MASENO UNIVERSITY

UNIVERSITY EXAMINATIONS 2012/2013

SECOND YEAR SECOND SEMESTER EXAMINATIONS FOR THE DEGREE OF BACHELOR OF SCIENCE AND BACHELOR OF EDUCATION (SCIENCE) WITH INFORMATION TECHNOLOGY (MAIN CAMPUS)

SPH 206: EMPIRICAL IDEAS OF QUANTUM PHYSICS AND RELATIVITY

Date: 22nd July, 2013 *Time: 8.30 – 10.30 a.m.*

SPH 206 : EMPIRICAL IDEAS OF QUANTUM PHYSICS AND RELATIVITY

INSTRUCTIONS
1. Section ONE is Compulsory
2. Answer Any TWO Questions from Section Two

Useful Constants

$c = 3.00\times10^{8}\ m/s$

$e = 1.60\times10^{-19}\ C$

$h = 6.626\times10^{-34}\ J\cdot s = 4.136\times10^{-15}\ eV\cdot s$

$m_e = 6.63\times10^{-31}\ kg$

$m_p = 1.67\times10^{-27}\ kg$

$\lambda_C = 2.426\ pm$

$k = \dfrac{1}{4\pi\varepsilon_0} = 8.99\times10^{9}\ N\cdot m^2/C^2$

Section One [30 mks]

a) State the two postulates of relativity. **[4 mks]**

b) High energy sub-atomic particles coming from space interact with atoms in the earth's upper atmosphere, producing unstable particles called muons. A muon decays with a mean life-time of 2.20×10^{-6} s as measured in a frame of reference in which it is at rest. If a muon is moving at $0.99c$ relative to the earth, what will its lifetime be relative to an observer on the earth? **[4 mks]**

c) A radio station antenna broadcasts at 89.3 MHz with a radiated power of 43.0 kW.
i) What is the magnitude of the momentum of each photon? **[4 mks]**
ii) How many photons does the antenna emit each second? **[4 mks]**

d) While conducting a photoelectric-effect experiment with light of a certain frequency, you find that a reverse potential difference of 1.25 V is required to reduce the potential to zero. Find
i) The maximum kinetic energy in electronvolts. **[4 mks]**
ii) The maximum speed of the emitted electrons. **[4 mks]**

e) i) Explain wave-particle duality. **[2 mks]**
ii) Find the kinetic energy (in electronvolts) of a proton whose de Broglie wavelength is 1.0 fm. **[4 mks]**

Section Two

Question Two [20 mks]

a) Define the term Doppler Effect. **[2 mks]**

b) i) Show that for electromagnetic waves, the frequency f as received by an observer is

$$f = \sqrt{\frac{c+u}{c-u}}\, f_o,$$

where u is the speed of the source approaching the stationary observer, c is the speed of light and f_o the frequency of light as emitted at the source. **[10 mks]**

ii) State an equivalent expression for a source moving away from the observer. **[2 mks]**

c) A number of galaxies have supermassive black holes at their centers. As material swirls around such a black hole, it is heated, becomes ionized, and generates strong magnetic fields. The resulting magnetic forces steer some of the material into high-speed jets that blast out of the galaxy into intergalactic space. The blue light normally observed from the jet has a frequency of about 6.66×10^{14} Hz, but in the frame of reference of the jet material, the light has a frequency of 5.55×10^{13} Hz (in the infrared region of the electromagnetic spectrum). At what speed is the jet material moving towards us (in terms of c)? **[6 mks]**

Question Three [20 mks]

a) Define the term Compton Effect. **[2 mks]**

b) Show that

$$\lambda - \lambda_o = \lambda_C(1-\cos\phi)$$

where λ is the wavelength of the scattered photon, λ_o is the wavelength of the incident photon, λ_C is the Compton wavelength and ϕ is the scattering angle of the photon. **[10 mks]**

c) X-rays of wavelength 10 pm are scattered from a target.

i) Find the wavelength of the x-rays scattered through $45°$. **[4 mks]**

ii) Find the maximum wavelength present in the scattered rays. **[4 mks]**

Question Four [20 mks]

a) Show that if a particle accelerates from zero to v, the relativistic kinetic energy K of the particle is given by

$$K = (\gamma - 1)mc^2,$$

where c is the speed of light, m is its mass and $\gamma = \dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}}$. **[6 mks]**

b) i) Using the binomial theorem, expand γ. **[4 mks]**

ii) Show that when v is much smaller than c, K reduces to the classical Newtonian expression $K = \frac{1}{2}mv^2$. **[2 mks]**

iii) Show that the total energy of a particle is given by

$E^2 = (mc^2)^2 + (pc)^2$,

where p is the momentum of the particle. **[4 mks]**

c) Find the speed of an electron (in terms of c) that has been accelerated by an electric field, from rest, through a potential difference of 20.0 kV. **[4 mks]**

Question Five [20 mks]

a) i) In the Bohr model of the Hydrogen atom, show that the total energy E is given by

$$E = -\frac{ke^2}{2r}$$

where k is a constant, r is the radial distance and e is the magnitude of the electronic charge. **[5 mks]**

ii) Assuming quantization of the orbital angular momentum, show that the possible energies are

$$E_n = -\frac{ke^2}{2a_B}\frac{1}{n^2}$$

where a_B is the Bohr radius and $n = 1, 2, 3 \ldots$ **[5 mks]**

b) i) State the Rydberg formula. **[2 mks]**

ii) Show that the Rydberg constant R is given by

$$R = \frac{ke^2}{2a_B(hc)}$$

where h is Plank's constant and c is the speed of light. **[3 mks]**

c) Find the wavelength of the photon emitted in the transition from the first excited level to the ground level. **[5 mks]**