Honors Physics
Exam 1a: Unit Analysis & Energy

Name: KEY
Period:

Show your work, box your final answer, and ignore the effects of air resistance and friction.

1. Work the following unit conversion and ratio problems, intended to assess your math skills.

   a. As you know, Mount Everest is the tallest mountain on Earth, with a peak elevation of 8,850 meters. Convert this height to miles.

   $$\left(\frac{8850\,m}{1}\right)\left(\frac{1\,km}{1000\,m}\right)\left(\frac{1\,mile}{1.61\,km}\right) = \boxed{5.5\text{ miles}}$$

   b. Mars is home to a mountain much larger than Everest, called Olympus Mons. Olympus Mons is 27 kilometers in height. How many times taller than Everest is Olympus Mons?

   $$\frac{h_{OM}}{h_{ME}} = \frac{27\,km}{8.85\,km} \approx \boxed{3\text{ times taller}}$$

   c. It may seem strange, but such a large mountain can form on Mars in part because it is a much less massive planet and therefore gravity is much weaker[1]. The volume of Mars is about 8 times smaller than the volume of Earth. How does the radius of Mars compare to the radius of Earth? Express your answer as a ratio.

   $$\frac{V_E}{V_M} = \frac{\cancel{\frac{4}{3}\pi} R_E^3}{\cancel{\frac{4}{3}\pi} R_M^3} = 8$$

   so $\sqrt[3]{\frac{R_E^3}{R_M^3}} = \sqrt[3]{8}$

   $$\boxed{\frac{R_E}{R_M} = 2}$$

   Radius of Earth is twice the Radius of Mars

   d. Not only is Mars smaller than Earth, it is also less dense. The mean density of Mars is 3.934 g/cm^3. Convert the density of Mars into kg/m^3.

   $$\left(\frac{3.934\,g}{1\,cm^3}\right)\left(\frac{1\,kg}{1000\,g}\right)\left(\frac{100^3\,cm^3}{1^3\,m^3}\right) = \boxed{3934\,kg/m^3}$$

   e. Mars is also farther away from the Sun than Earth, which means it takes Mars longer to make one revolution around the Sun. In fact, a Martian year is 5.9×10^7 seconds. How many Earth-days are in one Martian year?

   $$\left(\frac{5.9\times10^7\,s}{1}\right)\left(\frac{1\,hr}{3600\,s}\right)\left(\frac{1\,day}{24\,hr}\right) = \boxed{682.87\text{ Earth days in one Martian year}}$$

   f. Because it is farther from the Sun than the Earth, Mars orbits the Sun at a slower speed than the Earth, approximately 54,000 miles per hour. Convert Mars' orbital speed into meters per second.

   $$\left(\frac{54000\,miles}{1\,hr}\right)\left(\frac{1.61\,km}{1\,mile}\right)\left(\frac{1000\,m}{1\,km}\right)\left(\frac{1\,hr}{3600\,s}\right) = \boxed{24150\,m/s}$$

[1] This is not the *only* reason.

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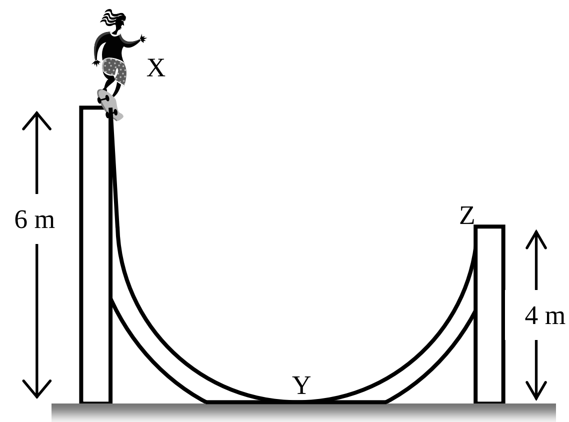
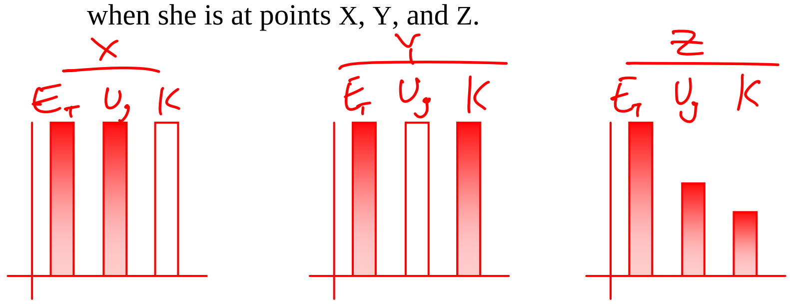
2. Consider a skateboarder of mass who starts from rest at position X, which refers to the top of a half-pipe, 6 meters above the ground, as shown in the picture.



a. Draw schematic energy bar graphs for the skateboarder when she is at points X, Y, and Z.



b. How fast should she be moving at point Y? At point Z?

$$E_{Ti} = E_{Tf}$$
$$U_{gi} + K_i = U_{gf} + K_f$$
$$\cancel{m}gh_i + \tfrac{1}{2}\cancel{m}v_i^2 = \cancel{m}gh_f + \tfrac{1}{2}\cancel{m}v_f^2$$

m cancels

Y

$$(10\,m/s^2)(6\,m) + 0 = 0 + \tfrac{1}{2}v_y^2$$
$$60\,m^2/s^2 = \tfrac{1}{2}v_y^2$$
$$\boxed{v_y = 10.95\,m/s}$$

Z

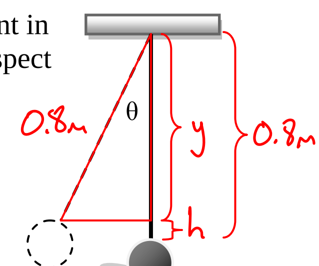
$$(10\,m/s^2)(6\,m) + 0 = (10\,m/s^2)(4\,m) + \tfrac{1}{2}v_z^2$$
$$60\,m^2/s^2 = 40\,m^2/s^2 + \tfrac{1}{2}v_z^2$$
$$20\,m^2/s^2 = \tfrac{1}{2}v_z^2$$
$$\boxed{v_z = 6.32\,m/s}$$

c. In words, explain how would your answers to *a* and *b* would change if you had to include the effects of friction and air resistance.

Friction and air resistance transform some of the skateboarder's energy into thermal energy (heat). For part *a*, I would include a fourth bar in each graph to display thermal energy. The 4th bar would be empty for X since she hasn't started moving; the bar would have a small amount of energy in part Y, reducing the kinetic energy (though the potential energy would still be zero and the total energy would still be full); the thermal energy bar would be slightly higher in part Z, reducing both the potential energy level and the kinetic energy level (but the total energy level would remain the same because energy is still conserved).

For part *b*, my answers would be slightly less because friction and air resistance would have reduced the amount of energy transformed into kinetic energy, thus reducing the velocity of the skateboarder.

3. A pendulum 0.8 meters long has a 1.5 kg bob hanging from the end. At the lowest point in its swing, the bob is moving with a speed of 3.3 m/s. Predict the angle θ made with respect to the vertical at the highest point in the pendulum's swing.



$$E_{Ti} = E_{Tf}$$
$$U_{gi} + K_i = U_{gf} + K_f$$
$$mgh_i + \tfrac{1}{2}mv_i^2 = mgh_f + \tfrac{1}{2}mv_f^2$$
$$(1.5\,kg)(10\,m/s^2)h_i + 0 = 0 + \tfrac{1}{2}(1.5\,kg)(3.3\,m/s)^2$$
$$(15\,kg\,m/s^2)\,h_i = (8.17\,kg\,m^2/s^2)$$
$$h_i = \frac{8.17\,kg\,m^2/s^2}{15\,kg\,m/s}$$
$$h_i = 0.5445\,m$$

$$\cos\theta = y/0.8\,m$$
$$y = 0.8\,m - h$$
$$\cos\theta = \frac{0.8\,m - h}{0.8\,m}$$
$$\cos\theta = \frac{0.8\,m - 0.5445\,m}{0.8\,m}$$
$$\cos\theta = 0.319375$$
$$\boxed{\theta = 71.4^\circ}$$

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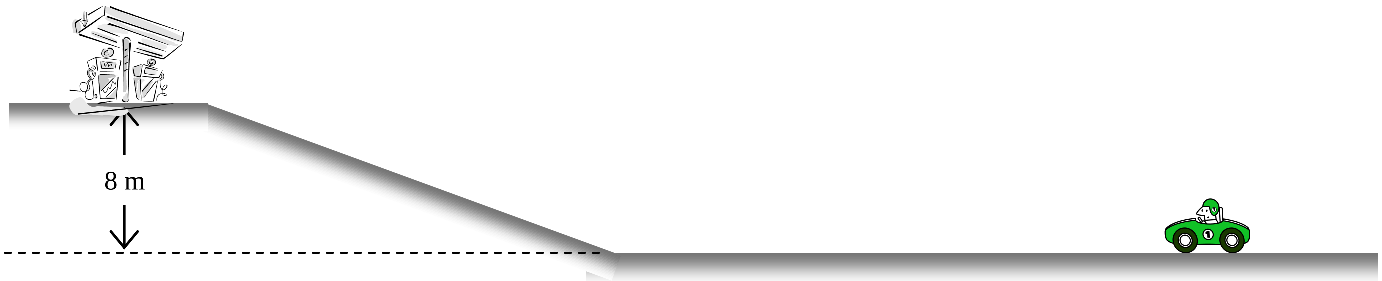

4. While cruising through town one day, Mario's car unfortunately runs out of gas. He continues coasting along the flat road at 15 m/s, hoping to make it to the gas station at the top of a hill 8 meters high.(Remember we are neglecting friction.)

   Will Mario make it to the gas station? *Circle one:* YES NO

   Justify your answer with clear calculations in the space below.

   $E_{T_i} = E_{T_f}$

   $U_{g_i} + K_i = U_{g_f} + K_f$

   $\cancel{m}gh_i + \frac{1}{2}\cancel{m}v_i^2 = \cancel{m}gh_f + \frac{1}{2}\cancel{m}v_f^2$

   m cancels $\quad h_i = 0 \quad$ How high can he go?

   $g = 10\ m/s^2 \quad v_i = 15\ m/s \quad v_f = 0$

   $h_f = ?$

   $(10\ m/s^2)(0) + \frac{1}{2}(15\ m/s)^2 = (10\ m/s^2)h_f + \frac{1}{2}(0)^2$

   $112\ m^2/s^2 = (10\ m/s^2)\ h_f$

   $h_f = 11.2\ m$, which is greater than 12 m so he can make it to the top

5. A young boy named Alfred sits on a sled at the top of a snow covered hill in his front yard. Starting from rest, Alfred slides down the hill and crashes into his parents' car. The collision makes a loud noise, breaks young Alfred's arm, and puts a huge dent in the car. Retell this story, but describe it using the language of energy. Be sure to include the concept of conservation of energy, and be sure to describe both how and when Alfred gained, transformed, and lost energy during his journey. Use the back of this page if you need additional space.

   There's no single correct "story" but it should go something like this…

   Alfred begins at the top of the hill with gravitational potential energy. As he slides down the hill, this potential energy is converted into kinetic energy. When he collides with the car and comes to a stop, then he no longer has kinetic energy (because he's not moving), but his energy didn't disappear. Conservation of energy requires that it go into another form. In fact, some of his energy went into the sound wave caused by the collision; some of his kinetic energy was absorbed by the bone in his arm, causing it to break; some of his energy was absorbed by the car, causing a dent in the metal. In other words, the energy Albert had at the top of his hill was conserved or transformed during his ride down the hill (kinetic energy) and his collision with the car (sound, breaking bone, dented metal).