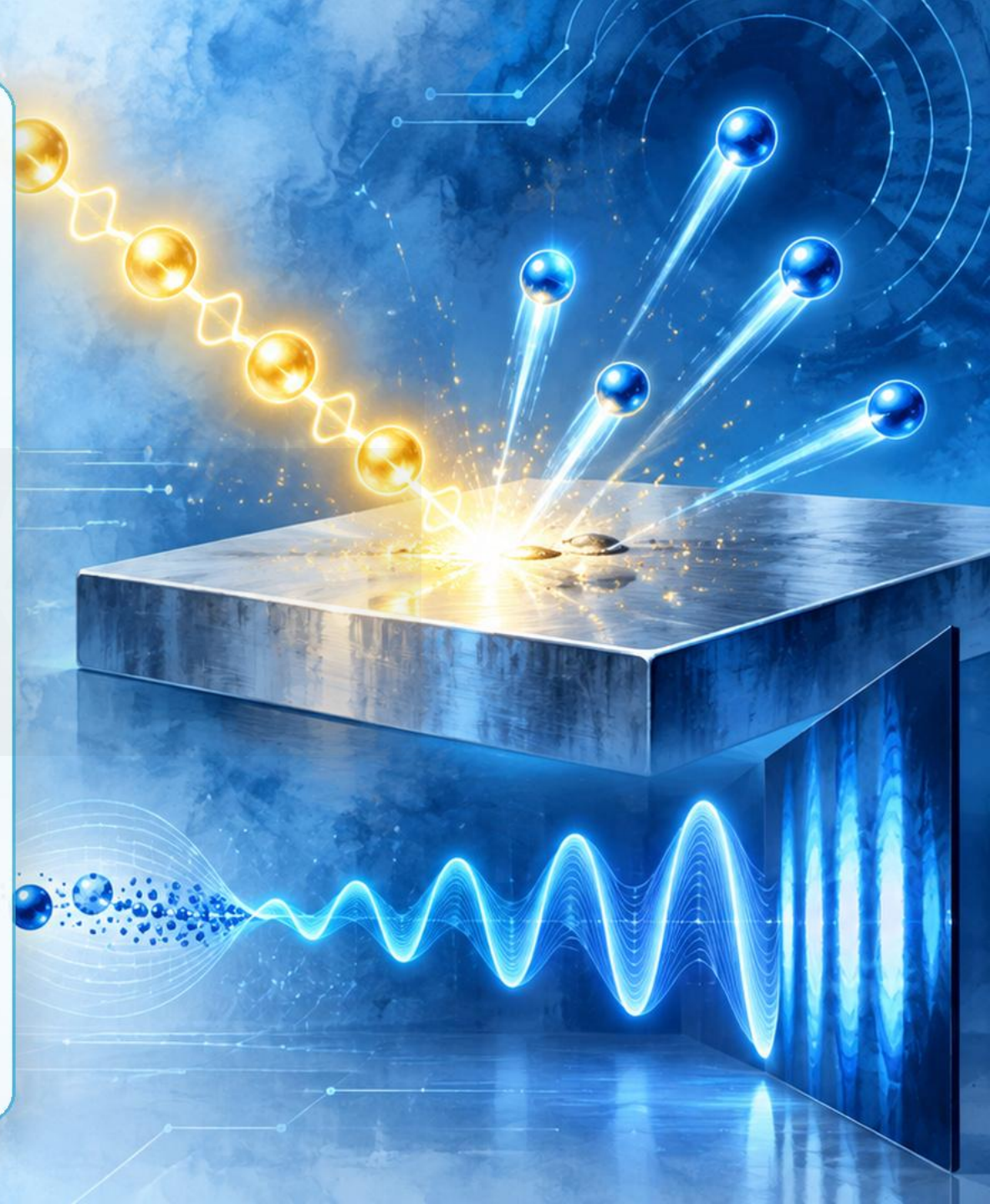


PHYSICS • CLASS 12

CHAPTER 11

Dual Nature of Radiation and Matter

NCERT SOLUTIONS



X-RAY LIMITS – EXERCISE 11.1

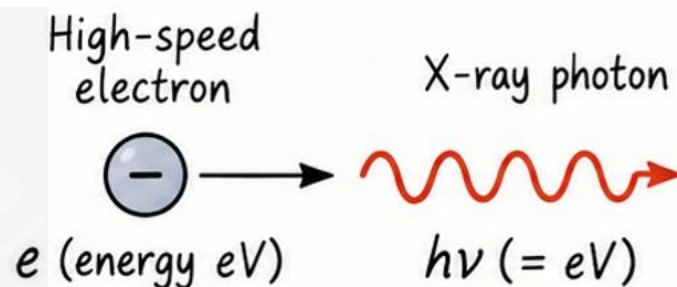
Q. Find (a) maximum frequency and (b) minimum wavelength of X-rays made by 30 kV electrons.

Given: $V = 30 \text{ kV} = 3.0 \times 10^4 \text{ V}$, $e = 1.602 \times 10^{-19} \text{ C}$, $h = 6.63 \times 10^{-34} \text{ J s}$,
 $c = 3.00 \times 10^8 \text{ m s}^{-1}$.

Answer:

The shortest-wavelength X-ray occurs when one electron gives all of its kinetic energy eV to one photon; this is the limiting case.

$$eV = h\nu_{\max} = \frac{hc}{\lambda_{\min}}.$$



(a) Maximum frequency:

$$\nu_{\max} = \frac{eV}{h} = \frac{(1.602 \times 10^{-19})(3.0 \times 10^4)}{6.63 \times 10^{-34}} = 7.25 \times 10^{18} \text{ Hz}.$$

$$\nu_{\max} = 7.25 \times 10^{18} \text{ Hz}$$

(b) Minimum wavelength:

$$\lambda_{\min} = \frac{c}{\nu_{\max}} = \frac{hc}{eV} = 4.14 \times 10^{-11} \text{ m} = 0.0414 \text{ nm}.$$

$$\lambda_{\min} = 0.0414 \text{ nm}$$

CAESIUM PHOTOELECTRONS — EXERCISE 11.2

Q. Caesium work function $\phi = 2.14$ eV. Incident light $\nu = 6.0 \times 10^{14}$ Hz. Find (a) maximum kinetic energy, (b) stopping potential, (c) maximum electron speed. Use $h = 6.63 \times 10^{-34}$ J s, $e = 1.602 \times 10^{-19}$ C, $m_e = 9.11 \times 10^{-31}$ kg.

Answer:

Einstein's photoelectric equation is photon energy = work function + maximum kinetic energy.

$$h\nu = 3.978 \times 10^{-19} \text{ J} = 2.483 \text{ eV}.$$

(a) Maximum kinetic energy

The maximum kinetic energy is the excess of photon energy over the work function.

$$\begin{aligned} K_{\max} &= h\nu - \phi \\ &= (2.483 - 2.14) \text{ eV} \\ &= 0.343 \text{ eV} \\ &= 5.50 \times 10^{-20} \text{ J}. \end{aligned}$$

(b) Stopping potential

The stopping potential V_0 is such that $eV_0 = K_{\max}$.

$$\begin{aligned} eV_0 &= K_{\max} \\ V_0 &= \frac{K_{\max}}{e} \\ &= 0.343 \text{ V} \\ &\approx 0.34 \text{ V}. \end{aligned}$$

(c) Maximum electron speed

The maximum speed v is obtained from $\frac{1}{2} m_e v^2 = K_{\max}$.

$$\begin{aligned} \frac{1}{2} m_e v^2 &= K_{\max} \\ v &= \sqrt{\frac{2K_{\max}}{m_e}} \\ &= \sqrt{\frac{2(5.50 \times 10^{-20})}{9.11 \times 10^{-31}}} \\ &= 3.47 \times 10^5 \text{ m s}^{-1}. \end{aligned}$$

Do not confuse photon energy with kinetic energy.

STOPPING VOLTAGE – EXERCISE 11.3

Q. The photoelectric cut-off (stopping) voltage is 1.5 V. Find the maximum kinetic energy of the emitted photoelectrons.

Answer:

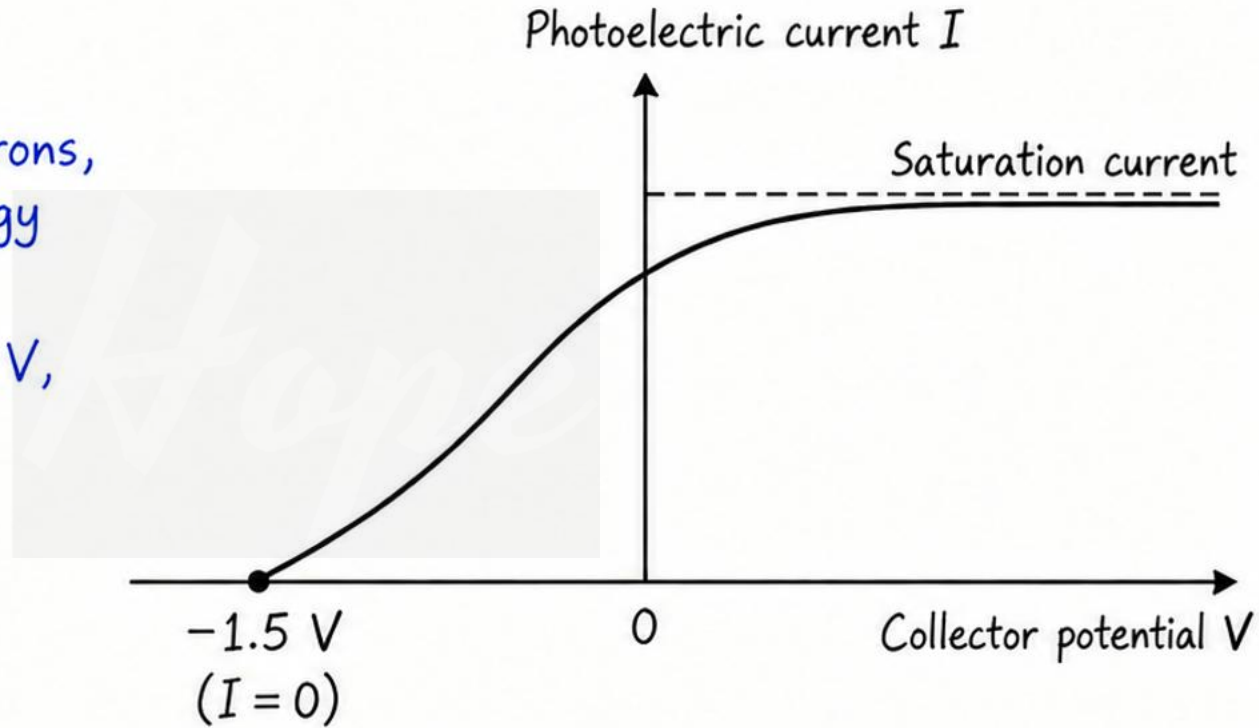
The retarding potential just stops the fastest electrons, so its magnitude in volts gives their maximum energy in electronvolts.

Here, the stopping voltage (cut-off voltage) is 1.5 V, so the maximum kinetic energy of the emitted photoelectrons is

$$\begin{aligned} K_{\max} &= e V_0 = (1.602 \times 10^{-19} \text{ C})(1.5 \text{ V}) \\ &= 2.403 \times 10^{-19} \text{ J} \\ &\approx 2.4 \times 10^{-19} \text{ J} \end{aligned}$$

Since $1 \text{ eV} = e \times 1 \text{ V}$, therefore

$$K_{\max} = 1.5 \text{ eV}.$$



Note that $V_0 = 1.5 \text{ V}$ is the positive magnitude of the stopping voltage, whereas the collector must be at $-V_0 = -1.5 \text{ V}$ (retarding potential) for the current to become zero, as shown in the graph.

LASER PHOTON ENERGY — EXERCISE 11.4(a)

Q. A helium-neon laser has wavelength $\lambda = 632.8 \text{ nm}$ and emitted power $P = 9.42 \text{ mW}$. Find the energy and momentum of each photon.

$$h = 6.63 \times 10^{-34} \text{ J s}, \quad c = 3.00 \times 10^8 \text{ m s}^{-1}, \quad \lambda = 632.8 \text{ nm} = 632.8 \times 10^{-9} \text{ m}.$$

Answer: Energy of each photon

A photon carries energy $h\nu$, where $\nu = c/\lambda$.

$$\begin{aligned} E &= \frac{hc}{\lambda} \\ &= \frac{(6.63 \times 10^{-34})(3.00 \times 10^8)}{632.8 \times 10^{-9}} \\ &= 3.14 \times 10^{-19} \text{ J} \\ &\approx 1.96 \text{ eV} \end{aligned}$$

$$E = 3.14 \times 10^{-19} \text{ J } (\approx 1.96 \text{ eV})$$

Answer: Momentum of each photon

A photon carries momentum h/λ .

$$\begin{aligned} p &= \frac{E}{c} = \frac{h}{\lambda} \\ &= \frac{6.63 \times 10^{-34}}{632.8 \times 10^{-9}} \\ &= 1.05 \times 10^{-27} \text{ kg m s}^{-1} \end{aligned}$$

$$p = 1.05 \times 10^{-27} \text{ kg m s}^{-1}$$



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