Physics 23

Midterm 1 Solutions

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(1)

a) [4 Points] The speed of waves on a string is

$$v = \left(\frac{T}{\mu}\right)^{1/2} = \left(\frac{10N}{0.1kg/4m}\right)^{1/2} = 20\ m/s. \tag{1}$$

b) [3 Points] The longest wavelength standing wave has n=1. Since the frequency is $f = nv/(2L)$, the desired wavelength is

$$\lambda = \left(\frac{2L}{n}\right) = \left(\frac{2L}{1}\right) = 8\ m. \tag{2}$$

c) [3 Points] Using $v = f\lambda$, we find $f = 5/2\ Hz$.

(2)

The frequency of the trumpet on the train is Doppler shifted upwards since the train is approaching the other trumpet. The observer (trumpet on the ground) hears the beat frequency

$$f_b = \mid f_d - f \mid, \ [3\ Points] \tag{3}$$

where $f_b = 10\ Hz$ is the beat frequency, $f = 330\ Hz$ is the original frequency and f_d is the Doppler shifted frequency from the train. When the source moves towards a stationary observer, the Doppler shifted frequency is

$$f_d = f\frac{c_s}{c_s - v_s}, \ [3\ Points] \tag{4}$$

where $c_s \approx 340\ m/s$ is the speed of sound in air and v_s is the speed of the observer to be found. Substituting Eqn.(4) into Eqn.(3) and then solving for v_s (the absolute value sign does not really matter here), we obtain

$$v_s = c_s - \frac{fc_s}{f_b + f} = 10\ m/s.\ [4\ Points] \tag{5}$$

(3)

Let Beryllium-proton and Beryllium-electron distance be r_1 and r_2, respectively. We use the position of Beryllium as the origin of our coordinate system with the three particles all lie along the x-axis. In particular, for the sake of convenience we place the electron to the right of the Beryllium. Since the Beryllium nucleus has charge +4e while the electron only has charge -e, the proton needs to be further away from the Be but closer to the electron in order for the forces to balance. We then position the proton to the RIGHT of the electron, opposite from the Be nucleus. [2 points] The electro-static forces on the proton are

$$F_{p,Be} = \frac{Q_{Be}Q_p}{4\pi\epsilon_0 r_1^2} = \frac{4e^2}{4\pi\epsilon_0 r_1^2}\ [2 Points] \tag{6}$$

and

$$F_{p,e} = \frac{Q_e Q_p}{4\pi\epsilon_0 r_2^2} = \frac{-e^2}{4\pi\epsilon_0 r_2^2}\ [2\ Points]. \tag{7}$$

Note that the forces are in opposite directions and must be equal in magnitudes. We therefore have

$$\mid F_{p,Be} \mid = \mid F_{p,e} \mid .\ [2 Points] \tag{8}$$

We also know that

$$r_2 - r_1 = 10^{-9}\ m. \tag{9}$$

We now substitute Eqn.(6) and (7) into Eqn.(8), then use Eqn.(9) to eliminate either r_1 or r_2 and solve for the remaining distance variable. The result is $r_1 = 2 \times 10^{-9}\ m$ or $r_2 = 10^-9\ m$. [2 Points]