = 10^{-4}$$

Hence, with λ_e we can see 4 orders smaller.

16. Solution: E, Only I is true. Young and Freeman, pg. 1485, Q38
17. Solution: A
18. Solution: C
19. Solution: D. Note: $E_n = -\frac{Z^2}{n^2}E_0$
20. Solution: D
21. ANS: B
22. ANS: C
23. ANS: A
24. ANS: B
25. ANS: A
26. ANS: B
27. ANS: A
28. ANS: B
29. ANS: C
30. ANS: C
31. ANS: E (Only IV is true)
32. ANS: D
33. ANS: D
34. ANS: D
35. (ANS: C)
36. (ANS: A)
37. (ANS: A)
38. ANS: C

$$l = \frac{h}{p_x}$$

$$\Delta x = 2l = \frac{2h}{p_x}$$

$$\Delta x \Delta p_x \geq \frac{\mathbf{h}}{2} \Rightarrow \frac{2h}{p_x}\Delta p_x \geq \frac{\mathbf{h}}{2} \Rightarrow \frac{\Delta p_x}{p_x} \geq \frac{\mathbf{h}}{4h} = \frac{1}{8p}$$

$$\frac{\Delta p_x}{p_x} = \frac{m\Delta v_x}{mv_x} \geq \frac{1}{8p} \Rightarrow \Delta v_x \geq \frac{v_x}{8p}$$

39. ANS: D

40. ANS: A

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

1(A) ANS
Elmer Anderson, pg49, problem 2-6.

(i) For short wavelength, the exponential term in Planck's law, $e^{hc/lkT}$, becomes very large compared to the value 1, $e^{hc/lkT}$ >>1, hence the term in the bracket in the denominator of the Planck's law reduces to $e^{hc/lkT}$, i.e.

$$\lim_{l\to 0}\frac{2p\,hc^2}{l^5\left(e^{hc/lkT}-1\right)}=\frac{2p\,hc^2}{l^5}e^{-hc/lkT}. \qquad \text{Eq. (1)}$$

Comparing Eq. (1) and the Wein's law, we find that both have the same form of l–dependence,

$$\frac{2p\,hc^2}{l^5}e^{-hc/lkT}\equiv\frac{ae^{-b/lT}}{l^5}.$$

[*satisfactory argument:* 2 MARKS]

(ii) Comparing both equation, we identify the constants *a* and *b* to be

$a\equiv 2p\,hc^2$ **[2 MARKS]**
$b\equiv hc/k$ **[2 MARKS]**

(iii)
Stafan-Boltzman law: $I(T)=s\,T^4$

Substitute Planck's law, $R(l,T)=\dfrac{2p\,hc^2}{l^5\left(e^{hc/lkT}-1\right)}$, into the definition of $I(T)=\int_0^\infty R(l,T)\mathrm{d}l$, we get

$$I(T)=\int_0^\infty R(l,T)\mathrm{d}l=\int_0^\infty\frac{2p\,hc^2}{l^5\left(e^{hc/lkT}-1\right)}\mathrm{d}l=2p\,hc^2\int_0^\infty\frac{1}{l^5\left(e^{hc/lkT}-1\right)}\mathrm{d}l.$$

Define $x=\dfrac{hc}{lkT}\Rightarrow \mathrm{d}x=-\dfrac{hc}{kT}\dfrac{1}{l^2}\mathrm{d}l$

$$I(T)=2p\,hc^2\int_0^\infty\frac{1}{l^5\left(e^{hc/lkT}-1\right)}\mathrm{d}l=2p\,hc^2\int_0^\infty\frac{1}{l^3\left(e^x-1\right)}\frac{\mathrm{d}l}{l^2}$$

$$=-\frac{2p\,k^4T^4}{h^3c^2}\int_\infty^0\frac{x^3}{e^x-1}\mathrm{d}x=\frac{2p\,k^4T^4}{h^3c^2}\int_0^\infty\frac{x^3}{e^x-1}\mathrm{d}x=\frac{2p\,k^4T^4}{h^3c^2}\frac{p^4}{15}=\frac{2p^5k^4T^4}{15h^3c^2}$$

Hence, the Stefan constant is $s=\dfrac{2p^5k^4}{15h^3c^2}$.**[4 marks]**

Mark will not be deduced if candidate leaves the s expression as $\dfrac{2p\,k^4T^4}{h^3c^2}\int_0^\infty\dfrac{x^3}{e^x-1}\mathrm{d}x$ without evaluating it.

IF candidate integrate over the wavelength using the Wein's law instead of the Planck's law, i.e. $I(T)=\int_0^\infty \frac{ae^{-b/kT}}{l^5}\mathrm{d}l=\frac{-aT^4}{b^4}\int_0^\infty y^3e^{-y}\mathrm{d}y=\frac{-aT^4}{b^4}\cdot(-6)=\frac{6aT^4}{b^4}\equiv s\,T^4$ to identify $s\equiv\frac{12p\,k^4}{h^3c^2}$ instead of the correct answer, $s=\frac{2p^5k^4}{15h^3c^2}$, a maximum of **3** marks will be given.

1(B) ANS: 4.04 eV

E. Anderson, pg. 57, Problem 2-16. **[4 marks]**

Retarding potential measures the maximal kinetic energy = 0.92 eV. Cutoff wavelength l_{cut} is related to the maximum kinetic energy and the work function Φ via

$$K_{\max}=\frac{hc}{l}-\Phi\,.$$

Hence $\Phi=\frac{hc}{l}-K_{\max}=\frac{1240\text{ nm}\cdot\text{eV}}{250\text{ nm}}-0.92\text{ eV}=4.04\,\text{eV}.$

1(C)(i) ANS: [3 marks]

$$E=pc=hf$$

$$\Rightarrow f=pc/h=\frac{\left(1.1\times10^{-23}\text{ kg}\cdot\text{m/s}\right)\left(3\times10^{8}\text{m/s}\right)}{\left(6.63\times10^{-34}\text{ Js}\right)}=5\times10^{18}\,/\text{s}=5\times10^{18}\,\text{Hz}$$

1(C)(ii) ANS: [3 marks]

$$E=pc=hf$$

$$\Rightarrow p=E/c=hf/c=\frac{hc}{c}\left(\frac{f}{c}\right)=\frac{1240\text{ nm}\cdot\text{eV}}{c}\left(\frac{5\times10^{18}/\text{s}}{3\times10^{8}\text{ m/s}}\right)=\frac{1240\text{ nm}\cdot\text{eV}}{c}\left(\frac{5\times10^{18}}{3\times10^{8}\cdot10^{9}\text{ nm}}\right)=\frac{20667\text{ eV}}{c}$$

or

$$l=c/f=0.06\text{ nm}$$

$$p=\frac{h}{l}=\frac{hc}{l\,c}=\frac{1240\text{ nm}\cdot\text{eV}}{l\,c}=\frac{1240\text{ nm}\cdot\text{eV}}{c(0.06\text{nm})}=20667\frac{\text{eV}}{c}$$

Alternatively:

1 Ns (=1 kg$\cdot$m/s) = 1 N·s·m/m = 1 N·m/(m·s) = 3×10^{8} N·m/(3×10^{8} ms)= 3×10^{8} J/c

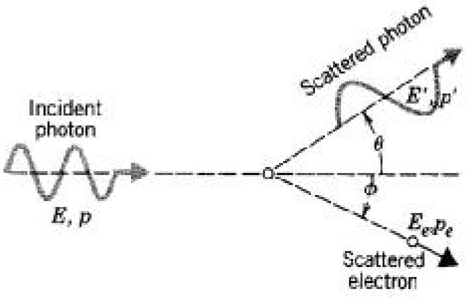
Q 1 J = $\frac{1}{1.6\times10^{-19}}$ eV, hence, from above,

1 Ns = 3×10^{8} J/c=$3\times10^{8}\cdot\frac{1}{1.6\times10^{-19}}$ eV/c=1.875×10^{27} eV/c

Hence, 1.1×10^{-23} kg$\cdot$m/s =$\left(1.1\times10^{-23}\right)\times\left(1.875\times10^{27}\right)$ eV/c= 20625 eV/c.

Note: 20625 eV /c or $\frac{20667\text{ eV}}{c}$ or similar values will all be accepted.

2(A) ANS Elmer E. Anderson, pg. 66 (BM version). **[10 marks]**



Conservation of total relativistic energy:

$E_i = E_f$

$pc + mc^2 = p'c + E_e$ Eq. (1)

Conservation of momentum in direction *x* and *y* direction:

Mom conservation in y : $p' \sin q = p_e \sin f$ Eq. (PY)

Mom conservation in x : $p = p' \cos q + p_e \cos f$ Eq. (PX)

Squaring Eq. (PY) + Squaring Eq. (PX):

$p'^2 \sin^2 q = p_e{}^2 \sin^2 f$

$(p - p' \cos q)^2 = p_e{}^2 \cos^2 f$

$p'^2 \sin^2 q + \left(p^2 + p'^2 \cos^2 q - 2pp' \cos q \right) = p_e{}^2 \left(\cos^2 f + \cos^2 f \right) = p_e{}^2$

$\Rightarrow c^2 p'^2 + c^2 p^2 - 2c^2 pp' \cos q = c^2 p_e{}^2$ Eq. (2)

For the electron, $E_e^2 = c_e^2 p_e^2 + m^2 c^4 \Rightarrow c_e^2 p_e^2 = E_e^2 - m^2 c^4$. Eq. (3)

Plug Eq. (3) into Eq. (2),

$$c^2 p'^2 + c^2 p^2 - 2c^2 pp' \cos q = E_e{}^2 - m^2 c^4 \quad \text{Eq. (4)}$$

From Eq. (1), $E_e = pc + mc^2 - p'c$ Eq. (5)

Plug Eq. (5) into Eq. (4),

$c^2 p'^2 + c^2 p^2 - 2c^2 pp' \cos q = \left(pc + mc^2 - p'c \right)^2 - m^2 c^4 = p^2 c^2 + p'^2 c^2 - 2p'pc^2 + 2mc^2 \left(pc - p'c \right)$ Simplifying the above equation, we arrive at

$mc(p - p') = p'p(1 - \cos q)$

$mc\left(\frac{h}{l} - \frac{h}{l'} \right) = \frac{h^2}{l'l}(1 - \cos q)$

$mc\left(\frac{l' - l}{l'l} \right) = \frac{h}{l'l}(1 - \cos q)$

$\Delta l = \frac{h}{mc}(1 - \cos q)$

[10 marks]

2(B) ANS: (Beiser, BM version, pg 161, Soalan 3) [5 marks]

Solution:

The energy of electron in the *n* state is given by $E_n = \frac{-13.6 \text{ eV}}{n^2}$.

Energy emitted when electron makes transition from the n=10 state to n = 1 state (the ground state) is $\Delta E = E_{10} - E_4 = \left(\frac{-13.6 \text{ eV}}{10^2}\right) - \left(\frac{-13.6 \text{ eV}}{1^2}\right) = 13.6 \text{ eV}\left(1 - \frac{1}{100}\right) = 13.6 \text{ eV}\left(\frac{99}{100}\right) = 13.5 \text{ eV}$ The energy is emitted in form of photon, which energy is related to the wavelength via

$$\frac{hc}{l} = \Delta E$$

Hence,

$$l = \frac{hc}{\Delta E} = \frac{1240 \text{ nm} \cdot \text{eV}}{13.5 \text{ eV}} = 92\text{nm}.$$

(Alternative calculation that makes used of $\frac{1}{l} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ is also acceptable).

2(C) ANS (Beiser, Ex. 19, pg. 198)

The probability density is given by $p_n(x) = y_n(x) y_n^*(x)$, where the wave function of a particle in a box is $y_n(x) = \sqrt{\frac{2}{L}} \sin\frac{np\, x}{L}$; The probability to find the particle between x_2 and x_1 within the box is

$P_n(x_2, x_1) = \int_{x_1}^{x_2} y_n(x) y_n^*(x) dx = \frac{2}{L}\int_{x_1}^{x_2} \sin^2\frac{np\, x}{L} dx = \left(\frac{x}{L} - \frac{x}{2np}\sin\frac{2p\, nx}{L}\right)\Big|_{x_1}^{x_2}$. Here, set $x_2 = L/n$, $x_1 = 0$,

$$P(L/n, 0) = \left(\frac{x}{L} - \frac{x}{2p}\sin\frac{2p\, x}{L}\right)\Big|_0^{L/n} = \left(\frac{1}{n} - \frac{L}{2p\, n}\sin 2p\, n\right) - (0 - 0) = \frac{1}{n}$$

[5 marks]

3(A) ANS

Elmer E. Anderson, pg. 19 (BM version), problem 1-10.

Take S′ to be the 'rest frame'. S′′ is moving with respect to S′ with a velocity of $u_x = b_2 c$. Take S as the "moving frame", moving at a velocity of $v = -b_1 c$ with respect to the frame S′. Hence, the velocity of S′′ with respect to S, u'_x, is related to both u_x and v via the formula

$$u'_x = \frac{u_x - v}{1 - \frac{u_x v}{c^2}} = \frac{b_2 c - (-b_1 c)}{1 - \frac{(b_2 c)(-b_1 c)}{c^2}} = \frac{(b_2 + b_1)c}{1 + b_2 b_1}$$

Note: one can check the correctness of the above result by considering two limiting cases:

i. When $b_2 \to 0$, S′′ becomes S′, hence, we should recover $u'_x \to b_1 c$.

ii. When $b_1 \to 0$, S becomes S′, hence, we should recover $u'_x \to b_2 c$.

[10 marks]

3(B) ANS (My own question)

(i) Total energy $E = K + M_\alpha c^2$ **[2 marks]**

(ii) $E = K + M_\alpha c^2 \Rightarrow E^2 = (K + M_\alpha c^2)^2$

Energy-momentum invariance: $E^2 = p^2 c^2 + M_\alpha^2 c^4$

Eliminating E in the above equations, $p = \sqrt{(K^2/c^2 + 2KM_\alpha)}$. **[3 marks]**

(iii) Let M be the relativistic mass of the alpha particle. Its total energy is then related to this mass as per $E = Mc^2$. But $E = K + M_\alpha c^2$, hence, the increase in mass $\times c^2$,

$\Delta M_\alpha c^2 = Mc^2 - M_\alpha c^2 = (K + M_\alpha c^2) - M_\alpha c = K$

$\Rightarrow \Delta M_\alpha c^2 = K$ **[2 marks]**

(iv) In the limit of $v << c$, the relativistic expression for the momentum reduces to classical one, i.e. $p_{SR} = gM_\alpha v \to p_{Classical} = M_\alpha v$. Hence, from (*ii*), as $v<<c$, $p = M_\alpha v = \sqrt{(K^2/c^2 + 2KM_\alpha)}$.

Squaring, $K^2/c^2 + 2KM_\alpha = M_\alpha^2 v^2$. Solving the quadratic equation in K:

$K^2 + 2KM_\alpha c^2 - M_\alpha^2 v^2 c^2 = 0$

The positive root is given by

$K = [-2M_\alpha c^2 + \sqrt{(4M_\alpha^2 c^4 + 4M_\alpha^2 v^2 c^2)}]/2 = -M_\alpha c^2 + \sqrt{(M_\alpha^2 c^4 + M_\alpha^2 v^2 c^2)}$

$= -M_\alpha c^2 + M_\alpha c^2 (1 + v^2/c^2)^{1/2} = -M_\alpha c^2 + M_\alpha c^2 (1 + v^2/2c^2 + \ldots)$ (Binomial expansion)

$= M_\alpha v^2/2$ (retaining the term up to order of v^2/c^2) **[3 marks]**