Q) Calculate the de Broglie wavelength of a proton that is accelerated through a potential difference of 10 MV.

a) 9.1×10^{-15} **m**
b) 4.5×10^{-15} **m**
c) 1.3×10^{-14} **m**
d) 3.1×10^{-15} **m**
e) 2.1×10^{-14} **m**

A 10 MeV proton has $K = 10\text{ MeV} << 2mc^2 = 1\,877\text{ MeV}$ so we can use the classical expression $p = (2mK)^{1/2}$. (See Problem 5-2)

$$\lambda = \frac{h}{p} = \frac{hc}{[(2)(938.3\text{ MeV})(10\text{ MeV})]^{1/2}} = \frac{1\,240\text{ MeV fm}}{\left[(2)(938.3)(10)(\text{MeV})^2\right]^{1/2}} = 9.05\text{ fm} = 9.05 \times 10^{-15}\text{ m}$$

Q) The speed of an electron is measured to within an uncertainty of 2.0 × 10⁴ m/s. What is the size of the smallest region of space in which the electron can be confined?

a) **2.9 nm**
b) **5.8 nm**
c) **7.3 nm**
d) **1.4 nm**
e) **15 nm**

$$\Delta x = \frac{\hbar}{2\Delta p} = \frac{\hbar}{2m\Delta v} = \frac{1.05 \times 10^{-34}\text{J. s}}{2(9.11 \times 10^{-31}\text{kg})(2.0 \times 10^4\text{m/s})} = 2.9 \times 10^{-9}\text{nm} = 2.9\text{ nm}$$

Q) Which of the following does NOT provide evidence for the wave nature of matter?

(a) The photoelectric effect
(b) Neutron diffraction
(c) The Heisenberg relationships
(d) Electron diffraction
(e) Feynman double-slit experiment

Q) Certain surface waves in a fluid travel with phase velocity $\sqrt{b/\lambda}$, where b is a constant. Find the group velocity of a packet of surface waves, in terms of the phase velocity.

a) $\frac{3}{2}v_p$
b) $\frac{1}{2}v_p$
c) $\frac{4}{3}v_p$
d) $\frac{5}{3}v_p$
e) $\frac{2}{5}v_p$

$$v_{\text{phase}} = \sqrt{\frac{b}{\lambda}} = \sqrt{\frac{bk}{2\pi}} = \frac{\omega}{k} \quad \text{or} \quad \omega = \sqrt{\frac{b}{2\pi}}k^{3/2}$$

$$v_{\text{group}} = \frac{d\omega}{dk} = \sqrt{\frac{b}{2\pi}}\frac{3}{2}k^{1/2} = \frac{3}{2}\sqrt{\frac{bk}{2\pi}} = \frac{3}{2}v_{\text{phase}}$$

Q) In the Davisson-Germer experiment using a Ni crystal, a second-order electron-beam is observed at an angle of 55.0°. If the separation between the atoms in the crystal is 0.215 nm, for what accelerating voltage does this occur?

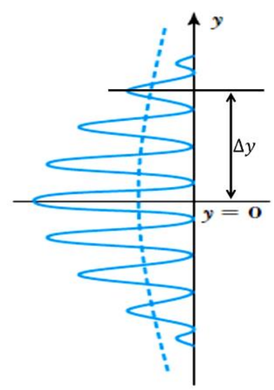
a) 194 eV
b) 332 eV
c) 50.1 eV
d) 100 eV
e) 589 eV

$$\lambda = \frac{d\sin\phi}{2} = \frac{(0.215\text{ nm})(\sin 55°)}{2} = 0.0881\text{ nm}$$

$$pc = \frac{hc}{\lambda} = \frac{1240\text{ eV}\cdot\text{nm}}{0.0881\text{ nm}} = 1.408\times10^4\text{ eV}$$

$$K = \frac{p^2}{2m} = \frac{(pc)^2}{2mc^2} = \frac{(1.408\times10^4\text{ eV})^2}{2(0.511\times10^6\text{ eV})} = 194\text{ eV}$$

Q) A neutron $(1.67 \times 10^{-27}\text{ kg})$ beam with a selected speed of 60 cm/s is directed through a double slit with a 1.5-mm separation. The detector is placed 10 m from the slits. What is the value of Δy?



a) 1.3 cm
b) 2.2 cm
c) 0.8 cm
d) 4.9 cm
e) 0.4 cm

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\text{J.s}}{(1.67 \times 10^{-27}\text{ kg}) \times 0.6\text{ m/s}} = 6.61 \times 10^{-7}\text{m}$$

$$D\frac{y_n}{L} = n\lambda \quad \rightarrow D\frac{\Delta y}{L} = 3\lambda \rightarrow \Delta y = \frac{3\lambda L}{D} = \frac{3\times(6.61\times10^{-7}\text{m})(10\text{ m})}{1.5\times10^{-3}\text{m}} = 0.013\text{ m} = 1.3\text{ cm}$$

Q) How de Broglie was able to explain that as the electrons revolve around the nucleus, they must have quantized electronic energies.

The circumference of the orbit fits a multiple integer of the wave matter of the electron. Therefore the electron's de Broglie wave behaves like a standing wave in the orbit.

Q) It is observed that α $(Z = 2)$ particles with kinetic energies of 13.9 MeV and higher, incident on Cu $(Z = 29)$ foils, do not obey Rutherford's $(\sin(\frac{\varphi}{2}))^{-4}$ law. Estimate the nuclear size of copper from this observation, assuming that the Cu nucleus remains fixed in a head-on collision with an α particle.

a) 6.01×10^{-15}m
b) 4.81×10^{-9}m
c) 1.75×10^{-15}m
d) 3.21×10^{-9}m
e) 8.31×10^{-12}m

conservation of energy $E_i = E_f$, $K_\alpha = (k)\frac{2Ze^2}{r}$ or

$$r = (k)\frac{2Ze^2}{K_\alpha} = \frac{(2)(29)\left(1.60\times10^{-19}\right)^2\left(8.99\times10^9\right)}{\left(13.9\times10^6\text{ eV}\right)\left(1.60\times10^{-19}\text{ J/eV}\right)} = 6.00\times10^{-15}\text{ m}.$$

Q) Find the potential energy of an electron in the ground state of the hydrogen atom.

a) -27.2 eV
b) -13.6 eV
c) -40.8 eV
d) $+34.0$ eV
e) -6.80 eV

$E = K + U = \frac{mv^2}{2} - \frac{ke^2}{r}$. But $\frac{mv^2}{2} = \left(\frac{1}{2}\right)\frac{ke^2}{r}$. Thus $E = \left(\frac{1}{2}\right)\left(\frac{-ke^2}{r}\right) = \frac{U}{2}$, so

$U = 2E = 2(-13.6 \text{ eV}) = -27.2 \text{ eV}$ and $K = E - U = -13.6 \text{ eV} - (-27.2 \text{ eV}) = 13.6 \text{ eV}$.

Q) Calculate the frequency of revolution of the electron in the Bohr model of hydrogen for $n = 100$.

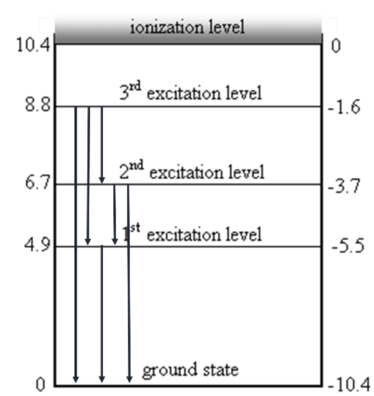
a) 6.58×10^9 Hz
b) 8.58×10^{12} Hz
c) 3.28×10^{15} Hz
d) 4.92×10^6 Hz
e) 2.11×10^9 Hz

$L = mvr_n = n\hbar \Rightarrow v = \frac{n\hbar}{mr_n}$

$$f_{revolution} = \frac{v}{2\pi r_n} = \frac{n\hbar}{2\pi m r_n^2} = \frac{n\hbar}{2\pi m n^4 a_0^2} = \frac{100 \times 1.05 \times 10^{-34}}{2\pi(9.11 \times 10^{-31}) \times 100^4 \times (0.0529 \times 10^{-9})^2} = 6.58 \times 10^9 \textbf{ Hz}$$

Q) If a voltage of 9.0 V has been applied across a Franck-Hertz apparatus. How many photons will you see emitted by the mercury?

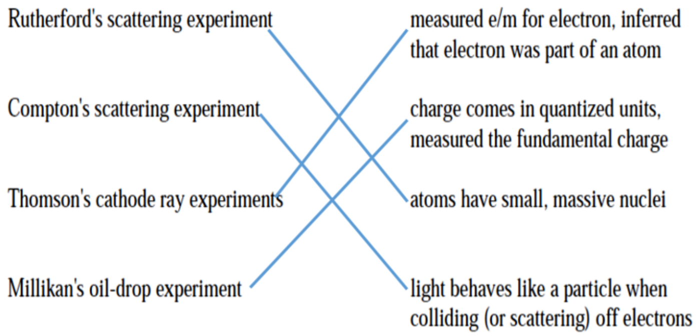
a) 6
b) 5
c) 8
d) 4
e) 3



Q) What is the Bohr's correspondence principle?

*This principle states that predictions of quantum theory must correspond to the predictions of classical physics in the region of sizes where classical theory is known to hold. Simply when the quantum number **n** is large, discrete states will be overlap and form continuum states.*

Q6)



Q) The power radiated per unit area by a tungsten filament is 4.62×10^6 W/m². What is the wavelength at which the peak occurs in the radiation emitted by tungsten?

- **a) 970 nm**
- **b) 750 nm**
- **c) 650 nm**
- **d) 830 nm**
- **e) 590 nm**

From Stefan's law, one has $\frac{P}{A} = \sigma T^4$. Therefore,

$$\frac{P}{A} = \left(5.7 \times 10^{-8}\ \mathrm{W/m^2 K^4}\right)(3000\ \mathrm{K})^4 = 4.62 \times 10^6\ \mathrm{W/m^2}.$$

Q2) The photocurrent of a photocell is cut off by a retarding potential of 2.92 V for radiation of wavelength 250 nm. Find the work function for the material.

- **a) 2.04 eV**
- **b) 4.97 eV**
- **c) 3.77 eV**
- **d) 1.34 eV**
- **e) 2.89 eV**

$$K = hf - \phi = \frac{hc}{\lambda - \phi}$$

$$\phi = \frac{hc}{\lambda - K} = \frac{1\,240\ \mathrm{eV\ nm}}{250\ \mathrm{nm}} - 2.92\ \mathrm{eV} = 2.04\ \mathrm{eV}$$

Q) X-rays with a wavelength of 0.040 nm undergo Compton scattering at angles of 30°. Find the energy of the scattered electrons corresponding to these scattered x-rays.

- **a) 250 eV**
- **b) 320 eV**
- **c) 480 eV**
- **d) 140 eV**
- **e) 31.1 eV**

$$\Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta) = 2.426 \times 10^{-12}\ \mathrm{m}\,(1 - \cos\theta)$$

For $\theta = 30°$

$$\Delta\lambda = 2.426 \times 10^{-12}\ \mathrm{m}\,(1 - \cos 30°) = 3.25 \times 10^{-11}\ \mathrm{m}\ ;\ \lambda' = \lambda_0 + \Delta\lambda,$$

$$\lambda' = 0.04 \times 10^{-9}\ \mathrm{m} + 3.25 \times 10^{-13}\ \mathrm{m} = 4.03 \times 10^{-11}\ \mathrm{m}$$

$$\frac{hc}{\lambda_0} = \frac{hc}{\lambda' + K_e},\ K_e hc\left(\frac{1}{\lambda_0} - \frac{1}{\lambda'}\right)$$

For $\theta = 30°$

$$K_e = \frac{\left(6.63 \times 10^{-34}\ \mathrm{J\ s}\right)\left(3 \times 10^8\ \mathrm{m/s}\right)}{\frac{1}{0.04 \times 10^{-9}} - \frac{1}{4.03 \times 10^{-11}}} = \left(3.70 \times 10^{-17}\ \mathrm{J}\right)\frac{1}{1.6 \times 10^{-19}\ \mathrm{J/eV}} = 231\ \mathrm{eV}.$$

Q4) When a beam of monochromatic x rays is incident on a particular NaCl crystal, Bragg reflection in the first order (with $n = 1$) occurs at $\theta = 20^o$. The value of $d = 0.28$ nm. What is the minimum voltage at which the x-ray tube can be operating?

a) **6.49 keV**
b) **18.0 keV**
c) **3.64 keV**
d) **22.9 keV**
e) **30.0 keV**

Bragg condition: $m\lambda = 2d\sin\theta$. $\lambda = (2)(0.28nm)(\sin 20°) = 1.92\times10^{-10}m = 0.192nm.$

This is the minimum wavelength λ_m that must be produced by the X ray tube.

$$\lambda_m = \frac{1.24\times10^3}{V}nm \quad \text{or} \quad V = \frac{1.24\times10^3}{0.192} = 6.47\times10^3V = 6.47kV$$

Q5) What is the momentum of a photon of red light of wavelength 650 nm?

a) **1.91 eV/c**
b) **2.53 eV/c**
c) **3.45 eV/c**
d) **4.09 eV/c**
e) **5.78 eV/c**
f)

$$p = \frac{h}{\lambda} = \frac{1}{c}\frac{hc}{\lambda} = \frac{1}{c}\left(\frac{1240\,\text{eV}\cdot\text{nm}}{650\,\text{nm}}\right) = 1.91\,\text{eV}/c$$

Q) The brehmsstrahlung process occurs when

a) **an electron decelerates near an atom.**
b) **an isolated electron emits a photon.**
c) **an electron encounters a positron.**
d) **an electron absorbs a photon.**
e) **an electron is captured by the nucleus.**

Q) An FM radio station of frequency 98.1 MHz puts out a signal of 50,000 W. How many photons per second are emitted?

a) 7.69×10^{29}
b) 3.55×10^{13}
c) 6.87×10^{32}
d) 8.41×10^{28}
e) 2.15×10^{27}

$$\text{Energy per photon } = hf = \left(6.626\times10^{-34}\,\text{J}\cdot\text{s}\right)\left(98.1\times10^{6}\,\text{s}^{-1}\right) = 6.50\times10^{-26}\text{ J}$$

$$\left(5.0\times10^{4}\text{ J/s}\right)\frac{1\text{ photon}}{6.50\times10^{-26}\text{ J}} = 7.69\times10^{29}\text{ photons/s}$$