ATOMIC

6. An atom has filled n=1 and n=2 levels. How many electrons does the atom have?

\# electrons / energy level: $2n^2$

$n=1 \longrightarrow 2(1)^2 = 2$
$n=2 \longrightarrow 2(2)^2 = 8$ $\Rightarrow$ **E. 10**

8. The energy from EM waves in equilibrium in a cavity is used to melt ice if the kelvin temperature of the cavity is increased by a factor of two, the mass of ice that can be melted in a fixed amount of time is increased by a factor of

energy $\propto T^4$

$T \rightarrow 2T \Rightarrow E \propto (2T)^4 = 16T \Rightarrow$ **D. 16**

12. In the Bohr model of the hydrogen atom the linear momentum of the electron at radius r_n is given by which of the following?

$[\text{momentum}] = [p] = [m \cdot v] = \text{mass} \times \frac{\text{distance}}{\text{time}} = kg \cdot m/s$

~~a.~~ $n\hbar$
~~b.~~ $nr_n\hbar$
c. $n\hbar/r_n$
~~d.~~ $n^2 r_n \hbar$
e. $n^2\hbar/r_n$

$[a] = [\hbar] = J \cdot s = kg\, m^2/s^2\, s = kg m^2/s$

need $\frac{\hbar}{r_n}$ in answer!

$\Rightarrow$ C or E

linear $\Rightarrow$ **C. $n\hbar/r_n$**

OR $2\pi r = n\lambda = n\, h/p$
$p = n\frac{h}{2\pi r} = n\frac{\hbar}{r}$ (standing wave condition)

19. The surface of the sun has a temperature close to 6000 K and it emits a blackbody (planck) spectrum that reaches a maximum near 500 nm. For a body with a surface temperature close to 300K, at what wavelength would the thermal spectrum reach a maximum?

$T \propto \frac{1}{\lambda} \rightarrow T\lambda = \text{constant}$

$T_1\lambda_1 = T_2\lambda_2$

$\lambda_2 = \frac{T_1\lambda_1}{T_2} = \frac{(6000K)(500nm)}{(300K)} = 20 \times 500nm$
$= 10^4 \times 10^{-9}$ m
$= 10^{-5}$ m
$= 10 \times 10^{-6}$ m $\Rightarrow$ **A 10 μm**

27. The lifetime for the 2p → 1s transition in hydrogen is 1.6×10^{-9} s. The natural line width for the radiation emitted during the transition is approximately.

[line width] = $\frac{1}{s}$

$$\Gamma \propto \frac{1}{\tau} = \frac{1}{1.6 \times 10^{-9}} = 6.25 \times 10^{8} \text{ Hz}$$
$$= 625 \times 10^{6} \text{ Hz}$$
$$= 625 \text{ MHz}$$

⇒ C. 100 MHz

(exact eqn: $\Gamma = \frac{\hbar}{\tau}$)

50 Which of the following expressions is proportional to the total energy for the levels of a one-electron Bohr atom?

a. $\frac{mze^2}{n}$

b. $\frac{mze^2}{n^2}$

c. $\frac{mz^2e^4}{n^2}$

d. $\frac{m^2z^2e^2}{n^2}$

e $\frac{m^2z^2e^4}{n^2}$

$$E = T + U = \frac{1}{2}mv^2 - \frac{z\,ke^2}{r}$$

* $e^2 \rightarrow ze^2$ *

balancing forces

$$\frac{z \cdot ke^2}{r^2} = \frac{mv^2}{r} \rightarrow mv^2 = \frac{z\,ke^2}{r}$$

⇒ C. $\frac{mz^2e^4}{n^2}$

$$E = \frac{1}{2}\frac{z\,ke^2}{r} - \frac{z \cdot ke^2}{r} = -\frac{1}{2}\frac{z \cdot ke^2}{r}$$

$$r_n = \frac{4\pi\varepsilon_0 \hbar^2}{m_e z e^2} n^2 = \frac{\hbar^2 n^2}{k m_e z e^2}$$

51. True statements about the absorption + emission of energy by an atom include which of the following?

I: An atom can only absorb photons of light that have certain specific energies

II: An atom can emit photons of light of any energy

III: At low T, the lines in the absorption spectrum of an atom coincide with the lines in its emission spectrum that represent transitions to the ground state

⇒ D. I + III only

66 A muon can be considered to be a heavy electron with a mass $m_\mu = 207\, m_e$. Imagine replacing the electron in a hydrogen atom with a muon what are the energy levels E_n?

$$E_e \propto \mu_e \rightarrow E_\mu \propto \mu_\mu = E_e \times \frac{\mu_\mu}{\mu_e}$$

$$= \frac{\frac{m_\mu m_p}{m_\mu + m_p}}{\frac{m_e m_p}{m_e + m_p}} = \frac{m_\mu m_p (m_e + m_p)}{m_e m_p (m_\mu + m_p)}$$

⇒ D. $E_n = \frac{-E_0}{n^2}\left[\frac{m_\mu (m_p + m_e)}{m_e (m_p + m_\mu)}\right]$

22. An electron has total energy equal to four times its rest energy. The momentum of the electron is

$E_{tot} = \sqrt{(pc)^2 + (mc^2)^2}$

$4m_ec^2 = \sqrt{(pc)^2 + (m_ec^2)^2}$ ⟶ $(pc)^2 = 15(m_ec^2)^2$ ⟹ **C. $\sqrt{15}\, m_e c$**

$16(m_ec^2)^2 = (pc)^2 + (m_ec^2)^2$

$p = \sqrt{\frac{15(m_ec^2)^2}{c^2}}$

23. Two spaceships approach Earth with equal speeds, as measured by an observer on Earth, but from opposite directions. A meterstick on one spaceship is measured to be 60cm long by an occupant of the other spaceship. What is the speed of each spaceship, as measured by the observer on Earth?

length contraction: $d' = \frac{d}{\gamma}$ ⟶ $0.6\,m = \frac{1m}{\gamma}$ ⟶ $\gamma = \frac{1}{0.6} = \frac{5}{3}$

$\gamma = \frac{1}{\sqrt{1-\beta^2}}$ ⟶ $\gamma^2 = \frac{1}{1-\beta^2}$ ⟶ $\beta^2 = 1 - \frac{1}{\gamma^2} = 1 - \frac{9}{25} = \frac{16}{25}$ ⟶ $\beta = \frac{4}{5} = \frac{v}{c}$

⟶ $v = 0.8c$ relative to the other spaceship.

velocity addition formula to get v_{ship} relative to Earth.

$u'_x = \frac{u_x - v}{1 - \frac{vu_x}{c^2}}$ $u'_x = 0.8c$, $u_x = -v$ ⟶ $-0.8c = \frac{-2v}{1+v^2/c^2}$ ⟶ $-0.8 = \frac{-2\beta}{1+\beta^2}$ ⟹ **B. 0.5c**

$u'_x = u_L$ in R frame

$u_x = u_L$ in E frame ⟶ $0.8\beta^2 - 2\beta + 0.8$ ⟶ $\beta = 2$ OR $\beta = 0.5$

$v = u_R$ in E frame

24. A meterstick with a speed of 0.8c moves past an observer. In the observer's reference frame, how long does it take the stick to pass the observer?

$t = \frac{\text{distance}}{\text{velocity}}$ ⟶ $v = 0.8c$ ⟹ $\gamma = 5/3$ $d' = d/\gamma = \frac{1m}{5/3} = 0.6\,m$ ⟹ **B. 2.5 ns**

$t = \frac{0.6\,m}{0.8c} = \frac{0.6\,m}{0.8(3\times10^8\,m/s)} = 2.5\times10^{-9}\,s$

39. A beam of muons travels through the laboratory with speed $v = 4/5\,c$. The lifetime of a muon in its rest frame is $\tau = 2.2\times10^{-6}\,s$. The mean distance traveled by the muons in the laboratory frame is

distance = vel × time ⟶ $v = 0.8c$ ⟹ $\gamma = 5/3$ $t' = t\times\gamma = 2.2\times10^{-6}\,s \times \frac{5}{3} = 3.667\times10^{-6}\,s$

$d = (0.8c)(3.667\times10^{-6}\,s) = 0.8\cdot3\cdot10^8\,m/s\cdot3.667\cdot10^{-6}\,s$ ⟹ **C. 880m**

$= 8.8\times10^2\,m$

40. A particle of mass M decays from rest into two particles one particle has mass m and the other particle is massless the momentum of the massless particle is

cons. of E: $Mc^2 = \sqrt{(mc^2)^2 + (p_m c)^2} + p_\gamma c$

cons. of mom: $0 = p_m + p_\gamma$

$\longrightarrow Mc^2 = \sqrt{(mc^2)^2 + (-pc)^2} + pc$ $\Rightarrow$ **B.** $\frac{(M^2 - m^2)c}{2M}$

$(Mc^2 - pc)^2 = (mc^2)^2 + (pc)^2$

$M^2c^4 - 2Mpc^3 + p^2c^2 = m^2c^4 + p^2c^2$

$p = \frac{(M^2 - m^2)c}{2M}$

55. A distant galaxy is observed to have its H-β line shifted to a wavelength of 580 nm, away from the laboratory value of 434 nm. Which of the following gives the approximate velocity of recession of the distant galaxy?

$\lambda_{obs} = \lambda_{em} \times \frac{\sqrt{1+\beta}}{\sqrt{1-\beta}} \Rightarrow \left(\frac{\lambda_{obs}}{\lambda_{em}}\right)^2 = \frac{1+\beta}{1-\beta} = \left(\frac{580}{434}\right)^2 \sim \frac{16}{9}$

$1 + \beta = 16/9 - 16/9\,\beta \longrightarrow (1 + \frac{16}{9})\beta = \frac{16}{9} - 1 \longrightarrow \beta = \frac{7/9}{25/9}$ $\Rightarrow$ **A.** 0.28c

94. An observer O at rest midway between two sources of light at x = 0 and at x = 10 m observes the two sources flash simultaneously. According to a second observer O', moving at a constant speed parallel to the x-axis, one source of light flashes 13 ns before the other. Which of the following gives the speed of O' relative to O?

O: $x_1 = 0$ $y_1 = 0$ $z_1 = 0$ $t_1 = 0$
$x_2 = 10$ $y_2 = 0$ $z_2 = 0$ $t_2 = 0$

Lorentz transforms: $t' = \gamma(t - \frac{vx}{c^2})$
$x' = \gamma(x - vt)$

O': $x'_1 = 0$ $y'_1 = 0$ $z'_1 = 0$ $t'_1 = 0$
$x'_2 = \gamma 10$ $y'_2 = 0$ $z'_2 = 0$ $t'_2 = \gamma(-\frac{v10}{c^2}) = \gamma(-\beta\frac{10}{c})$

$\Delta t' = t'_2 - t'_1 = 13\,ns = \gamma(-\beta\frac{10}{c}) = \frac{-\beta \cdot \frac{10}{c}}{\sqrt{1-\beta^2}} \longrightarrow 13\,ns \cdot \frac{c}{10} = \frac{-\beta}{\sqrt{1-\beta^2}}$ $\Rightarrow$ **C.** 0.36c

$\frac{\beta^2}{1-\beta^2} = \left(\frac{13 \cdot 10^{-9} \cdot 3 \cdot 10^8}{10}\right)^2 = (0.39)^2$

$\hookrightarrow \beta^2 = (0.39)^2(1-\beta^2) \rightarrow \beta = \frac{0.39}{\sqrt{1+(0.39)^2}} = 0.36$

97. In the Compton effect, a photon with energy E scatters through a 90 angle from a stationary of mass m. The energy of the scattered photon is

$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$, $E = hc/\lambda$

$\rightarrow \frac{hc}{E'} - \frac{hc}{E} = \frac{h}{m_e c}(1-\cos\theta) \rightarrow \frac{hc}{E'} = \frac{h(1-\cos\theta)}{m_e c} - \frac{hc}{E}$ $\Rightarrow$ **E.** $\frac{E \cdot mc^2}{E + mc^2}$

$E' = hc\left(\frac{m_e c \cdot E}{h(1-\cos\theta)E + hc^2 m_e}\right)$ $\theta = 90 \Rightarrow E' = \frac{m_e c^2 \cdot E}{E + m_e c^2}$

LAB METHODS

13. The figure represents a log-log plot of variable y vs. variable x. The origin represents x=1 and y=1. Which of the following gives the approximate functional relationship between y and x?

large x ⇒ smaller y. pick points (3, 10) + (300, 100)

rules out C, D, E.

⇒ A. $y = 6\sqrt{x}$

14. Two experimental techniques determine the mass of an object to be 11±1 kg and 10±2 kg. These two measurements can be combined to give a weighted average. The uncertainty of the weighted average is equal to which of the following?

weighted avg: $w_i = \frac{1}{(\Delta x_i)^2}$, $f = \frac{w_1 x_1 + w_2 x_2}{w_1 + w_2} = \frac{1a + \frac{1}{4}b}{1 + 1/4} = \frac{4a + b}{5}$ ⇒ B. $\frac{2}{\sqrt{5}}$

Propagation of error: $\delta f = \sqrt{\left(\frac{\partial f}{\partial a}\delta a\right)^2 + \left(\frac{\partial f}{\partial b}\delta b\right)^2} = \sqrt{\left(\frac{4}{5}\cdot 1\right)^2 + \left(\frac{1}{5}\cdot 2\right)^2} = \sqrt{\frac{16+4}{25}} = \sqrt{\frac{4}{5}}$

41. In an experimental observation of the photoelectric effect, the stopping potential was plotted vs. the light frequency, as shown in the figure. The best straight line was fitted to the points. Which of the following gives the slope of the line?

photoelectric effect: $K_{max} = hf - \varphi$, $K_{max} = q_e V_0 = e \cdot V$

$\rightarrow e \cdot V = hf - \varphi \Rightarrow V = \frac{h}{e} f - \frac{\varphi}{e}$ ⇒ B. $\frac{h}{e}$

42. Two sinusoidal waveforms of the same frequency are displayed on an oscilloscope screen, as indicated in the figure. The horizontal sweep of the oscilloscope is set to 100 ns/cm and the vertical gains of channels 1 and 2 are each set to 2 V/cm. The zero voltage level of each channel is given at the right. The phase difference between the two waveforms is most nearly

6 cm ~ 2π ⇒ 1 cm ~ 2π/6 ⇒ 2 cm = 2π/6 × 2 = 2π/3 ⇒ E. 120°

49. Which of the following lasers utilizes transitions that involve the energy levels of free atoms?

⇒ D. gas laser