

- Q1. (8 pts) a) What is the temperature of an ideal gas whose molecules have a kinetic energy of 4.6×10^{-20} J?
- b) If that gas consists of 10^{22} molecules in a container of volume 0.25 m^3 calculate the pressure of the gas.
- c) If the gas is compressed to half its original volume while maintaining this pressure calculate the work done on the gas.
- d) If this compression occurs in such a way as to prevent any heat flow into or out of the system compute the change in internal energy of the gas.

a) $K = \frac{3}{2} kT \rightarrow T = \frac{2}{3} K/k$
 (3 pts) $= \frac{2 \cdot 2 \times 10^{-20}}{10^{-23}} = 2,200 \text{ K}$
units

b) $pV = NkT$
 $\therefore p = \frac{10^{22} \times 1.38 \times 10^{-23} \times 2,200}{0.25} = 1.2 \times 10^4 \times 10^{22} \times 10^{-23}$
 (3 pts) $= \underline{\underline{1.2 \times 10^3 \text{ N/m}^2}}$

c) $W = -P\Delta V = 0.125 \times 1.2 \times 10^3$
 $= \underline{\underline{1.5 \times 10^2 \text{ J}}}$ (2 pts)

d) $\Delta U = W$ ($Q=0$)

$\therefore \Delta U = \underline{\underline{+150 \text{ J}}}$

1 pt

Q2.(5pts) What is the uncertainty principle in quantum physics. Write down a mathematical form of the principle. Use this to estimate the energy of a neutron with mass 1.6×10^{-27} kg confined to a region the size of an atomic nucleus 10^{-14} m

It is impossible in principle to know simultaneously both the exact position & momentum of a particle (or something along those lines)

$$\Delta x \Delta p \geq h$$

(equality, factors of 2 not necessary)

$$\rightarrow P_N \approx \frac{h}{10^{-14}} = \frac{6.6 \times 10^{-34}}{10^{-14}} = 6.6 \times 10^{-20} \text{ kg m/s}$$

$$\rightarrow K_N = \frac{P_N^2}{2m} = \frac{(6.6 \times 10^{-20})^2}{2 \times 1.6 \times 10^{-27}}$$

3pts \rightarrow

$$= \frac{13.6 \times 10^{-40}}{10^{-27}} = 13.6 \times 10^{-13} \text{ J}$$

$$= \underline{\underline{1.4 \times 10^{-12} \text{ J}}}$$

swap with 2

Q3. (2 pts) What is the energy in Joules of an electron that has been accelerated through a potential difference of 100 V.

electron has 100 eV

$$= 100 \times 1.6 \times 10^{-19} \text{ J}$$

$$= \underline{\underline{1.6 \times 10^{-17} \text{ J}}}$$

3
Q4. (2 pts) The minimum energy required to remove an electron from a particular metal is 2.6 eV. What is the longest wavelength photon that can eject an electron from this surface ?

to eject electron with no kinetic energy
requires photon energy = 2.6 eV (1 pt)

$$\frac{hc}{\lambda} = 2.6 \times 1.6 \times 10^{-19}$$
$$= 4.16 \times 10^{-19}$$

$$= \lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{\cancel{2.6} \times 4.16 \times 10^{-19}} = \underline{\underline{4.8 \times 10^{-7} \text{ m}}}$$

(2 pts)

3.
Q5. (4pts) Calculate the wavelength of EM radiation required to ionize a H atom in its ground state. What type of radiation is this?

from Bohr formula

$$eV + 13.6 = E_{\text{ionize}}$$

($n=1$
ground
state)

$$-\frac{hc}{\lambda} = 13.6 \times 1.6 \times 10^{-19}$$

$$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{13.6 \times 1.6 \times 10^{-19}}$$

$$= \frac{0.9 \times 10^{-7} \text{ m}}{1} = 9 \times 10^{-8} \text{ m} \\ = \underline{\underline{90 \text{ nm}}}$$

(2pts)

V.V radiation

(1pt)

Q6. (4pts) An electron beam is diffracted by a single slit of width 0.01 mm. A minimum intensity is observed at an angle of 0.1° .

- a) What is the de Broglie wavelength of the electrons ?
 b) What is the energy of the electrons ?

$$\lambda = h/p$$

also a) $\lambda = a\theta$ θ small

$$\begin{aligned} \rightarrow \lambda &= 0.01 \times 10^{-3} \times 0.1 \times \frac{\pi}{180} \\ &= 10^{-6} \times \frac{\pi}{180} \\ &= 0.017 \times 10^{-6} = \underline{1.7 \times 10^{-8} \text{ m}} \\ &= \underline{17 \text{ nm}} \end{aligned}$$

(2 pts)

b) $p = h/\lambda = \frac{6.6 \times 10^{-34}}{1.7 \times 10^{-8}} = 3.8 \times 10^{-26} \text{ kg m/s}$

(2 pts) $\therefore E = \frac{p^2}{2m} = \frac{14.8 \times 10^{-52}}{2 \times 9 \times 10^{-31}} = \underline{0.82 \times 10^{-21} \text{ J}}$

Q7. (4pts) Give the name of the three possible ways in which electrons can absorb or emit photons. Explain how one of these is crucial to the operation of a laser.

absorption

spontaneous emission

≈ stimulated emission

↑

letter important for operation of laser

→ sample contains large population of atoms

in excited metastable state. Decays

by stimulated emission → cascade

of coherent photons

(2pts)

↑ for laser

Key issues →

(any 2 of these)

stimulated emission
decay of metastable state

many identical photons produced

Q8. (3pts) A hydrogen atom in its ground state absorbs a photon of energy 12.1 eV. To what energy level is the atom excited (i.e. what value of the quantum number n)

$$E = -13.6 / n^2 \quad \frac{1 \text{ pt}}$$

$$n=1 \rightarrow E_1 = -13.6 \text{ eV}$$

$$n=2 \rightarrow E_2 = -13.6/4 = -3.4 \text{ eV}$$

$$n=3 \rightarrow E_3 = -13.6/9 = 1.51 \text{ eV} \quad \Delta E = 12.1$$

i.e. electron excited to

$n=3$ level

Q9. (5 pts) A rubidium surface has a work function of 2.16 eV.

- a) What is the maximum kinetic energy of ejected **Electrons** if the incident radiation has wavelength 413 nm.
 b) What is the threshold wavelength for this surface?

$$E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{4.13 \times 10^{-7}} = 4.8 \times 10^{-19} \text{ J photon}$$

$$\therefore \text{max } K = 2.53 - 2.16 = 2.53 \text{ eV}$$

$$= 0.37 \text{ eV}$$

$$= 0.23 \times 10^{-19} \text{ J}$$

$$f_0 = \frac{2.16 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}} = 0.52 \times 10^{15} \text{ Hz}$$

$$\rightarrow \lambda_0 = 5.8 \times 10^{-7} \text{ m}$$

Q10. (4pts) (4pts) Calculate the energy of

- a) A photon with wavelength 100 nm
 b) A photon with wavelength 1 nm

$$a) E = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{10^{-7}} = 19.8 \times 10^{-19} \text{ J}$$

$$b) \underline{19.8 \times 10^{-17} \text{ J}}$$