PHYS 1211 *University Physics I* — Problem Set 5

Winter Quarter, 2007 — SOLUTIONS

Instructor

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Penny-Pedestrian Redux

In an earlier Quiz, we calculated the velocity of a penny dropped from the 1250 foot tall Empire State Building when it hits the sidewalk below. Now we consider the more realistic case by considering air resistance, or drag, on the penny. Assume you have a 2.50 gram penny, that tumbles as it falls. Assume a Coefficient of Drag, $C = 0.75$ (20 points total).

1. Estimate the effective cross-sectional area of the tumbling penny using a simple average of minimum and maximum cross-sections.

   ANSWER: The minimum cross-sectional area of the penny is "edge-on" and is simply $A_{min} = d_{\text{penny}} \cdot t_{\text{penny}}$, where D_{penny} is the diameter and t_{penny} is the thickness. The maximum cross-section is the circular cross-section when the penny is horizontal to the ground, $A_{max} = \pi(d_{\text{penny}})^2$ The average of these is $A_{eff} = (A_{min} + A_{max})/2$. Many methods to measure or estimate the diameter and thickness of a penny are acceptable. My methods gave $A_{min} = 3.14 \times 10^{-5}\ \text{m}^2$, and $A_{max} = 2.85 \times 10^{-4}\ \text{m}^2$, so that $A_{eff} = 1.58 \times 10^{-4}\ \text{m}^2$.

2. What is the terminal velocity of the penny?

   ANSWER:

$$v_t = \sqrt{\frac{2mg}{C\rho A_{eff}}} = \sqrt{\frac{2(2.5 \times 10^{-3}\ \text{kg})9.8\ \text{m/s}^2}{0.75(1.2\ \text{kg/m}^3 2.85 \times 10^{-4}\ \text{m}^2}} = 18.5\ \text{m/s}$$

3. How far does the penny fall before reaching terminal velocity? Here we want to see how far a truly free-falling penny would fall before reaching 18.5 m/s. Kinematics tells us:

$$v^2 = 2gh \rightarrow h = \frac{v^2}{2g} = \frac{(18.5\ \text{m/s})^2}{2 \cdot 9.8\ \text{m/s}^2} = 17.4\ \text{m}$$

4. Are you afraid of the penny-wielding tourists atop the ESB? No, because getting hit by a penny falling from a great height is essentially no different than being hit by one dropped from ~ 20 meters. It would probably hurt a bit, but not do any serious damage...

Halliday, Resnick, and Walker (HRW)

See following pages...

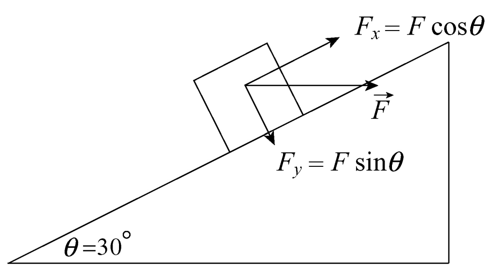
Chapter 5

21. (a) The slope of each graph gives the corresponding component of acceleration. Thus, we find a_x = 3.00 m/s^2 and a_y = –5.00 m/s^2. The magnitude of the acceleration vector is therefore $a = \sqrt{(3.00\ \text{m/s}^2)^2 + (-5.00\ \text{m/s}^2)^2} = 5.83\ \text{m/s}^2$, and the force is obtained from this by multiplying with the mass (m= 2.00 kg). The result is $F = ma$ =11.7 N.

(b) The direction of the force is the same as that of the acceleration:

$$\theta = \tan^{-1}[(-5.00\ \text{m/s}^2)/(3.00\ \text{m/s}^2)] = -59.0°.$$

32. We resolve this horizontal force into appropriate components.



(a) Newton's second law applied to the x-axis produces

$$F\cos\theta - mg\sin\theta = ma.$$

For a = 0, this yields F = 566 N.

(b) Applying Newton's second law to the y axis (where there is no acceleration), we have

$$F_N - F\sin\theta - mg\cos\theta = 0$$

which yields the normal force $F_N = 1.13 \times 10^3$ N.

51. We apply Newton's second law first to the three blocks as a single system and then to the individual blocks. The +x direction is to the right in Fig. 5-49.

(a) With $m_{sys} = m_1 + m_2 + m_3$ = 67.0 kg, we apply Eq. 5-2 to the x motion of the system – in which case, there is only one force $\vec{T}_3 = +\vec{T}_3\ \hat{\text{i}}$. Therefore,

$$T_3 = m_{sys}a \quad \Rightarrow \quad 65.0\ \text{N} = (67.0\ \text{kg})a$$

which yields $a = 0.970$ m/s^2 for the system (and for each of the blocks individually).

(b) Applying Eq. 5-2 to block 1, we find

$$T_1 = m_1 a = (12.0\,\text{kg})(0.970\,\text{m/s}^2) = 11.6\,\text{N}.$$

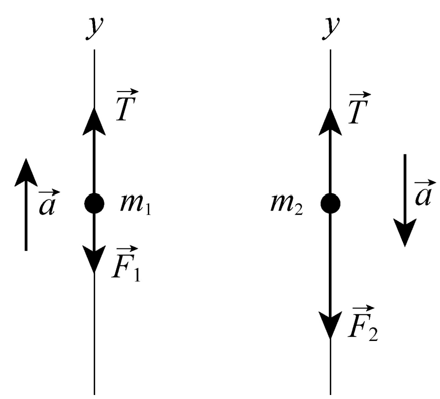
(c) In order to find T_2, we can either analyze the forces on block 3 or we can treat blocks 1 and 2 as a system and examine its forces. We choose the latter.

$$T_2 = (m_1 + m_2)a = (12.0\text{ kg} + 24.0\text{ kg})(0.970\text{ m/s}^2) = 34.9\text{ N}.$$

55. The free-body diagrams for m_1 and m_2 are shown in the figures below. The only forces on the blocks are the upward tension $\vec{T}$ and the downward gravitational forces $\vec{F}_1 = m_1 g$ and $\vec{F}_2 = m_2 g$. Applying Newton's second law, we obtain:

$$T - m_1 g = m_1 a$$

$$m_2 g - T = m_2 a$$



which can be solved to yield

$$a = \left(\frac{m_2 - m_1}{m_2 + m_1}\right) g$$

Substituting the result back, we have

$$T = \left(\frac{2m_1 m_2}{m_1 + m_2}\right) g$$

(a) With $m_1 = 1.3$ kg and $m_2 = 2.8$ kg, the acceleration becomes

$$a = \left(\frac{2.80\,\text{kg} - 1.30\,\text{kg}}{2.80\,\text{kg} + 1.30\,\text{kg}}\right)(9.80\,\text{m/s}^2) = 3.59\ \text{m/s}^2.$$

(b) Similarly, the tension in the cord is

$$T = \frac{2(1.30\,\text{kg})(2.80\,\text{kg})}{1.30\,\text{kg} + 2.80\,\text{kg}}(9.80\,\text{m/s}^2) = 17.4\ \text{N}.$$

73. Although the full specification of $\vec{F}_{\text{net}} = m\vec{a}$ in this situation involves both x and y axes, only the x-application is needed to find what this particular problem asks for. We note that $a_y = 0$ so that there is no ambiguity denoting a_x simply as a. We choose $+x$ to the right and $+y$ up. We also note that the x component of the rope's tension (acting on the crate) is

$$F_x = F\cos\theta = (450\text{ N})\cos 38° = 355\text{ N},$$

and the resistive force (pointing in the $-x$ direction) has magnitude $f = 125$ N.

(a) Newton's second law leads to

$$F_x - f = ma \Rightarrow a = \frac{355\text{ N} - 125\text{ N}}{310\text{ kg}} = 0.74\,\text{m/s}^2.$$

(b) In this case, we use Eq. 5-12 to find the mass: $m = W/g = 31.6$ kg. Now, Newton's second law leads to

$$T_x - f = ma \;\Rightarrow\; a = \frac{355\text{ N} - 125\text{ N}}{31.6\text{ kg}} = 7.3\text{ m/s}^2 .$$

74. Since the velocity of the particle does not change, it undergoes no acceleration and must therefore be subject to zero net force. Therefore,

$$\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0 .$$

Thus, the third force $\vec{F}_3$ is given by

$$\vec{F}_3 = -\vec{F}_1 - \vec{F}_2 = -\left(2\hat{\text{i}} + 3\hat{\text{j}} - 2\hat{\text{k}}\right)\text{N} - \left(-5\hat{\text{i}} + 8\hat{\text{j}} - 2\hat{\text{k}}\right)\text{N} = \left(3\hat{\text{i}} - 11\hat{\text{j}} + 4\hat{\text{k}}\right)\text{N}.$$

The specific value of the velocity is not used in the computation.

Chapter 6

2. To maintain the stone's motion, a horizontal force (in the $+x$ direction) is needed that cancels the retarding effect due to kinetic friction. Applying Newton's second to the x and y axes, we obtain

$$F - f_k = ma$$
$$F_N - mg = 0$$

respectively. The second equation yields the normal force $F_N = mg$, so that (using Eq. 6-2) the kinetic friction becomes $f_k = \mu_k mg$. Thus, the first equation becomes

$$F - \mu_k mg = ma = 0$$

where we have set $a = 0$ to be consistent with the idea that the horizontal velocity of the stone should remain constant. With $m = 20$ kg and $\mu_k = 0.80$, we find $F = 1.6 \times 10^2$ N.

12. (a) Using the result obtained in Sample Problem 6-2, the maximum angle for which static friction applies is

$$\theta_{\max} = \tan^{-1} \mu_s = \tan^{-1} 0.63 \approx 32° .$$

This is greater than the dip angle in the problem, so the block does not slide.

(b) We analyze forces in a manner similar to that shown in Sample Problem 6-3, but with the addition of a downhill force F.

$$F + mg \sin \theta - f_{s,\max} = ma = 0$$
$$F_N - mg \cos \theta = 0.$$

Along with Eq. 6-1 ($f_{s,\max} = \mu_s F_N$) we have enough information to solve for F. With $\theta = 24°$ and $m = 1.8 \times 10^7$ kg, we find

$$F = mg\left(\mu_s \cos\theta - \sin\theta\right) = 3.0 \times 10^7 \text{ N}.$$