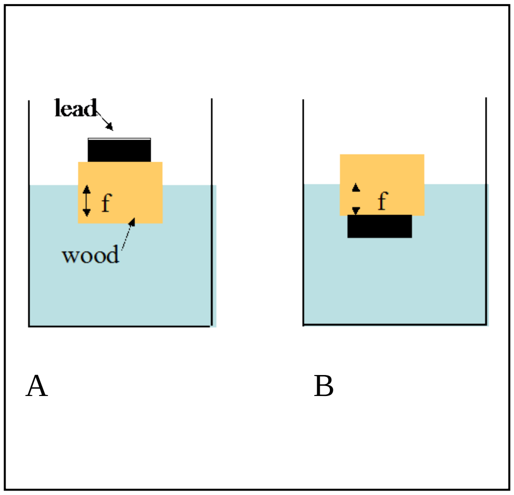
Basic Physics – Fall 2016 Solutions

1. (7 pts) A block of wood of mass M_w and mass density ρ_w is to be loaded with a block of lead, mass density ρ_{Pb}, as shown in Fig. A, such that the wood block is 90% submerged (*f*=.9) in water $\rho_{H2O} > \rho_W$.



(A) What is the mass of lead that can be loaded on top of the wood block to achieve a 90 % fraction of wood submerged? Give your answer in terms of the density and mass variables described above. (2 pts)

(B) Now consider the case in which the lead is attached to the bottom of the wood block as shown in Fig B. What mass of lead can be attached to achieve the 90% submerged figure. (3 pts)

(C) Suppose sufficient lead is added that the block begins to sink. Describe in words the rate of fall and indicate the physical processes at work. (2 pts)

Solution:

A) Volume of wood $V_w = M_w / \rho_w$. Mass of water displaced $= 0.9 V_w \rho_{H2O}$

$$M_W + M_{Pb} = 0.9 V_w \rho_{H2O} = 0.9 M_w \rho_{H2O} / \rho_w$$

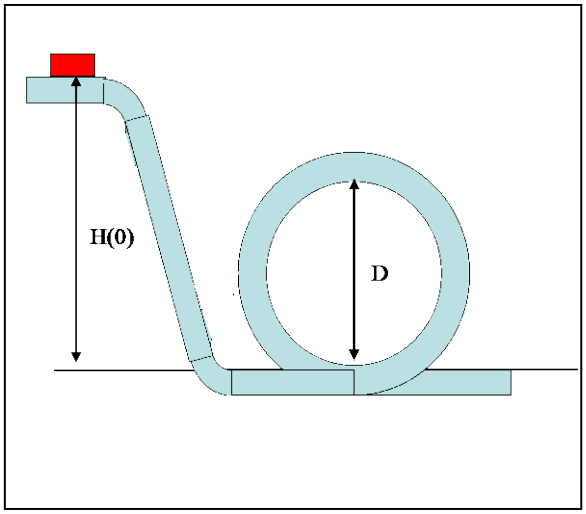
B) Volume of H_2O displaced $= (V_{Pb} + 0.9 V_W) = (\frac{M_{Pb}}{\rho_{Pb}} + 0.9 \frac{M_w}{\rho_w})$

Mass of H_2O displaced $\rho_{H_2O}(\frac{M_{Pb}}{\rho_{Pb}} + 0.9 \frac{M_w}{\rho_w}) = M_w + M_{Pb}$

Solution $M_{Pb} = M_w(0.9 \frac{\rho_{H2O}}{\rho_w} - 1) / (1 - \frac{\rho_{H2O}}{\rho_{Pb}})$

C) Initally the wood and lead will accelerate downward due to the negative buoyancy. However, that happens for only some time. Then drag due to the transfer of energy to the flow of water causes the downward velocity to stop increasing and it reaches the so-called terminal value.

2. (7 pts) A block slides without friction on a track with a loop of diameter D as shown in the figure. The initial height above the ground of the center of mass is *H(0)*, the initial speed is zero, and the acceleration due to gravity is *g*.



(A) What is the speed of the block as a function of its center of mass height above ground *H(t)*? (2 pts). You may treat the mass as a point particle.

(B) How high must be the initial height H(0) to ensure that the block remains in contact with the track on the loop? (3 pts)

(C) Now suppose the block instead of sliding, has wheels that roll without slipping. Describe qualitatively how your answers to A and B change. (2 pts)

Solution:

$$\frac{1}{2}Mv^2 + MgH(t) = MgH(0)$$

A) Total energy is constant

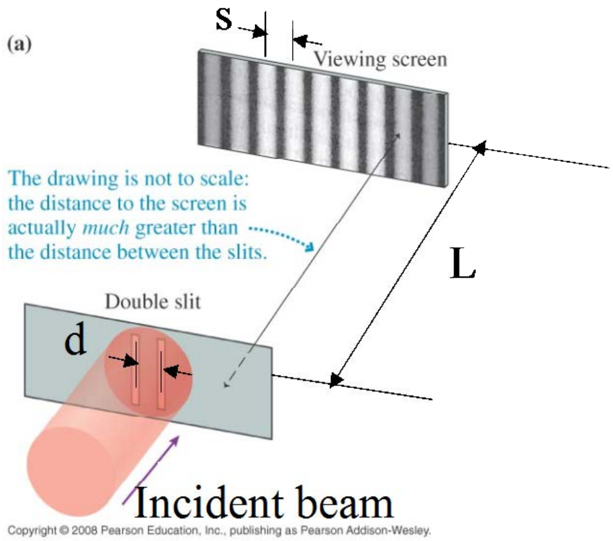
$$v = \sqrt{2g(H(0) - H(t))}$$

B) Require centripetal acceleration > g

$$\frac{v^2}{D/2} = \frac{2g(H(0)-D)}{D/2} > g \qquad \text{Or equivalently} \quad \frac{4(H(0)-D)}{D} > 1$$

C) If the cart has wheels there will be energy stored in their rotational motion. This will reduce the velocity of the cart at each height. Consequently the initial height will have to be greater than what is calculated in part B too keep the cart in contact with the track.

3. (6 pts) A dual slit interference experiment is conducted with a spatially coherent beam as shown at left. The slit spacing is *d*, the spacing of the bright fringes is *s* and the distance to the screen from the slits is *L*>>*s*.



A. Show that the wavelength of the incident beam can be determined from the spacing *s* according to the formula $\lambda \approx ds / L$. (2 pts)

B. If the incident beam is a light beam, what are the wavelength, frequency and energy of its photons in terms *L*, *s*, and *d*? (2 pts)

C. If the incident beam is an electron beam, with electron mass m_e, what are the speed and energy of the electrons in terms of the same variables and the electron mass? (2 pts)

Solution:

A) Difference in distance to nth bright spot from left and right slit

$$r_+ - r_- = n\lambda$$

$$r_\pm = \left[L^2 + \left(h_n \pm \frac{d}{2}\right)^2\right]^{1/2} \approx L\left[1 + \frac{1}{2L^2}\left(h_n^2 \pm dh_n + \frac{d^4}{4}\right)\right]$$

$$r_+ - r_- \approx \frac{dh_n}{L} = n\lambda$$

$$h_{n+1} - h_n = s = \lambda L / d$$

B) Photons: $f = c/\lambda, \quad E = hf = hc/\lambda$

C) Electrons: $p = h/\lambda \quad v = p/m \quad E = \frac{1}{2}mv^2$