Physics 2020: Sample Problems for Exam 3

1. A 2.52 kg mass is connected to a spring of spring constant 462 N/m, which is connected to a wall. The mass is released from rest at 12.2 cm from the equilibrium position. (a) What is the total energy of this system if it oscillates horizontally on a frictionless plane? (b) What is the maximum speed of this mass as it oscillates? (c) What is the period of the oscillation?

\[ E = KE + PE = \frac{1}{2} m v^2 + \frac{1}{2} k x^2 \]

At maximum extension,

\[ v = 0, \quad x = x_0 = A = 12.2 \text{ cm} = 0.122 \text{ m} \]

\[ E = \frac{1}{2} m v_0^2 + \frac{1}{2} k A^2 = \frac{1}{2} (462 \text{ N/m}) (0.122 \text{ m})^2 \]

\[ = \boxed{3.44 \text{ J}} \]

(b) \( v_{\text{max}} \) occurs when \( x = 0 \):

\[ E = \frac{1}{2} m v_{\text{max}}^2 \]

\[ v_{\text{max}} = \sqrt{\frac{2E}{m}} \]

\[ v_{\text{max}} = \sqrt{\frac{2(3.44 \text{ J})}{2.52 \text{ kg}}} = \boxed{1.65 \text{ m/s}} \]

(c) \( T = 2\pi \sqrt{\frac{m}{k}} = 2\pi \sqrt{\frac{2.52 \text{ kg}}{462 \text{ N/m}}} \)

\[ = \boxed{0.464 \text{ s}} \]
2. An amplifier in a stereo drives one of the speakers at 132 W. How far are we standing from the speaker if we hear it at 92.0 dB? (Hint: Remember that the threshold of hearing is at $1.00 \times 10^{-12} \text{ W/m}^2$.)

\[
\begin{align*}
\beta &= 132 \text{ W}, \quad \beta = 92.0 \text{ dB} \\
\beta &= 10 \log \left( \frac{I}{I_0} \right), \quad \log \left( \frac{I}{I_0} \right) = \frac{\beta}{10} \\
\frac{I}{I_0} &= 10^{\beta/10}, \quad I = I_0 \cdot 10^{\beta/10} \\
I &= \left( 1.00 \times 10^{-12} \text{ W/m}^2 \right) 10^{92.0/10} \\
&= 1.58 \times 10^{-3} \text{ W/m}^2 \\
I &= \frac{P}{4\pi r^2}, \quad r^2 = \frac{6}{4\pi I} \\
\gamma &= \sqrt{\frac{6}{4\pi I}} = \sqrt{\frac{132 \text{ W}}{4\pi \left( 1.58 \times 10^{-3} \text{ W/m}^2 \right)}} \\
&= \sqrt{81.4 \text{ m}}
\end{align*}
\]
3. A star emits its maximum brightness at 292 nm and is 122 times the brightness of the Sun. 
(a) How hot is this star? (b) How big is this star in solar diameters? (c) What is the energy flux of this star?

\[ \lambda_{\text{MAX}} = 292 \text{ nm}, \quad L = 122 \cdot L_\odot \]

(a) \[ \lambda_{\text{MAX}} = \frac{2.897 \times 10^6 \text{ mm K}}{T} \]

\[ T = \frac{2.897 \times 10^6 \text{ mm K}}{\lambda_{\text{MAX}}} = \frac{2.897 \times 10^6 \text{ mm K}}{292 \text{ mm}} \]

\[ = 9920 \text{ K} \]

(b) \[ \frac{L}{L_\odot} = \left( \frac{R}{R_\odot} \right)^2 \left( \frac{T}{T_\odot} \right)^4 \]

\[ \left( \frac{R}{R_\odot} \right)^2 = \left( \frac{L}{L_\odot} \right) \left( \frac{T_\odot}{T} \right)^4 \]

\[ \frac{R}{R_\odot} = \sqrt{\frac{L}{L_\odot}} \left( \frac{T_\odot}{T} \right)^2 = \sqrt{\frac{122 L_\odot}{L_\odot}} \left( \frac{5800 \text{ K}}{9920 \text{ K}} \right)^2 \]

\[ = 3.77 \]

\[ R = 3.77 R_\odot \]

\[ R = \frac{1}{2} D \]

\[ \frac{1}{2} D = 3.77 \left( \frac{1}{2} D_\odot \right) \]

\[ D = 7.54 D_\odot \]

(c) \[ F = \sigma T^4 = \left( 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4} \right) \left( 9920 \text{ K} \right)^4 \]

\[ = 5.49 \times 10^8 \text{ W/m}^2 \]
4. Calculate (a) the size of the first excited state of H, (b) the orbital speed of the electron in this state (start from first principles), and (c) the total energy of this electron (KE + PE) in eV.

(a) \[ r_n = n^2 \left( 0.0529 \text{ nm} \right) \]

\[ r_2 = 2^2 \left( 0.0529 \text{ nm} \right) \]

\[ r_2 = 0.2116 \text{ nm} = 0.212 \text{ mm} \]

(b) \[ F_c = \frac{F_e}{e} \]

\[ \frac{m_e r_m^2}{\sqrt{r_m}} = \frac{q_e e^2}{\sqrt{r_m}} \]

\[ N_m = \frac{q_e e^2}{m_e (r_m)} \]

\[ N_2 = 2 \sqrt{\frac{8.89 \times 10^{-9} \text{ Nm}^2/\text{C}^2 \left( 1.602 \times 10^{-19} \text{ C} \right)^2}{9.11 \times 10^{-31} \text{ kg} \left( 0.2116 \times 10^{-9} \text{ m} \right)}} \]

\[ N_2 = 1.09 \times 10^6 \text{ m/s} \]

(c) \[ E = KE + PE = \frac{1}{2} m_e v_m^2 + \frac{q_e (-e)(e)}{\sqrt{r_m}} \]

\[ E = \frac{1}{2} \left( 9.11 \times 10^{-31} \text{ kg} \left( 1.09 \times 10^6 \text{ m/s} \right)^2 \right) \]

\[ - \left( 8.99 \times 10^9 \text{ Nm}^2/\text{C}^2 \right) \left( 1.602 \times 10^{-19} \text{ C} \right)^2 \]

\[ 0.2116 \times 10^{-9} \text{ m} \]
\[ E = 5.45 \times 10^{-19} \text{ J} - 1.09 \times 10^{-18} \text{ J} \]

\[ = -5.45 \times 10^{-19} \text{ J} \times \frac{1 \text{ eV}}{1.602 \times 10^{-19} \text{ J}} \]

\[ = -3.40 \text{ eV} \]