Lecture 16: Power

<u>Announcements</u>

- Homework **and** Get-Ready Assignments on Gradescope
  - Regrade requests can be used to ask for clarification on feedback you have received.
  - This week's homework is long, in order to keep next week's homework shorter.
- Project Peer Review
  - Complete your feedback by Friday at the latest.
  - Please offer criticisms with care and respect; you are trying to help your peers improve their work.
  - You should write 1-2 paragraphs for each peer review.
  - Point out things that were done well, and things that can be improved.
    - Giving positive comments on what works and should be kept is just as important as suggesting revisions and giving constructive criticism.
  - Scientific communication is a major goal of this work, so don't be shy about asking (nicely) for things to be explained better.
    - If you don't understand something, don't be shy about admitting it.
    - If you do understand something, but think it could be explained better, remark on this as well.

A Deeper Model for Interactions

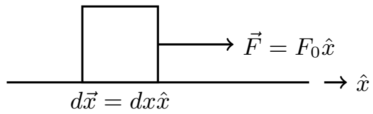
- Quantities
  - Energy E
  - Kinetic Energy $K = \frac{1}{2}mv^2$
- Laws
  - Work-energy theorem $W_{\text{net,ext}} = \Delta E_{\text{total}}$

Power

- When the energy of a system changes, we sometimes want to know how *fast* it changes.
- *Power* is the time rate of change of energy:

$$P = \frac{dE}{dt}.$$

- Power is measured in watts (W).



Total Energy
The block can have kinetic energy, so its change in total energy is the difference of its final and initial kinetic energies. Its initial speed is 0 m/s, so

$$\Delta E = K_f - K_i = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = \frac{1}{2}mv_f^2.$$

Plugging in numbers, we obtain $\Delta E = 9000$ J.

Distance
By the work-energy theorem, $W_{\text{net,ext}} = \Delta E$, so if there is no friction and the winch is the only thing doing work, then we can calculate the distance d from the work it did:

$$W = \int_0^d \vec{F} \cdot d\vec{x} = F_0 d = \Delta E = \frac{1}{2}mv_f^2.$$

Solving for d gives us $d = \frac{m}{2F_0}v_f^2$, and plugging in numbers gives us $d = 0.5$ m.

Power
We know how much energy the winch put into this endeavor, so all we need to find out is the time it took to move the block. For constant acceleration (which we have in this situation of constant force), we know $a = \frac{\Delta v}{\Delta t} = \frac{F_0}{m}$, so $\Delta t = \frac{v_f m}{F_0} = \frac{1}{6}$ s. This means that the power is

$$P = \frac{\Delta E}{\Delta t} = \frac{F_0 d}{v_f m / F_0} = \frac{F_0^2 d}{v_f m}.$$

Given what we know about the distance, this simplifies to

$$P = \frac{F_0^2}{v_f m}\frac{m}{2F_0}v_f^2 = \frac{F_0 v_f}{2} = 54,000 \text{ W}.$$

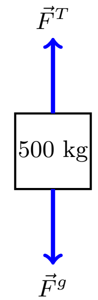
For comparison, the light bulb in my desk lamp in my apartment consumes 9 W while on (this is much more efficient than an equivalently bright incandescent bulb, which would take about 60 W). This much power could light 6,000 desk lamps (or 900 if using an incandescent bulb)!

L16-1: The Winch – Part 1

A winch acts a constant force $F_0 = 18,000$ N on a metal block ($m = 500$ kg) to accelerate it across level ground from rest to a final speed of $v_f = 6$ m/s.

- What is the block's change in total energy?
- How far did the winch move the block?
- How much power does this winch use?

Force
To keep the block at constant speed, the winch must exert a force equal in magnitude to the force of gravity on the block:



$$F^T = F^g = mg \approx (500\text{ kg})(10\text{ m/s}^2) = 5000\text{ N}$$

Distance Lifted
We know the speed of the block and how long it is in motion, so we can calculate its displacement directly from this:

$$\Delta y = v\Delta t = (2\text{ m/s})(30\text{ s}) = 60\text{ m}.$$

Work

$$\begin{aligned} W &= \int_{y_i}^{y_f} \vec{F}\cdot d\vec{y} = \int_{y_i}^{y_f} (F\hat{y})\cdot(dy\hat{y}) = \int_{y_i}^{y_f} F dy \\ &= F\Delta y = (5000\text{ N})(60\text{ m}) = 300,000\text{ J} \end{aligned}$$

Note that the speed is not changing, so the total energy of the block is not changing. That means $W_{\text{net,ext}} = \Delta E_{\text{total}} = 0$. Something else must be doing work to remove energy from the system! This is being done by gravity.
Power
The winch is transferring 300,000 J of energy over the course of 30 s, so the power is

$$P = \frac{\Delta E}{\Delta t} = \frac{300,000\text{ J}}{30\text{ s}} = 10,000\text{ W}.$$

This much power could light about 1,111 desk lamps (or about 166 if using an incandescent bulb)!

L16-1: The Winch – Part 2

You want to use the winch to lift the block into the air at a constant speed: $v = 2$ m/s.

- What force should you set the winch for?
- How far does the winch move the block from $t = 0$ s to $t = 30$ s?
- How much work does the winch do in $\Delta t = 30$ s?
  - Is anything else doing work on the block?
- How much power does the winch use now?

Energy Analysis

- Understanding: Identify a system and the types of energy within the system.
- Calculating: Is your system's energy conserved or not? Once you know, use the work-energy theorem!
- Sensemaking: All the sensemaking strategies you have will work, but a new strategy is sometimes useful: Solve Multiple Ways.
  - You have kinematics and force techniques at your disposal, so you can solve problems with these and compare their results to the results of your energy approach.

Main Ideas

- Energy is a powerful, ubiquitous concept that can help us solve a wide array of physics problems.
- Energy is a *scalar*—it is not a vector.
- There are different forms of energy, and energy can be transferred between objects and between forms.