AP® Physics B
2003 Sample Student Responses

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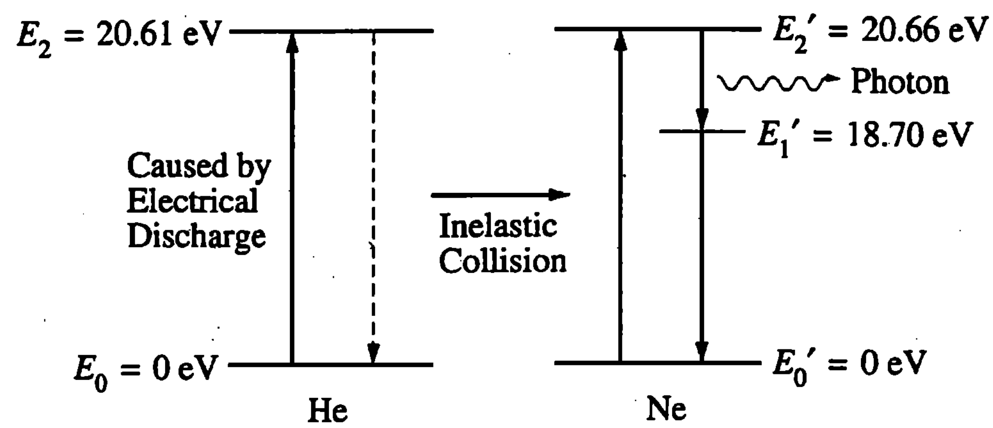
AF1



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'.

$v_f = ?$

$m_1 = 4(1.66\times10^{-27}\,kg)$

$m_1 = 6.64\times10^{-27}\,kg$

$m_2 = 20(1.66\times10^{-27}\,kg)$

$m_2 = 3.32\times10^{-26}\,kg$

$m_1v_1 + m_2v_2)_0 = (m_1+m_2)v_f$

$(6.64\times10^{-27}\,kg)(5\,m/s) + (3.32\times10^{-26}\,kg)(5\,m/s) = (6.64\times10^{-27}\,kg + 3.32\times10^{-26}\,kg) = v_f$

$1.99\times10^{-25}\,kg\cdot m/s = (3.98\times10^{-26}\,kg)\,v_f$

$v_f = 5\,m/s$

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

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

$= \frac{h}{mv}$

$\lambda = \frac{(6.63\times10^{-34}\,J\cdot s)}{4(1.66\times10^{-27}\,kg)(5\,m/s)}$

$\lambda = 1.997\times10^{-8}\,m$

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AF2

(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.

$E_o - E_f = hf$

$E_2' - E_1' = hf$

$20.66eV - 18.70eV = hf$

$1.96eV = hf$

$1.96eV \times \frac{1.60\times10^{-19} J}{1eV} = \frac{3.14\times10^{-19} J}{6.63\times10^{-34} J} = f$

$f = 4.74\times10^{14} Hz$

$v = f\lambda$

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

$= \frac{3\times10^8 m/s}{4.74\times10^{14} Hz}$

$\lambda = 6.33\times10^{-7} m$

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

$P = .05 W$

$t = 20\times10^{-3} s$

$E_o = 3.14\times10^{-19} J$

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

$Pt = E$

$(.50W)(20\times10^{-3}s) = E$

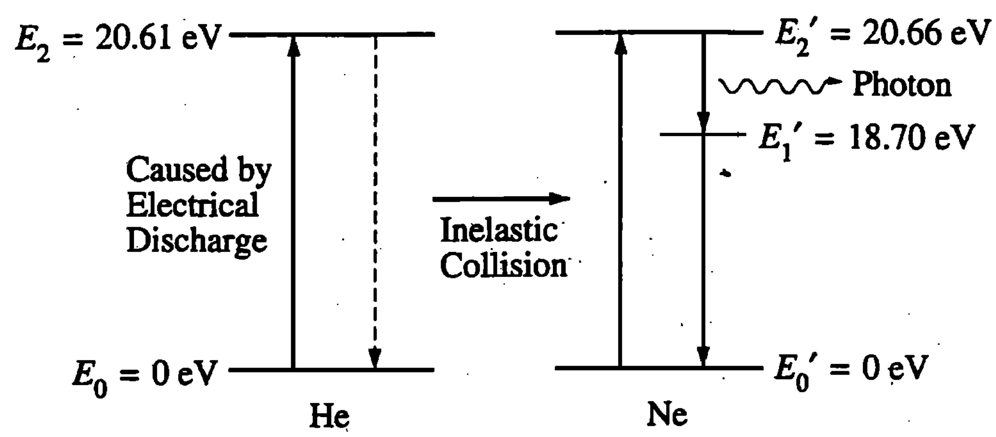
$E = .01 J$

$\frac{E}{E_o}$ = # of photons

$\frac{(.01J)}{(3.14\times10^{-19}J)} =$

3.18×10^{16} photons

AH1



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

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

$v = \sqrt{\dfrac{2 \cdot 8 \cdot 10^{-21}\,J}{4u \cdot 1.66 \cdot 10^{-27}\,kg/u}}$

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

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

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

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

$\lambda = \dfrac{h}{mv} = \dfrac{6.63 \cdot 10^{-34}\,J/s}{4u \cdot 1.66 \cdot 10^{-27}\,kg/u \cdot v}$

$c = f\lambda$

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

$p = \frac{hf}{c}$

$\lambda = \dfrac{9.9849 \cdot 10^{-8}}{v}$

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

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

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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.

$\Delta E = 20.66\,eV - 18.7\,eV$

$\Delta E = 1.96\,eV$

$\Delta E = h \cdot f$

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

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

(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?

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

$E_{pulse} = 0.01\,J \,/\, (1.6 \cdot 10^{-19})\,J/eV$

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

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

$n = \frac{1.6 \cdot 10^{17}\,eV}{~~18~~\;1.96\,eV}$

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