



AP[®] Physics B 2003 Sample Student Responses

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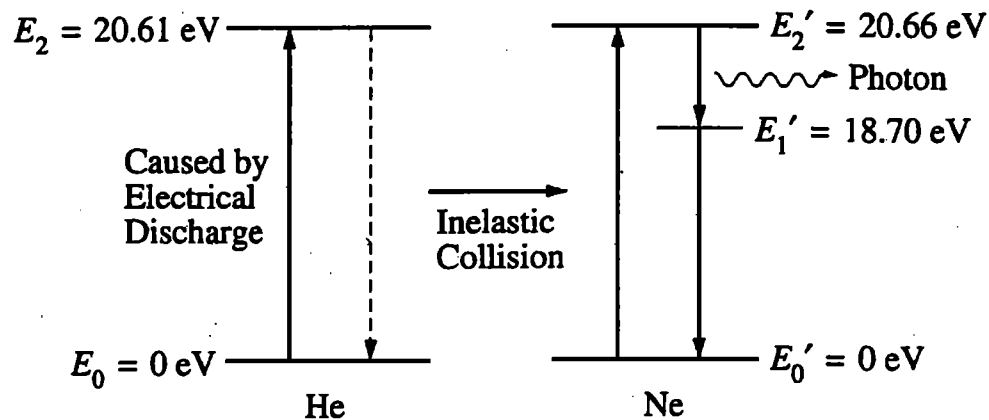
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7. (10 points)

Energy-level diagrams for atoms that comprise a helium-neon laser are given above. As indicated on the left, the helium atom is excited by an electrical discharge and an electron jumps from energy level E_0 to energy level E_2 . The helium atom (atomic mass 4) then collides inelastically with a neon atom (atomic mass 20), and the helium atom falls to the ground state, giving the neon atom enough energy to raise an electron from E_0' to E_2' . The laser emits light when an electron in the neon atom falls from energy level E_2' to energy level E_1' .

(a) Calculate the minimum speed the helium atom must have in order to raise the neon electron from E_0' to E_2' .

$v_f = ?$

$$m_1 v_1 + m_2 v_2 \Big|_0 = (m_1 + m_2) v_f$$

$$(6.64 \times 10^{-27} \text{ kg})(5 \text{ m/s}) + (3.32 \times 10^{-26} \text{ kg})(0) = (6.64 \times 10^{-27} \text{ kg} + 3.32 \times 10^{-26} \text{ kg}) v_f$$

$$1.99 \times 10^{-25} \text{ kg} \cdot \text{m/s} = (3.98 \times 10^{-26} \text{ kg}) v_f$$

$$v_f = 5 \text{ m/s}$$

(b) Calculate the DeBroglie wavelength of the helium atom when it has the speed determined in (a).

$$\lambda = \frac{h}{p}$$

$$= \frac{h}{mv}$$

$$\lambda = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})}{4(1.66 \times 10^{-27} \text{ kg})(5 \text{ m/s})}$$

$$\lambda = 1.997 \times 10^{-8} \text{ m}$$

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- (c) The excited neon electron then falls from E_2' to E_1' and emits a photon of laser light. Calculate the wavelength of this light.

$$E_0 - E_f = hf$$

$$E_2' - E_1' = hf$$

$$20.66\text{eV} - 18.70\text{eV} = hf$$

$$\frac{1.96\text{eV} \times 1.60 \times 10^{-19}\text{J}}{1\text{eV}} =$$

$$1.96\text{eV} = hf$$

$$\frac{3.14 \times 10^{-19}\text{J}}{6.63 \times 10^{-34}\text{J}} = f$$

$$f = 4.74 \times 10^{14}\text{Hz}$$

$$v = f\lambda$$

$$\lambda = \frac{c}{f}$$

$$= \frac{3 \times 10^8\text{m/s}}{4.74 \times 10^{14}\text{Hz}}$$

$$\lambda = 6.33 \times 10^{-7}\text{m}$$

- (d) This laser light is now used to repair a detached retina in a patient's eye. The laser puts out pulses of length $20 \times 10^{-3}\text{s}$ that average 0.50W output per pulse. How many photons does each pulse contain?

$$P = 0.5\text{W}$$

$$P = \frac{W}{t} = \frac{E}{t}$$

$$t = 20 \times 10^{-3}\text{s}$$

$$Pt = E$$

$$E_0 = 3.14 \times 10^{-19}\text{J}$$

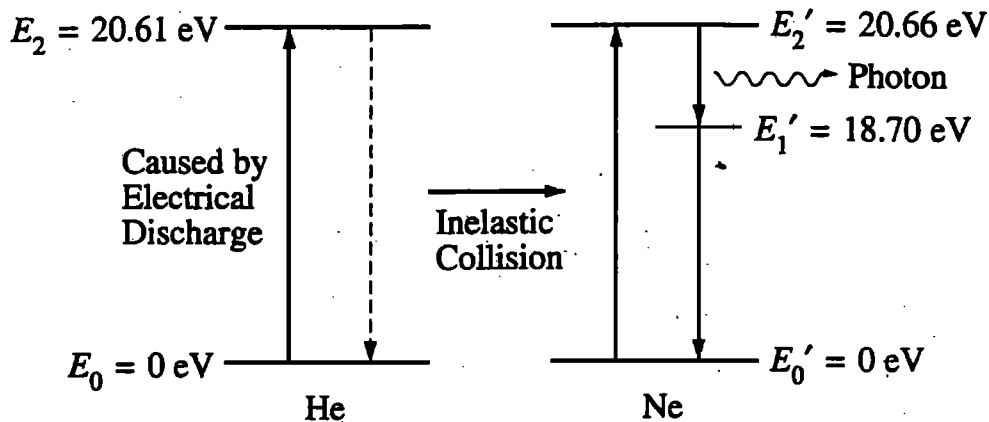
$$(0.50\text{W})(20 \times 10^{-3}\text{s}) = E$$

$$E = 0.01\text{J}$$

$$\frac{E}{E_0} = \# \text{ of photons}$$

$$\frac{(0.01\text{J})}{(3.14 \times 10^{-19}\text{J})} =$$

$$3.18 \times 10^{16} \text{ photons}$$



7. (10 points)

Energy-level diagrams for atoms that comprise a helium-neon laser are given above. As indicated on the left, the helium atom is excited by an electrical discharge and an electron jumps from energy level E_0 to energy level E_2 . The helium atom (atomic mass 4) then collides inelastically with a neon atom (atomic mass 20), and the helium atom falls to the ground state, giving the neon atom enough energy to raise an electron from E_0' to E_2' . The laser emits light when an electron in the neon atom falls from energy level E_2' to energy level E_1' .

(a) Calculate the minimum speed the helium atom must have in order to raise the neon electron from E_0' to E_2' .

when helium atom falls to

$$KE_{\text{Helium}} = 20.66 \text{ eV} - 20.61 \text{ eV} = 0.05 \text{ eV} = 8 \cdot 10^{-21} \text{ J}$$

$$\frac{1}{2} m v^2 = 8 \cdot 10^{-21} \text{ J}$$

$$v = \sqrt{\frac{2 \cdot 8 \cdot 10^{-21} \text{ J}}{4 \cdot 1.66 \cdot 10^{-27} \text{ kg}}}$$

$$v = \sqrt{\frac{16 \cdot 10^{-21} \text{ J}}{6.64 \cdot 10^{-27} \text{ kg}}}$$

$$v = 2.409 \cdot 10^6 \text{ m/s}$$

(b) Calculate the DeBroglie wavelength of the helium atom when it has the speed determined in (a).

$$\lambda = \frac{h}{p} = \frac{h}{m v} = \frac{6.63 \cdot 10^{-34} \text{ J}\cdot\text{s}}{4 \cdot 1.66 \cdot 10^{-27} \text{ kg} \cdot 2.409 \cdot 10^6 \text{ m/s}}$$

$$c = \lambda \nu$$

$$\lambda = \frac{c}{\nu}$$

$$p = \frac{h \nu}{c}$$

$$\lambda = \frac{9.9849 \cdot 10^{-8} \text{ m}}{2.409 \cdot 10^6 \text{ m/s}}$$

$$\lambda = \frac{9.9849 \cdot 10^{-8} \text{ m}}{2.409 \cdot 10^6 \text{ m/s}}$$

$$\lambda = 4.1448 \cdot 10^{-14} \text{ m}$$

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- (c) The excited neon electron then falls from E_2' to E_1' and emits a photon of laser light. Calculate the wavelength of this light.

$$\Delta E = 20.66 \text{ eV} - 18.7 \text{ eV}$$

$$\Delta E = 1.96 \text{ eV}$$

$$\Delta E = h \cdot f$$

$$\frac{\Delta E}{h} = f = \frac{1.96 \text{ eV}}{4.14 \cdot 10^{-15} \frac{\text{eV}}{\text{s}}}$$

$$f = 4.7329 \cdot 10^{14} \text{ Hz}$$

- (d) This laser light is now used to repair a detached retina in a patient's eye. The laser puts out pulses of length 20×10^{-3} s that average 0.50 W output per pulse. How many photons does each pulse contain?

$$E_{\text{pulse}} = 0.50 \text{ W} \cdot 20 \cdot 10^{-3} \text{ s}$$

$$E_{\text{pulse}} = 0.01 \text{ J} \quad \left(1.6 \cdot 10^{-19} \text{ eV} \right)$$

$$E_{\text{pulse}} = 1.6 \cdot 10^{17} \text{ eV}$$

$$n = \text{number of photons} \quad n = \frac{E_{\text{pulse}}}{\Delta E}$$

$$n = \frac{1.6 \cdot 10^{17} \text{ eV}}{1.96 \text{ eV}}$$

$$n = 8.163 \cdot 10^{16} \text{ photons}$$