ZCT 104/3E Modern Physics
Semester II, Sessi 2005/06
Test II (24 March 2006)

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

1. Which of the following statements is true regarding Rayleigh-Jeans explanation of the blackbody radiation?

   A. The classical theory explanation of the blackbody radiation by Rayleigh-Jeans fails in the limit wavelength $\to$ 0.
   B. The classical theory explanation of the blackbody radiation by Rayleigh-Jeans fails in the limit frequency $\to$ 0.
   C. They postulate that the energy of electromagnetic waves is quantised.
   D. None of the above.

   ANS: A

2. Which of the following statements is (are) true regarding Planck theory of the blackbody radiation?

   I. The energy of the blackbody radiation is quantised. (T)
   II. The average energy of blackbody radiation is given by $\varepsilon = kT$. (F)
   III. There is no ultraviolet catastrophe. (T)

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

   ANS:D, Tut 2 04/05, CQ 1,2

3. What are the flaws in Rayleigh-Jeans law for blackbody radiation?

   I. It predicts ultraviolet catastrophe (T)
   II. It predicts much more power output from a black-body than is observed experimentally. (T)
   III. Blackbody radiation is universal and depends only on temperature. (Not a flaw)

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

   ANS:C, Tut 2 04/05, CQ 3

4. **What are the distinctive physical characteristics that exclusively differentiate a classical particle from a classical wave?**

	Classical Particle	Classical Wave
I.	Completely localized	A wave can be "simultaneously everywhere" at a given instance in time
II.	Is has mass	No mass is associated with a classical wave.
III.	Energy is concentrated in it and is not spreading beyond the boundary that defines its physical location.	Energy carried by wave spreads over a (possibly infinite) region of space along the direction the wave propagates
IV.	Momentum and position can be measured with infinite precision.	No momentum or precise location can be defined for a wave

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

   ANS:A, Tut 2 04/05, CQ 4

5. The Compton-scattering formula suggests that objects viewed from different angles should reflect light of different wavelengths. Why don't we observe a change in colour of objects as we change the viewing angle?

   A. There is actually no change in the wavelength as predicted by the Compton-scattering formula.
   B. Because the change in wavelength is too tiny to be observed by human eye.
   C. Visible light doesn't undergo Compton scattering.
   D. None of A, B, C.

ANS:B, Tut 2, 05/06, Q6

6. In Compton scattering, the maximum wavelength shift is in the order of

   A. ~ pm
   B. ~ nm
   C. ~ μm
   D. ~mm

ANS:A, $\Delta\lambda_{\max} = 2\lambda_e = 2.43\text{pm}$. (My Own Question)

7. Compton wavelength of the electron is given by $\lambda_e = \frac{h}{m_e c}$. What will the size of the Compton wavelength of a proton be in comparison to λ_e?

   A. λ_{proton} shall be larger than λ_e by about 2 orders of magnitude.
   B. λ_{proton} shall be smaller than λ_e by about 2 orders of magnitude.
   C. λ_{proton} shall be of the same order of magnitude with λ_e.
   D. None of A, B, C

ANS:D, $\lambda_e = \frac{h}{m_e c}; \lambda_p = \frac{h}{m_p c} \Rightarrow \lambda_p = \lambda_e \frac{m_e}{m_p} \sim \frac{1\text{ MeV}}{1000\text{ MeV}}\lambda_e = 10^{-3}\lambda_e$. (My Own Question)

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

   I. The photoelectric effect doesn't work for free electron (T)
   II. The Compton effect doesn't work for free electron (F)
   III. Pair production does not occurs in free space (T)
   IV. Pair annihilation between an electron and positron does not occurs in free space (F)

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

ANS:D, I, III are true; II, IV are false. (My Own Question)

9. Which of the observed properties of the photoelectric effect fail to be accounted for by the wave nature of light?

   I. Photoelectron is emitted almost instantaneously. (T)
   II. The saturation photoelectric current increases as intensity increases. (F)
   III. Stopping potential is independent of the radiation intensity. (T)
   IV. Existence of the cut-off frequency. (T)

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

ANS:C, I, II are true; II, IV are false. (My Own Question)

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

   I. The photoelectric effect is essentially a non-relativistic phenomena. (T)
   II. The Compton effect is essentially a relativistic phenomena. (T)
   III. Pair production is essentially a non-relativistic phenomena. (F)
   IV. Pair production is essentially a relativistic phenomena. (T)

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

ANS: C. (My Own Question)

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

I. X-ray diffraction can be experimentally discernable if it is scattered by atoms in a crystal lattice. (T)
II. X-ray diffraction is experimentally discernable if it is scattered by an optical diffraction grating with line density 3,000 lines per mm. (F)
III. The energy of an X-ray photon is much larger than that of an ordinary photon in the visible part of the EM spectrum. (T)
IV. X-rays wavelength lies approximately in the order of 400 nm - ~ 700 nm. (F)

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

ANS: (Only I, III are true) D. (My Own Question)

12. Why can't a photon undergoes pair production in free space?

I. Because the photon doesn't has sufficient energy in free space. (F)
II. Because the photon doesn't has sufficient momentum in free space. (F)
III. Because it is not possible to conserve both energy and moment simultaneously in free space. (T)
IV. Because it is not possible to create matter out of pure energy. (F)

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

ANS:D. Only III is true. The rest is not. (My Own Question). For (I), even if the photon has sufficient energy pair production wouldn't happen as long as it is in free space. For II, 'sufficiency' in momentum is not an issue. The important issue is whether the momentum is conserved in a process, and whether the process is in vacuum. For (IV), it is possible to create matter out of pure energy from $E=mc^2$.

13. Which of the following statements is (are) true regarding electron?

I. Electron behaves like wave in a diffraction experiment. (T)
II. Electron behaves like particle in a photoelectric experiment. (T)
III. Electron behaves like particle in a Compton scattering experiment. (T)
IV. Electron can manifest both particle and wave nature in a single experiment. (F)

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

ANS: A. (My Own Question)

14. Consider a matter particle with rest mass m_0, moving with a speed v. Which of the following statements is (are) true regarding its de Broglie wave?

I. The de Broglie wavelength of the matter particle is $\lambda = h/(m_0 v)$ regardless of whether the particle is relativistic or not (F).
II. The de Broglie wavelength of the matter particle is $\lambda = h/(m_0 v)$ only if it is non relativistic (T).
III. The de Broglie wavelength of the matter particle is not given by $\lambda = h/(m_0 v)$ if it is relativistic (T).
IV. If the speed v of the matter particle is relativistic, its de Broglie wavelength is larger than $h/(m_0 v)$. (F)

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

ANS: B. (My Own Question)

For IV: $\lambda_{NR} = h/(m_0 v)= h/p_{NR}$; $\lambda_R = h/(p_R)$; $\lambda_R = h/(p_R)$; $\lambda_R = \lambda_{NR} (p_{NR}/ p_R)= \lambda_{NR} /\gamma \Rightarrow \lambda_R < \lambda_{NR} = h/(m_0 v)$.

15. Which of the statements is (are) true regarding a proton-antiproton annihilation process into photon.

I. The annihilation must produce at least two daughter photons. (T)
II. The proton-antiproton annihilation would produce photons which are much energetic than that produced by electron-positron annihilation. (T)
III. Each daughter photon produced must be at least of energy $2m_p c^2$ (m_p is the mass of the proton). (F)
IV. The magnitude of momentum of each daughter photon produced must be at least $m_p c$ (m_p is the mass of the proton). (T)

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

ANS: C. (My Own Question)

16. Consider a very weak light beam strikes a fluorescence screen with one photon in a time. The detection of the photon is displayed as a dot on the screen. In this process, the light being detected is

A. a particle B. a wave C. neither a wave nor a particle
D. both wave and particle
ANS: A

17. Consider a very weak electron beam strikes a fluorescence screen with one electron in a time. The detection of the electron is displayed as a dot on the screen. In this process, the electron being detected is

A. a particle B. a wave C. neither a wave nor a particle
D. both wave and particle
ANS: A

18. A wavepulse is a result of superposition of many different waves with a spread in wave number, Δk. The width of the wavepulse, Δx, is quantitatively related to Δk as

A. $\Delta x \propto \Delta k$ B. $\Delta x \propto 1/\Delta k$ C. Δx not related to Δk
D. None of A, B, C, D
ANS: B

19. Which of the following statements is (are) true?
    I. In an experiment, we use a light of certain wavelength to probe a quantum particle. If we use a light with <u>smaller</u> wavelength we will obtain a <u>less</u> precise knowledge about the position of the quantum particle and also a <u>more</u> precise knowledge on the linear momentum of the quantum particle. (F)
    II. In an experiment, we use a light of certain wavelength to probe a quantum particle. If we use a light with <u>smaller</u> wavelength we will obtain a <u>more</u> precise knowledge about the position of the quantum particle and a <u>less</u> precise knowledge on the linear momentum of the quantum particle. (T)
    III. In an experiment, we use a light of certain wavelength to probe a quantum particle. If we use a light with <u>larger</u> wavelength we will obtain a <u>more</u> precise knowledge about the position of the quantum particle and also a <u>less</u> precise knowledge on the linear momentum of the quantum particle. (F)
    IV. In an experiment, we use a light of certain wavelength to probe a quantum particle. If we use a light with <u>larger</u> wavelength we will obtain a <u>less</u> precise knowledge about the position of the quantum particle and a <u>more</u> precise knowledge on the linear momentum of the quantum particle. (T)

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

ANS: B

20. The diameter of an atomic nucleus is about 10×10^{-15} m. In order to study the diffraction of photons by nuclei, the energy of the photon has to be in the range of order
    A. ~ eV
    B. ~ keV
    C. ~ MeV
    D. None of A, B, C

ANS:D, Tut 2, 05/06, Q3

$$E = \frac{hc}{\lambda} = \frac{1240\text{nm}\cdot\text{eV}}{10\times10^{-15}\,\text{m}} = \frac{1.24\times10^{3}\times10^{-9}\,\text{m}\cdot\text{eV}}{10^{-14}\,\text{m}} = 1.24\times10^{8}\,\text{eV} \sim 10^{2}\,\text{MeV}$$