

Final Exam
Phys 204
Term 211
Dec 29, 2021

Time: 2.5 hrs

Student Name: _____

Student ID: _____

Student Sec _____

Set -01

Q1. (Total Pts = 8)

Particles can be classified into Fermion, Boson, Hadron and Lepton. Fill in the table with right categories (could be more than one)

Particle	Type I	Type 2
Alpha Particle	Boson	Hadron
Beta Particle	Fermion	Lepton
Neutron	Fermion	Hadron
Gamma Particle	Boson	X

Q2.1 (Total Pts = 8)

When 2.0 kg helium is formed by fusing hydrogen deep within the Sun. The fusion equation is provided as: (ignore the mass of positron)



$m_{\text{He}} = 4.002603\text{u}$, $m_{\text{p}} = 1.007825\text{u}$ and $c^2 = 931.5 \text{ MeV/u}$

a) How many helium atoms are formed?

b) Find the value of E (released energy)

$$\begin{aligned} \text{a) } \frac{N}{N_A} &= \frac{m}{M} \\ N &= \frac{m}{M} N_A = \frac{2}{4 \times 10^{-3}} \times \frac{3.01}{6.02} \times 10^{23} \\ \boxed{N = 3.01 \times 10^{26}} \end{aligned}$$

$$\begin{aligned} \text{b) } E_f &= -\Delta mc^2 \\ &= -(m_{\text{He}} - 4m_{\text{H}}) c^2 \\ &= -(4.002603 - 4 \times 1.007825) 931.5 \text{ MeV} \\ E_f &= 26.7 \text{ MeV} \end{aligned}$$

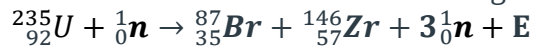
$$\text{Total } E = NE_f$$

$$= 3.01 \times 10^{26} \times 26.7$$

$$\boxed{E = 8.05 \times 10^{27} \text{ MeV}}$$

Q-2.2 (Total Pts = 8)

When 2.0 kg ^{235}U is bombarded with thermal neutrons the following fission reaction takes place



a) How many Uranium atoms undergo fission?

b) If 30% of total energy generated from the fission reaction is converted to electricity how much electricity is generated?

$$m_{\text{Br}} = 86.913371\text{u}, m_{\text{Zr}} = 145.925793\text{u}, m_{\text{U}} = 235.043930\text{u}, m_{\text{n}} = 1.0088665\text{u}$$

$$\frac{N}{N_A} = \frac{m}{M}$$

$$N = \frac{m}{M} \times N_A$$

$$= \frac{2000}{235} \times 6.02 \times 10^{23} \quad \boxed{N = 5.1 \times 10^{24}}$$

$$E_1 = \Delta mc^2$$

$$= -(m_{\text{Br}} + m_{\text{Zr}} + 3m_{\text{n}} - m_{\text{U}} - m_{\text{n}})c^2$$

$$= -(86.913371 + 145.925793 + 1.0088665 \times 3 - 235.043932) \times 931.5$$

$$\boxed{E_1 = 174.2 \text{ MeV}}$$

$$E = N E_1 \Rightarrow \boxed{E = 8.93 \times 10^{26} \text{ MeV}}$$

Changed to electricity

$$E' = 0.3 \times E = \underline{2.6 \times 10^{26} \text{ MeV}}$$

Q-2.3 (Total Pts = 8)

When Hydro-Carbon (Petroleum) is burned CO_2 is released. If 6.6×10^{-19} J per CO_2 molecule energy produced during this chemical burning, (molar mass of $\text{CO}_2 = 44$ g)

a) how much total energy is produced when 2.0 kg of CO_2 is released?

b) Compare Fission (2.1) and Fusion (2.2) energy with the chemical energy.

$$\begin{aligned} \text{a)} \quad N &= \frac{m}{M} N_A \\ &= \frac{2000 \text{ g}}{44 \text{ g}} \times 6.02 \times 10^{23} \\ &\quad \boxed{N = 2.74 \times 10^{25}} \end{aligned}$$

$$E = \frac{N \times 6.6 \times 10^{-19}}{1.6 \times 10^{-19} \times 10^6} = 1.13 \times 10^{20} \text{ MeV}$$

$$\text{b)} \quad \frac{E_{\text{Fission}}}{E_{\text{chemical}}} = \frac{8.93 \times 10^{26}}{1.13 \times 10^{20}} = 7.9 \text{ Million times}$$

$$\frac{E_{\text{fusion}}}{E_{\text{chemical}}} = \frac{8.05 \times 10^{27}}{1.13 \times 10^{20}} = 71 \text{ Million times}$$

Q-3 (Total Pts. =8),

A particular rock is thought to be 223 million years old. If it contains 2.94 mg of ^{238}U , how much ^{206}Pb should it contain? Assume ^{238}U decays directly to ^{206}Pb with a half-life of 4.47×10^9 y. (Assume there was no Pb present during the formation of the rock)

$$T_{1/2} = \frac{\ln 2}{\lambda} \Rightarrow \lambda = \frac{\ln 2}{T_{1/2}}$$

$$m = m_0 e^{-\lambda t}$$

$$m = 2.94, \quad m_0 = \text{original mass}$$

$$m_0 = m e^{\lambda t}$$

$$= 2.94 \times e^{\frac{\ln 2}{4.47 \times 10^9} \times 223 \times 10^6}$$

total disintegrated mass of U

$$\Delta m = m_0 - m$$

Fraction of U changed to Pb

238 mg U changed to 208 mg of Pb

$$1 \text{ mg U} \quad \text{,, ,} \quad \frac{208}{238} \text{ mg of Pb}$$

$$\Delta m \text{ U} \rightarrow \frac{208}{238} \times \Delta m$$

$$\approx \underline{\underline{0.0904 \text{ mg}}}$$

Q-4: (Total Pts = 15)

A certain monovalent metal has density 8.908 g/cm^3 and molar mass 87.7 g/mol .

Calculate

- (a) the number density of conduction electrons (pts. 6),
- (b) the Fermi energy (pts. 3)
- (c) the Fermi speed (pts. 3)
- (d) the de Broglie wavelength corresponding to this electron speed (pts. 3),

$$\begin{aligned} \text{a) } n &= \frac{N}{V} & \left| \quad \frac{N}{N_A} &= \frac{m}{M} \right. \\ &= \frac{m}{M} \frac{N_A}{V} & N &= \frac{m}{M} N_A \\ &= \rho \frac{N_A}{M} = 8.908 \times \frac{6.02 \times 10^{23}}{87.7} \end{aligned}$$

$$\text{b) } E_F = \frac{0.121 h^2}{m_e} n^{2/3} \quad n = \underline{6.1 \times 10^{28} / \text{m}^3}$$

$$\begin{aligned} \text{c) } E_F &= \frac{1}{2} m_e v_F^2 & &= \underline{9.1 \times 10^{-19} \text{ J}} \\ v_F &= \sqrt{\frac{2 E_F}{m_e}} = \underline{1.41 \times 10^6 \text{ m/s}} \end{aligned}$$

$$\begin{aligned} \text{d) } p_F &= \frac{h}{\lambda_F} \\ \lambda_F &= \frac{h}{m_e v_F} = \underline{\underline{5.2 \times 10^{-10} \text{ m}}} \end{aligned}$$

Q-5.1 (Total Pts 5)

A helium–neon laser emits laser light at a wavelength of 632.8 nm and a power of 2.3 mW. At what rate are photons emitted by this device? (pts. 5)

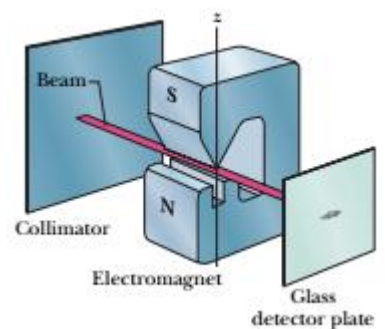
$$P = \frac{DE}{t} = \frac{Nhf}{t} = \frac{N}{t} \frac{hc}{\lambda}$$

$$\therefore \frac{N}{t} = \frac{P\lambda}{hc} = \frac{2.3 \times 10^{-3} \times 632.8 \times 10^{-9}}{663 \times 10^{-34} \times 3 \times 10^8}$$

$$\boxed{\frac{N}{t} = 7.3 \times 10^{15}}$$

Q-5.2 (Total Pts 10)

In the Stern – Gerlach experiment of Fig. a beam of silver atoms passes through a magnetic field gradient dB/dz of magnitude 2.0 T/mm that is set up along the z-axis. This region has a length w of 5 cm in the direction of the original beam. The speed of the atoms is 700 m/s. By what distance d have the atoms been deflected when they leave the region of the field gradient? The mass M of a silver atom is 1.8×10^{-25} kg.



$$F_z = \mu_B \frac{dB}{dz}$$

$$ma_z = \mu_B \left(\frac{dB}{dz} \right)$$

$$a_z = \frac{\mu_B}{m} \left(\frac{dB}{dz} \right)$$

z-direction

$$v_{0z} = 0,$$

$$z = v_0 t + \frac{1}{2} a_z t^2$$

$$d = \frac{1}{2} \left(\frac{\mu_B}{m} \frac{dB}{dz} \right) \frac{w^2}{v^2}$$

$$= \frac{1}{2} \frac{9.27 \times 10^{-24} \times 2 \times 10^3 \times \left(\frac{5 \times 10^{-2}}{7000} \right)^2}{1.8 \times 10^{-25}}$$

$$\boxed{d = 2.6 \times 10^{-6} \text{ m}}$$



x-direction

$$a_x = 0,$$

$$v_x = \frac{w}{t}$$

$$t = \frac{w}{v}$$

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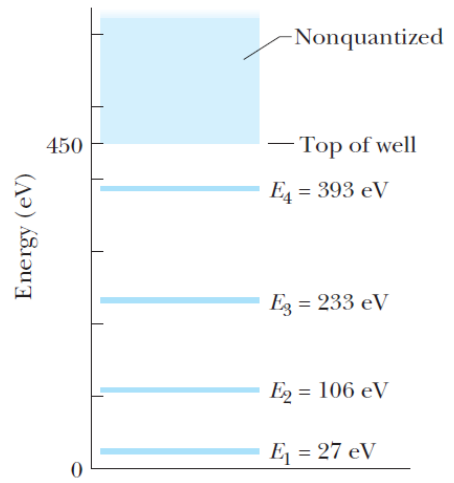
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Set -02

Q-6.1 (Total Pts = 5)

An electron in the finite well of Fig. a absorbs 257 eV energy from an external source. Its kinetic energy after absorption is 200 eV. Determine the initial state of this electron inside the well (provide the quantum number n)



$$\text{Absorbed energy} = \Delta K + \Delta U$$

$$257 \text{ eV} = 200 + \Delta U$$

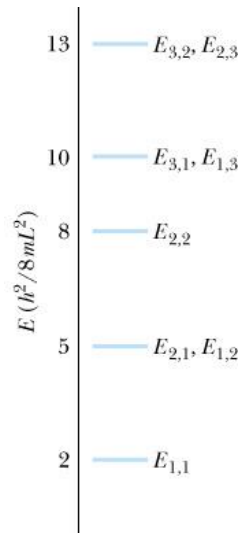
$$57 \text{ eV} = \Delta U$$

$$E_{\text{Top}} - E_y = 450 - 393 = 57 \text{ eV}$$

$\therefore$ Initial state is $E_y = 393 \text{ eV}$

Q-6.2 (Total Pts = 5)

In a 2D potential square well of length 40 nm an electron jumps from $E_{2,2}$ to $E_{1,2}$. Find the frequency of the generated photon.



$$\Delta E = E_8 - E_5$$

$$hf = \frac{h^2}{8mL^2} (2^2 + 2^2 - 1^2 - 2^2)$$

$$f = \frac{h}{8mL^2} \cdot 3$$

$$= \frac{6.63 \times 10^{-34} \cdot 3}{8 \times 9.1 \times 10^{-31} \times (40 \times 10^{-9})^2}$$

$$f = 1.71 \times 10^{11} \text{ Hz}$$

Q7 (Total Pts = 15)

- a) What is the energy needed to extract (take out) an electron from the state $n=4$ for a hydrogen atom? (pts = 3)
- b) What is the minimum energy needed to ionize the hydrogen atom? (pts = 1)
- c) What is the radius of the state $n=4$ for the hydrogen atom? (pts = 3)
- d) What is the smallest wavelength emitted due an electronic transition between the levels in hydrogen atom? (pts = 4)
- e) Write the configuration of Calcium (Ca) which has 20 electrons using the sub-shells symbols s, p, d, f (pts = 2)
- f) How many valence electrons does it have? (pts = 1)
- g) What is the configuration of the nearest inert element to it? (pts = 1)

a) $\Delta E = \frac{13.6}{n^2} - 0$

$= \frac{13.6}{4^2} \text{ eV} = 0.85 \text{ eV}$

Energy level diagram for hydrogen atom:

n	Energy (eV)
n=4	$\frac{13.6}{4^2}$
n=3	$\frac{13.6}{3^2}$
n=2	$\frac{13.6}{2^2}$
n=1	13.6

b) $\Delta E = 13.6 - 0 = 13.6 \text{ eV}$

c) $r = a_0 n^2 = 0.53 \times 10^{-10} \times 4^2 = 8.5 \times 10^{-10} \text{ m}$

d) Smallest wavelength = biggest frequency

$\therefore \Delta E_{\text{max}} = E_4 - E_1$

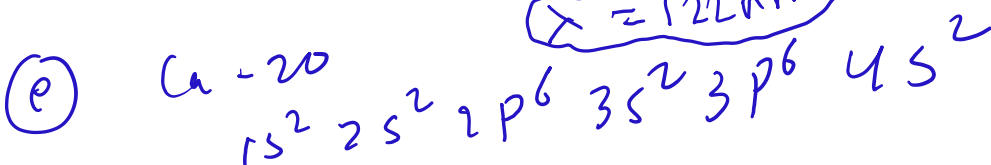
$\frac{hc}{\lambda} = -\frac{13.6}{4^2} + 13.6$

Energy level diagram showing transition from n=4 to n=1:

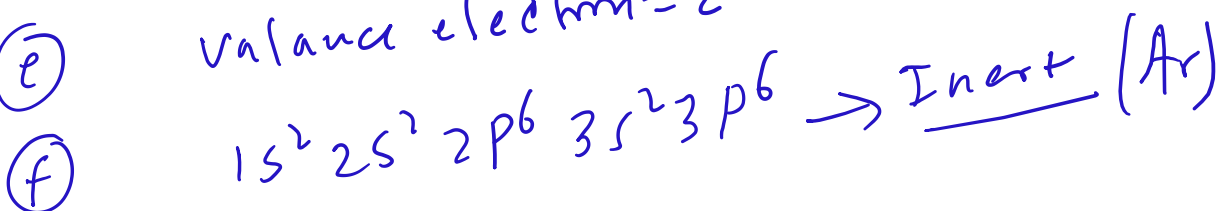
n	Energy (eV)
n=4	$-\frac{13.6}{4^2}$
n=1	13.6

$\lambda = \frac{hc}{13.6 \times 0.75} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{13.6 \times 0.75 \times 1.6 \times 10^{-19}}$

$\lambda = 122 \text{ nm}$



f) valance electron = 2



Q-8.1 (Total Pts = 5)

Light of 170 nm wavelength strikes a surface, causing photoelectric emission. The stopping potential for the ejected electrons is 5.0 V. What will be the stopping potential if the wavelength of the light is doubled?

$$eV_1 = hf_1 - \phi$$

$$V_1 = \frac{hc}{e\lambda_1} - \frac{\phi}{e}, \quad V_2 = \frac{hc}{e(2\lambda_1)} - \frac{\phi}{e}$$

$$V_2 - V_1 = \frac{hc}{e} \left(\frac{1}{2\lambda_1} - \frac{1}{\lambda_1} \right)$$

$$V_2 = V_1 - \frac{hc}{2e\lambda_1} = 5 - \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{2 \times 1.6 \times 10^{-19} \times 170 \times 10^{-9}}$$

$$V_2 = 1.35 \text{ V}$$

Q-8.2 (Total Pts = 5)

An alpha particle with kinetic energy $K=5.6 \text{ MeV}$ happens, by chance, to be headed directly toward the nucleus of a neutral unknown atom. If the distance of closest approach d (least-center to-center separation when it stops) to the nucleus is $d=1.58 \times 10^{-14} \text{ m}$. What is the atomic number of the target element?

$$\Delta K + \Delta U = 0$$

$$-K + U = 0$$

$$K = U$$

$$5.6 \times 10^6 \text{ eV} = \frac{K(2e)(Ze)}{d}$$

$$Z = \frac{5.6 \times 10^6 \times 1.58 \times 10^{-14}}{9 \times 10^9 \times 2 \times 1.6 \times 10^{-19}}$$

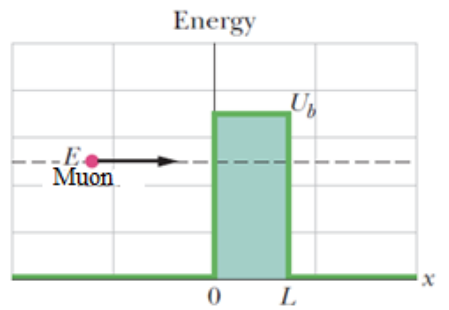
$$= 30.7$$

$$Z = 31$$

Q-9.1 (Total Pts = 10)

A Muon is a particle with a mass 207 times that of the electron. Consider such particle tunneling through a barrier with a height U_b and a width 40 pm with an energy $E=7.2$ eV.

- a) What is in eV, the value of U_b such that the probability of this process is 0.001?
- b) If the particle is an electron, what should be the width L of the barrier to have the same probability of tunneling?



$$T = e^{-2\kappa L}$$

$$0.001 = e^{-2 \sqrt{\frac{8\pi^2 m (U_b - E)}{h^2}} L}$$

$$\ln(0.001) = -2 \sqrt{8\pi^2 m (U_b - E)} L$$

$$E + \frac{[\ln(0.001)]^2 h^2}{32\pi^2 m L^2} = U_b$$

$$U_b = 7.2 + \frac{[\ln(0.001)]^2 \times 6.63 \times 10^{-34}}{32 \times 3.14 \times 207 \times 9.11 \times 10^{-31} \times (40 \times 10^{-12})^2}$$

$$U_b = 8.58 \text{ eV}$$

(b)

For same probability

$$m_\mu L_\mu^2 = m_e L_e^2$$

$$L_e = \sqrt{\frac{m_\mu}{m_e}} L_\mu$$

$$= \sqrt{207} \times 40 \text{ pm}$$

$$L_e = 575.5 \text{ pm}$$

Q-9.2 (Total Pts = 5)

What must be the momentum of a proton so that the total energy of the particle is 3.00 times its rest energy?

$$E = \sqrt{m_0^2 c^4 + p^2 c^2}$$
$$3 m_0 c^2 = \sqrt{m_0^2 c^4 + p^2 c^2}$$

$$9 m_0^2 c^4 = m_0^2 c^4 + p^2 c^2$$

$$8 m_0^2 c^4 = p^2 c^2$$

$$p = 2\sqrt{2} m_0 c$$

$$p = 2 \times 1.41 \times 1.67 \times 10^{-27} \times 3 \times 10^8$$
$$= 1.42 \times 10^{-18} \text{ kg m/s}$$

Q-10 (Total Pts = 12)

True or False Questions

1. In a propagating electromagnetic wave, the Electric field and the magnetic field at a given position do not have zero values at the same time.

Answer: False

2. If an object is at the focal F_1 of a converging lens its image will be at the focal F_2 (focus on opposite side).

Answer: False

3. A cube at rest in your reference has a volume a^3 . It is moving now in the x direction with a velocity $v = \frac{c}{2}$. The volume of the cube you measure now is $\text{Vol} = (a/\gamma)^3$, where $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$, and c is the speed of light.

Answer: False

4. A thermal neutron can cause fission reaction on the ^{238}U nucleus.

Answer: False

5. The conductivity of a semiconductor increases with temperature.

Answer: True

6. In a nuclear reaction, a huge amount of energy can be released, thus, the number of protons remains unchanged. The same applies for neutrons.

Answer: False

Q-11 (Total Pts = 9)
Multiple Choice Questions

Q-11.1

The diagram shows two small paramagnetic spheres, one near each end of a bar magnet. Which of the following statements is true?



- A) The force on 1 is toward the magnet and the force on 2 is away from the magnet
- B) The force on 1 is away from the magnet and the force on 2 is away from the magnet
- C) The forces on 1 and 2 are both toward the magnet
- D) The forces on 1 and 2 are both away from the magnet
- E) The magnet does not exert a force on either sphere

Q-11.2

In a purely resistive circuit the current:

- A) leads the voltage by 1/4 cycle
- B) leads the voltage by 1/2 cycle
- C) lags the voltage by 1/4 cycle
- D) lags the voltage by 1/2 cycle
- E) is in phase with the voltage

$V = iR$

Q-11.3

Which of the following equations can be used to show that magnetic field lines form closed loops?

- A) $\oint \vec{E} \cdot d\vec{A} = q/\epsilon_0$
- B) $\oint \vec{B} \cdot d\vec{A} = 0$
- C) $\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$
- D) $\oint \vec{B} \cdot d\vec{s} = \mu_0 i + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$
- E) none of these