Physics 126 Spring 2009 **Name:**
Exam 5
Time Allowed: 2 hours **Total marks: 103.**
Credits are given for numerical problems only if evidence of calculations is presented.
Some Physics Constants: **Speed of light in vacuum $c=3.0\times10^{8}$ m/s**
Planck's constant $h = 6.63\times10^{-34}$ J.s
Mass of electron $m_e = 9.1\times10^{-31}$ kg
Mass of proton $m_p=1.67\times10^{-27}$ kg
Charge of electron $e = 1.6\times10^{-19}$ C
Avogadro's number $N_A = 6.02\times10^{23}$
Energy equivalence of 1 u=931 MeV

PART I Qualitative Questions (3 points each)

1. A superboat approaches a lighthouse with a speed of $c/3$ where c is the velocity of light. What is the speed of the light from the lighthouse as observed from the boat?

(a) $c/3$ (b) $2c/3$ [✓ (c) c] (d) $4c/3$

2. Which of the following color light corresponds to photons with the highest energy?

(a) red [✓ (b) blue] (c) green (d) yellow

3. How is X-ray produced?

(a) Using radioactive nuclides
(b) Using a particle accelerator
[✓ (c) Using an electron beam]
(d) Using fluorescent materials

4. If the half life of a certain radionuclide is one year, which of the following statements is (are) correct?

[✓ (a) The probability of a radionuclide to decay is ½ in one year.]
(b) If a radionuclide is produced, it will decay after two years.
[✓ (c) Half of a large sample of the radionuclide would decay in one year.]
[✓ (d) Only 50% of the initial activity of one gram of the radionuclide will remain after one year.]

5. Which of the following statements is **incorrect** as an explanation why the wave nature of a tennis ball is not observed ?

(a) Its de Broglie wavelength is too small
(b) Its mass is not small enough
[✓ (c) Its velocity is too low]
(d) Planck's constant is very small

6. An electron in a confined volume cannot be at rest. This is a consequence of

(a) The exclusion principle
(b) The relativity principle
[✓ (c) The uncertainty principle]
(d) Wave particle duality

PART II Quantitative Questions (5 points each)

7. Superman runs a one mile race at three quarters the speed of light. Taking the speed of light to be 1 ft/ns, what is his run time according to his wrist watch? (1 mile = 5280 ft.)

(a) 2100 ns
(b) 3450 ns
[✓ (c) 4660 ns]
(d) 5730 ns

$v = \frac{3}{4}c = 0.75$ ft/ns

$\Delta t = \frac{\Delta x}{v} = \frac{5280}{0.75} = 7040$ ns

$\Delta t_0 = \Delta t\sqrt{1-\left(\frac{v}{c}\right)^2} = 7040\sqrt{1-\left(\frac{3}{4}\right)^2} = 4660$ ns

↑
proper time

8. Standing by the railroad track, you find that the arrival times of the front and the rear end of a super train differ by 5×10^{-7}s. You also know that the speed of the train is 1.8×10^{8} m/s. If the train comes to a stop, what length would you measure for the train?

(a) 90m
[✓ (b) 72m]
(c) 65m
(d) 52m

Moving length $L = v\Delta t_0 = 1.8\times10^{8}\times5\times10^{-7} = 90$ m

Stationary length $L_0 = L\sqrt{1-\left(\frac{v}{c}\right)^2} = 90\sqrt{1-\left(\frac{1.8\times10^{8}}{3.0\times10^{8}}\right)^2}$

$= 90\times0.8 = 72$ m

9. The trans oceanic journey of a ship requires the operation of a 150 kW engine for seven days. If the engine is fueled by the energy obtained from the annihilation of a certain matter with an equal amount of antimatter, how large a mass of the matter the ship should carry?

m

[✓ (a) 0.5×10^{-3} g]
(b) 0.8×10^{-3} g
(c) 1.0×10^{-3} g
(d) 2.4×10^{-3} g

$2mc^2 = E$

$m = \frac{E}{2c^2} = \frac{150\times10^3\times7\times24\times3600}{2\times(3\times10^8)^2} = 5.0\times10^{-7}$ kg

$= 5.0\times10^{-4}$ g $= 0.5\times10^{-3}$ g

10. The LHC is the largest accelerator in the world. One of its missions is to detect an elementary particle called the Higgs boson. It is believed that the rest mass of Higgs boson corresponds to an energy of 117 GeV. If one such particle is found to have a kinetic energy of 300 GeV, what would its velocity be as a multiple of the velocity of light?

(a) 0.81c
(b) 0.89c
(c) 0.94c
[✓ (d) 0.96c]

Total energy $E = 117 + 300 = 417$ GeV

From $E = \frac{E_0}{\sqrt{1-\beta^2}}$ where $\beta = \frac{v}{c}$

$1-\beta^2 = \left(\frac{E_0}{E}\right)^2$ $\beta = \sqrt{1-\left(\frac{E_0}{E}\right)^2} = \sqrt{1-\left(\frac{117}{417}\right)^2} = 0.96$

11. Hydrogen atoms can emit radiation with wavelength of 21 cm. What is the energy of the photon of this radiation?

$\lambda = 21\,cm = 0.21\,m$

(a) 3.3×10^{-5} eV
(b) 3.3×10^{-6} eV
(c) 5.9×10^{-5} eV
[✓ (d)] 5.9×10^{-6} eV

$$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{0.21} = 9.47\times10^{-25}\,J$$

$$= \frac{9.47\times10^{-25}}{1.6\times10^{-19}}\,eV = 5.9\times10^{-6}\,eV$$

12. How many photons are contained in a 5.0 nJ laser pulse, if the frequency of the laser is 3.4×10^{14} Hz?

(a) 3.3×10^{10}
[✓ (b)] 2.2×10^{10}
(c) 4.4×10^{9}
(d) 6.6×10^{8}

$$\text{no. of photons} = \frac{E}{hf} = \frac{5\times10^{-9}}{6.63\times10^{-34}\times3.4\times10^{14}}$$

$$= 2.2\times10^{10}$$

13. The list below gives the work functions of four metals. Circle the metal(s) that can produce photoelectrons from light of wavelength 300nm.

[✓ (a)] Mg 3.7 eV   (b) Al 4.3 eV   [✓ (c)] Ca 2.9eV   (d) Au 5.1eV

$$\text{photon energy} = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{300\times10^{-9}} = 6.63\times10^{-19}\,J = 4.1\,eV$$

14. Referring to the previous problem, what is the stopping potential when ultraviolet light of frequency ~~0.7~~$\times10^{15}$ Hz is incident on the metal with the highest work function?
2.1

(a) 1.5 eV
(b) 2.8 eV
[✓ (c)] 3.6 eV
(d) 4.7 eV

$$E_{photon} = W + K_{max}$$

$$E_{photon} = hf = 6.63\times10^{-34}\times2.1\times10^{15}$$

$$= \cancel{4.4}\ 1.4\times10^{-18}\,J = \cancel{27.7\,eV}\ 8.7$$

$$= 8.7\,eV$$

$$K_{max} = E - W = \cancel{2}8.7 - 5.1 =$$

$$= 3.6\,eV$$

15. The inter-atomic spacing in a certain crystal is 2.5×10^{-11}m. If a neutron beam is used to study the crystal structure, what should be the energy of the beam so that its de Broglie wavelength is equal to the inter-atomic spacing? (Use non-relativistic kinematics. Mass of neutron = 1.67×10^{-27} kg)

(a) 23 keV
(b) 420 eV
(c) 57 eV
[✓ (d)] 1.3 eV

$$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{2.5\times10^{-11}} = 2.65\times10^{-23}$$

$$K = \frac{p^2}{2m} = \frac{(2.65\times10^{-23})^2}{2\times1.67\times10^{-27}} = 2.1\times10^{-19}\,J = 1.3\,eV$$

16. Determine the longest wavelength radiation that an electron in the $n = 3$ state of a hydrogen atom can emit.

The transition is from $n=3$ to $n=2$.

[✓ (a) 660nm]
(b) 580nm
(c) 510nm
(d) 490nm

Photon energy $E_\gamma = E_3 - E_2 = 13.6\left(\frac{1}{2^2}-\frac{1}{3^2}\right) = 13.6 \times \frac{5}{36} = 1.89\,eV$

From $E_\gamma = \frac{hc}{\lambda}$ $\quad \lambda = \frac{hc}{E_\gamma} = \frac{6.63\times10^{-34}\times 3\times10^{8}}{1.89\times1.6\times10^{-19}}\,m = 6.58\times10^{-7}\,m$

$\cong 660\ nm$

17. Determine the ionization energy from the **first excited state** of Be^{+++} ion. (The number of protons in a Be nucleus is 4)

$Z = 4$ hydrogen-like $n=2$ for first excited state

(a) 218 eV
[✓ (b) 54.4eV]
(c) 27.2eV
(d) 13.6eV

$13.6 \times \frac{4^2}{2^2} =$ ~~218 eV~~ 54.4 eV

18. Write down the ground state electronic configuration of ${}_{17}Cl$.

$1s^2\,2s^2\,2p^6\,3s^2\,3p^5$

19. Determine the binding energy per nucleon of ${}_{26}Fe^{56}$ from the following mass data:

$m\left({}_{26}Fe^{56}\right) = 55.9344u \quad m\left({}_{1}H^{1}\right) = 1.0078u \quad m_n = 1.0087u$

(a) 6.3MeV
(b) 7.5MeV
[✓ (c) 8.8MeV]
(d) 9.3MeV

$\Delta m = 26\, m({}_1H^1) + (56-26)\times m_n - m({}_{26}Fe^{56})$

$= 0.5294\,u$

$E = 0.5294 \times 931\ MeV = 493\ MeV$

$493/56 = 8.8\ MeV/nucleon$

20. Using the protons in 5.0g of water (molecular mass = 18), how much energy can be generated via the fusion reaction

$p + p \rightarrow D + {}_{+1}e + \nu_e + 0.42MeV$

2 protons in one molecule of H_2O.

no. of H_2O molecules $= \frac{5}{18} \times 6.02\times10^{23} = 1.67\times10^{23}$

Energy released $= 1.67\times10^{23} \times 0.42\times10^{6} \times 1.6\times10^{-19}\,J$

$= 1.1\times10^{10}\,J$

(a) 4.4×10^{10} J
(b) 3.3×10^{10} J
(c) 2.2×10^{10} J
[✓ (d) 1.1×10^{10} J]

21. Determine the values of Z and A for the nuclide Pa produced in the decay chain:

$${}_{92}U^{238} \rightarrow {}^{234}_{90}Th + \alpha \qquad {}^{234}_{90}Th \rightarrow {}_{Z}Pa^{A} + {}_{-1}e^{0} + \bar{\nu}_e$$

Ans: Z= 91 A= 234

22. The half life of a certain radionuclide is 5 weeks. How many of an initial sample of ten million nuclides will have decayed after 8 weeks?

(a) 9.4×10^6
[✓ (b)] 6.7×10^6
(c) 4.8×10^6
(d) 3.3×10^6

$$N = N_0 e^{-0.693\frac{t}{\tau}}$$

$$= 10^7 e^{-0.693\times\frac{8}{5}} = 3.3\times10^6$$

$$10^7 - 3.3\times10^6 = 6.7\times10^6$$

23. The activity of a freshly prepared sample of a certain radionuclide is reduced to 40% after 45 minutes. How much longer will it take to reduce to 10%?

(a) 34 minutes
(b) 57 minutes
[✓ (c)] 69 minutes
(d) 113 minutes

$$\frac{A}{A_0} = e^{-0.693\frac{t}{\tau}}$$

$$0.4 = e^{-0.693\times\frac{45}{\tau}}$$

$$\ln 0.4 = -0.693\times\frac{45}{\tau}$$

$$\tau = -\frac{0.693\times45}{\ln 0.4} = 34 \text{ min.}$$

Next,

$$0.1 = e^{-0.693\times\frac{t}{34}}$$

$$\ln 0.1 = -0.693\times\frac{t}{34}$$

$$t = -\frac{\ln 0.1}{0.693}\times34 = 113 \text{ min}$$

$$113 - 45 = 68$$