Shelf-life of ideas at the Bookstore

Some stay fresh for hundreds of years—others go bad in a few days.

Main points of today’s lecture:

- Frictional forces:
  - kinetic friction:
    \[ f_k = \mu_k N \]
  - static friction
    \[ f_s < \mu_s N \]

- Work:
  \[ W = F \Delta s \cos(\theta) = F_x \Delta x \]

- Kinetic energy:
  \[ KE = \frac{1}{2}mv^2 \]

- Work-energy theorem:
  \[ W_{total} = KE_f - KE_0 \]
Checking Understanding

A rod is suspended by a string as shown. The lower end of the rod slides on a frictionless surface. Which figure correctly shows the equilibrium position of the rod?
The pulley holding up mass $M$ has four forces on it, $M_2 g$, $M_c g$, $T_L$ and $T_R$. Note $T_L = T_R = T$. Both tensions pull upward on the pulley and both weights pull down. You can pull up with twice the effective force this way. If you had three loops, you could increase your effective force by a factor of 6.
Friction

- Friction impedes the motion of one object along the surfaces of another. It occurs because the surfaces of the two objects temporarily stick together via “microwelds”. The frictional force can be larger if the two surfaces are at rest with respect to each other.

- Experimentally we have two cases:
  - kinetic friction:
    \[ f_k = \mu_k N \]
  - static friction
    \[ f_s < \mu_s N \]

- The coefficient of static friction generally exceeds that for kinetic friction: \( \mu_s > \mu_k \)

- Frictional forces always oppose the motion of one surface with respect to the other.
Example with static friction

• Consider the figure below, with $M_1 = 105$ kg and $M_2 = 44.1$ kg. What is the minimum static coefficient of friction necessary to keep the block from slipping.

$$T = M_2 g$$

If $M_1$ doesn’t move

$$T = f_s = M_2 g$$

$$f_s \leq \mu_s N = \mu_s M_1 g$$

Putting it together

$$\frac{M_2 g}{M_1 g} \leq \mu_s$$

$$\frac{M_2}{M_1} \leq \mu_s$$

If this isn’t true, $M_1$ will slip
Example kinetic friction with ramp

- The block shown below starts sliding down the ramp. Assuming the coefficient of kinetic friction $\mu_k = 0.3$, how long does it take for the block to travel 2m to the bottom of the ramp?

1. Draw the forces.
2. Choose an appropriate coordinate system.
3. Calculate the components.
4. Use Newton’s 2nd to get $t$

$W, f_k, N$ are magnitude of forces

$x : \sum_i F_{i,x} = f_k - W_x = ma_x$

$\Rightarrow \mu_k N - mg \sin(\theta) = ma_x$

$y : \sum_i F_{i,y} = N - W_y = 0$

$\Rightarrow N = mg \cos(\theta)$

$\Rightarrow \mu_k mg \cos(40^\circ) - mg \sin(40^\circ) = ma_x$

$\Rightarrow a_x = -4.05 \text{ m/s}^2$ (after plugging in)

$\Delta x = \frac{1}{2} a_x t^2$ \Rightarrow $t = \sqrt{\frac{2\Delta x}{a_x}} = \sqrt{\frac{-4 \text{m}}{-4.05 \text{m/s}^2}} = 1 \text{s}$
Work

• Physicists have a precise definition of work done by a force on an object. It is computed from the displacement of the object while being acted on by the force.

\[ W = F\Delta s \cos(\theta) = F\Delta x \]

• Note: work is only done if there is a displacement in the direction of the force.
  – if \( \theta = 0^\circ \), \( W = F\Delta s \)
  – if \( \theta = 90^\circ \), \( W = 0 \).
  – if \( \theta = 180^\circ \), \( W = -F\Delta s \)

• The units for work are \( \text{N}\cdot\text{m} = \text{J} \) (Joules). These are the units we will use in this chapter. Other units are cal (calorie). 1 cal = 4.186J. Calorie (Food calories) is another unit. 1 Calorie = 1000 cal.

• Work is not the same thing as effort.
What work is being done by me?

- Indicate with your response unit whether:
  - a) positive work is being done
  - b) no work is being done
  - c) negative work is being done

What work is being done by gravity?

- Indicate with your response unit whether:
  - a) positive work is being done
  - b) no work is being done
  - c) negative work is being done
What work is being done by me?

• Indicate with your response unit whether:
  – a) positive work is being done
  – b) no work is being done
  – c) negative work is being done

What work is being done by friction?

• Indicate with your response unit whether:
  – a) positive work is being done
  – b) no work is being done
  – c) negative work is being done
What work is being done by the string?

- a) positive work
- b) negative work
- c) zero work
- d) cannot be determined
Example

- A workman lifts a 4 kg brick 1.5 meter vertically. a) What is the work done by the workman? b) What is the work done by gravity? c) If the workman lowers it back to the ground, what work does he do in lowering the brick? d) What would be his total work? Assume all motions are at constant velocity.

<table>
<thead>
<tr>
<th>m</th>
<th>4 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δy parts</td>
<td>1.5 m</td>
</tr>
<tr>
<td>a&amp;b</td>
<td>-1.5 m</td>
</tr>
</tbody>
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\[
W_y = -mg = -39.2 \text{N}
\]

\[
F_{\text{man},y} = -W = 39.2 \text{N}
\]

a) \[W_{\text{man,up}} = F_y \Delta y = (39.2)(1.5) \text{J} = 59 \text{J}\]

b) \[W_{\text{grav,up}} = -mg\Delta y = -59 \text{J}\]

c) \[W_{\text{man,down}} = F_y \Delta y = (39.2)(-1.5) \text{J} = -59 \text{J}\]

d) \[W_{\text{man,total}} = W_{\text{man,up}} + W_{\text{man,down}} = 0\]