İzmir Kâtip Çelebi University
Materials Science and Engineering
Mse228 Engineering Quantum Mechanics
Midterm Examination
April 12, 2017 09:30 – 11:30
Good Luck!

NAME-SURNAME:

SIGNATURE:

ID:

DEPARTMENT:

DURATION: 120 minutes

◇ **Answer all the questions.**
◇ **Write the solutions explicitly and clearly. Use the physical terminology.**
◇ **You are allowed to use Formulae Sheet.**
◇ **Calculator is allowed.**
◇ **You are not allowed to use any other electronic equipment in the exam.**

Question	Grade	Out of
1		20
2		30
3		20
4		20
5		20
TOTAL		110

1. A) Electrons are accelerated in television tubes through potential differences of about 20 kV. Find the highest frequency of the electromagnetic waves emitted when these electrons strike the screen of the tube.

of the tube.

Potential difference $V \rightarrow qV = U = KE_{max}$ of the e^-s $\rightarrow (1.602\times10^{-19}\,C)(20\,000\,V)$

$KE = 3.204\times10^{-15}\,J = \frac{3.20\times10^{-15}\,J}{1.602\times10^{-19}\,J/eV} = 20\,keV$ (as a note $20\,keV \ll 0.511\,MeV$ rest mass energy)

e^-s strike the screen and all the energy given to the emitted em wave

$$\Rightarrow 20\,keV = h\,\nu_{max} \rightarrow \nu_{max} = \frac{20\,keV}{\frac{6.626\times10^{-34}\,J/s}{1.602\times10^{-19}\,J/eV}} = 4.85\times10^{18}\,Hz$$

B) An electron moves in the x-direction with a speed of 3.6×10^6 m/s. We can measure its speed to a precision of 2%. With what precision can we simultaneously measure its x coordinate?

x-direction, speed of precision of 2% $\Rightarrow \Delta v_x = v_x \times \frac{2}{100}$

$\Delta p_x = m\Delta v_x = (9.11\times10^{-31}\,kg)(7.2\times10^{4}\,m/s) = 6.56\times10^{-26}\,kg\,m/s$

$$\rightarrow \Delta x \Delta p_x \geq \hbar \rightarrow \Delta x \simeq \frac{\hbar}{\Delta p_x} = \frac{1.05\times10^{-34}\,Js}{6.56\times10^{-26}\,kg\,m/s} = 1.6\times10^{-9}\,m = 1.6\,nm$$

$\left(J \equiv kg\frac{m^2}{s^2}\right)$

2. Suppose that light of total intensity 1.0 $\mu W/cm^2$ falls on a clean iron sample 1.0 cm^2 in area. Assume that the iron sample reflects 96% of the light and that only 3.0% of the absorbed energy lies in the violet region of the spectrum above the threshold frequency.

   i What intensity is actually available for the photoelectric effect?

   ii Assuming that all the photons in the violet region have an effective wavelength of 250 nm, how many electrons will be emitted per second? (Hints: For an efficiency of 100%, one photon of energy, $h\nu$, will produce one electron & Intensity=Power/Area & Power=Energy/Time)

   iii Calculate the current in the phototube in amperes.

   iv If the cutoff frequency is $\nu_0 = 1.1 \times 10^{15}\ Hz$, find the work function, ϕ, for iron.

   v Find the stopping voltage for iron if photoelectrons are produced by light with $\lambda = 250\ nm$.

region of the spectrum above the threshold frequency.

$I_0 = 1.0\ mW/cm^2$

i What intensity is actually available for the photoelectric effect?

Only 4% of the incident energy is absorbed & only 3% of that absorbed energy is able to produce photoelectrons $\rightarrow I = (0.04 I_0)\,0.03 = 1.2\ nW/cm^2$

ii Assuming that all the photons in the violet region have an effective wavelength of 250 nm, how many electrons will be emitted per second? (Hints: For an efficiency of 100%, one photon of energy, $h\nu$, will produce one electron & Intensity=Power/Area & Power=Energy/Time)

$$\left.\frac{\#\ of\ e^-}{second}\right|_{at\ 1\,cm^2} = \frac{1.2\times10^{-9}\,W}{h\nu} = \frac{(250\times10^{-9}\,m)(1.2\times10^{-9}\,J/s)}{(6.626\times10^{-34}\,J\,s)(3\times10^{8}\,m/s)} = 1.5\times10^{9}$$

($h\nu$: energy of one photon $\rightarrow \frac{hc}{\lambda}$)

iii Calculate the current in the phototube in amperes.

$$\frac{q}{t} = i = \frac{(\#\ of\ e^-) \times e}{time} = \frac{(1.5\times10^{9})(1.602\times10^{-19}\,C)}{1\ second} = 2.4\times10^{-10}\,A$$

iv If the cutoff frequency is $\nu_0 = 1.1\times10^{15}\ Hz$, find the work function, ϕ, for iron.

$$\phi = h\nu_0 = \left(\frac{6.626\times10^{-34}\,J.s}{1.602\times10^{-19}\,J/eV}\right)(1.1\times10^{15}\,1/s) = 4.5\,eV$$

v Find the stopping voltage for iron if photoelectrons are produced by light with $\lambda = 250\ nm$.

KE of photoelectrons $= h\nu - \phi \equiv$ Stopping Potential

$$\left(\frac{6.626\times10^{-34}\,J.s}{1.602\times10^{-19}\,J/eV}\right)\left(\frac{3\times10^{8}\,m/s}{250\times10^{-9}\,m}\right) - 4.5\,eV = 0.46\,eV$$

3. X-rays of wavelength $\lambda = 0.200\ nm$ are aimed at a block of carbon. The scattered x-rays are observed at an angle of 45.0^o to the incident beam. Calculate the increased wavelength of the scattered x-rays at this angle.

this angle.

$$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta) = \frac{(6.626 \times 10^{-34}\ J.s)}{(9.11 \times 10^{-31} kg)(3 \times 10^{8} m/s)}(1 - \cos 45)$$

$$= 7.11 \times 10^{-13}\ m = 0.000711\ nm$$

$$\rightarrow \lambda = 0.200\ nm$$

$$\Rightarrow \lambda' = 0.200\ nm + 0.000711\ nm = \underline{0.200711\ nm}$$

4. If moving at 900 m/s, what would be the wavelength of

i an electron?

ii a 25,000 kg airplane?

iii Which is more likely to exhibit a wave nature?

i an electron?

$$\lambda_e = \frac{h}{p} = \frac{6.626 \times 10^{-34}\ J \cdot s}{(9.11 \times 10^{-31} kg)(900\ m/s)} = \underline{8.08 \times 10^{-7}\ m}$$

$$(J \equiv kg\ m^2/s^2)$$

ii a 25,000 kg airplane?

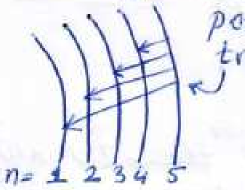
$$\lambda_{airplane} = \frac{h}{p} = \frac{6.626 \times 10^{-34}\ J/s}{(25 \times 10^3 kg)(900\ m/s)} = \underline{2.95 \times 10^{-41}\ m}$$

iii Which is more likely to exhibit a wave nature?

- 900 m/s is very slow as electron speed
- airplane's wavelength is much smaller than electron's wavelength!
- electron's wavelength is in order of micrometers!
- airplane's wavelength is much smaller than an atomic nucleus.

5. A) An electron is in the n = 5 state of hydrogen. To what states can the electron make transitions, and what are the energies of the emitted radiations?

Initially $n=5$, $E_n = \frac{E_1}{n^2} = \frac{-13.6\,eV}{25} = -0.544\,eV$



possible transitions

i	f	$|\Delta E| = |E_f - E_i| = h\nu$
5	4	$\rightsquigarrow -0.850eV-(-0.544eV) = 0.306eV$
5	3	$\rightsquigarrow -1.51eV-(-0.544eV) = 0.97eV$
5	2	$\rightsquigarrow -3.40eV-(-0.544eV) = 2.86eV$
5	1	$\rightsquigarrow -13.6eV-(-0.544eV) = 13.1eV$

$E_5 = \frac{-13.6\,eV}{25} = -0.544\,eV$

$E_4 = \frac{-13.6\,eV}{16} = -0.850\,eV$

$E_3 = -1.51\,eV$, $E_2 = -3.40\,eV$, $E_1 = -13.6\,eV$

B) A collection of hydrogen atoms in the ground state is illuminated with ultraviolet light of wavelength 59.0 nm. Find the kinetic energy of the emitted electrons.

energy of the emitted electrons.

energy of incident light : $h\nu = h\frac{c}{\lambda} = \frac{(6.626\times10^{-34}\,J.s)(3\times10^{8}\,m/s)}{(59\times10^{-9}\,m)}$

$\Rightarrow 21.0\,eV$

Hydrogen atom in its ground state $\rightsquigarrow n=1 \rightsquigarrow E_1 = -13.6\,eV$

$(21.0 - 13.6)\,eV = 7.4\,eV$: KE of the electrons