FEELING JOULES AND WATTS

OVERVIEW & PURPOSE

Power was originally measured in horsepower – literally the number of horses it took to do a particular amount of work. James Watt developed this term in the 18th century to compare the output of steam engines to the power of draft horses. This allowed people who used horses for work on a regular basis to have an intuitive understanding of power. 1 horsepower is about 746 watts. In this lab, you'll learn about energy, work and power – including your own capacity to do work.

Energy is the ability to do work. Without energy, nothing would grow, move, or change. **Work** is using a force to move something over some distance.

$$work \ = \ force \ x \ distance$$

Energy and work are measured in **joules**. One joule equals the work done (or energy used) when a force of one **newton** moves an object one meter. One newton equals the force required to accelerate one kilogram one meter per second squared.

> How much energy would it take to lift a can of soda (weighing 4 newtons) up two meters?

$$work \ = \ force \ x \ distance \ = \ 4N \ x \ 2m \ = \ 8 \ joules$$

Whether you lift the can of soda quickly or slowly, you are doing 8 joules of work (using 8 joules of energy). It's often helpful, though, to measure *how quickly* we are doing work (or using energy). **Power** is the amount of work (or energy used) in a given amount of time.
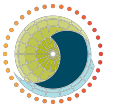
$$power \ = \frac{work}{time}$$

Power is measured in **watts**. One watt equals one joule per second.

> How much power would it take to lift this same can of soda up two meters in one second?

$$power \ = \frac{work}{time} \ = \frac{8\ joules}{second} = \ 8\ watts$$

So, it takes 8 watts of power to lift this can of soda up two meters in one second.

> How much power would it take to lift this same can of soda up two meters in ten seconds?

$$power \ = \frac{work}{time} \ = \frac{8\ joules}{10\ seconds} = \ 0.8\ watts$$

So, lifting the can slower uses less power but the same amount of energy (work). Conversely, lifting the can quicker would require more power but the same amount of energy (work).

Because a watt represents such a small amount of power, we often use **kilowatts** (1 kW = 1,000 watts) and **megawatts** (1 MW = 1 million watts) to describe the power output of things like kitchen appliances and power plants, respectively.

Energy and work can also be measured in **calories**. 1 calorie ≈ 4 joules. Calories are simply a way of describing how much energy your body would get from eating or drinking food and beverages. 1 calorie is the amount of energy needed to raise the temperature of one gram of water one degree Celsius. The food Calories that you see on food labels in the United States are actually kilocalories (equal to 1,000 calories) and are written with a capital C. So, 1 Calorie = 1 kilocalorie = 1,000 calories.
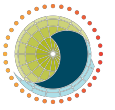
Having so many different units can be confusing, but remember that calories, kilocalories, Calories, and joules *all measure the same thing* -- energy and work.

$$1,000 \; calories \; = \; 1 \; kilocalorie \; = \; 1 \; Calorie \; = \; 4,184 \; joules$$

Watts, kilowatts, megawatts, and horsepower *all measure the same thing*: power.

$$1 \; watt \; = \; 1,000 \; kilowatts \; = \; 1,000,000 \; megawatts \; = \; 0.00134102 \; horsepower$$

How much power can a human produce? What do joules and watts *feel* like? Let's find out.

OBJECTIVES

- Define energy, work, and power, and give examples of each.
- Understand the relationships between energy, work and power.
- Experience what joules and watts feel like.

METHOD

Students gain an intuition for what joules and watts *feel like* by doing work and generating power themselves.

MATERIALS (per group of students)

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❏ one-liter bottles of water (x 6)	❏ reusable bags with handles (x 1)	❏ metric tape measures (x 1)
❏ pedal exerciser (x 1)	❏ stopwatches (x 1)	❏ hand crank generators (x 1)
❏ lamp (x 1)	❏ 60-watt bulb (x 1)	
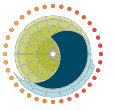
PROCEDURE

Groups of at least three students work well for this lab. One student will do the physical work, another will hold the tape measure, and another will operate the stopwatch.

As you work through this lab, write your answers to the questions in your lab notebook.

1. Lift one liter of water up one meter (100 cm). (1 liter of water has a mass of 1,000 grams = 1 kilogram). Concentrate on how it feels to lift this mass.
   a. Take turns so that each person in your group lifts the water.
   b. Why is this **work**?
   c. How much **work** (in joules) is being done each time you lift the liter of water?
   d. How much **work** (in food Calories) is being done each time you lift the liter of water?
   e. Does lifting the bottle quickly or slowly change the amount of **work** that you're doing?
   f. What are two other examples of **work** that you can observe in everyday life?

2. Lift one liter of water up one meter in one second (about the time it takes to say "one-one-thousand"). Lower the liter. Repeat this once per second for at least ten seconds. Concentrate on how it feels to lift this mass at this speed.
   a. Take turns so that each person in your group lifts the water.
   b. How much **power** are you generating as you lift the bottle one meter in one second?
   c. As you lift the same weight (1 kg of water) up the same height (1 meter) over and over again, how would you change the amount of **power** you are generating?

3. Place 6 bottles of water inside one reusable bag. Lift the bag up one meter every
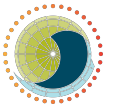
second over and over again. Concentrate on how it feels to lift this mass at this speed.

   a. Take turns so that each person in your group lifts the water.
   b. How much power are you generating as you lift 6 bottles up one meter per second?
   c. How fast would you need to lift one bottle of water up one meter in order to generate the same amount of power?
   d. How many bottles would you need to lift one meter per second in order to generate the same **power** as a 100-watt light bulb? a microwave oven (about 1 kilowatt)? a megawatt?

4. Move on to the pedal exerciser. Pedal at a steady rate for one minute and observe how many Calories you are "burning" (generating). Concentrate on how it feels to generate this much **energy**.

   a. *Reset the Calorie display to zero on the pedal exerciser by holding down the red button for 5 seconds.*
   b. Take turns so that each person in your group pedals. One student will pedal while another holds down the front of the pedal exerciser to keep it from sliding.
   c. Does pedaling slowly or quickly for the same distance change the amount of **work** you are doing?
   d. How much **energy** [in food Calories] did you produce by pedaling for one minute?
   e. How much **power** [in watts] did you generate by pedaling for one minute? (watts = joules per second)
   f. How many times faster would you have to pedal to **power** a 60-watt light bulb?

5. Move on to the hand crank generator. Turn the crank at a steady rate for several seconds. Concentrate on how it feels while generating enough electrical **energy** to light the 3-watt bulb.

   a. Take turns so that each person in your group turns the crank.
   b. What happens to the bulb as you turn the crank slowly and then gradually faster?
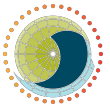
POST-LAB QUESTIONS

Check for student understanding.

1. Usually, an engine's power is measured in horsepower rather than watts. The same quantity (**work** over time) is being measured, only in different units. 1 horsepower equals about 746 watts. If an engine generates one horsepower, how many pounds would it have to lift up one foot in one second?
2. Use the internet to find a specific car and how much horsepower its engine generates.
   a. List the model of car and its horsepower capacity.
   b. How many watts would this car's engine generate?
   c. How many 100-watt light bulbs would be required to use the same amount of power as the car?
3. Using your data from the pedal exerciser, how many of you would it take to produce the same amount of power as the car?
4. How many of you would it take to produce the same amount of **power** as a 100-watt light bulb?
5. How many hours would you have to pedal to light a 60-watt bulb for 8 hours?
6. How many hours would you have to pedal to pop a bag of microwave popcorn? (Assume that the microwave is 1,000 watts and you'll have to power it for 3 minutes to pop the bag of popcorn.)
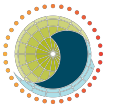
EQUATIONS

work = force x distance

force = mass x acceleration

Using standard metric units for force, mass, and acceleration, we get

$1\ Newton = 1\ kg \cdot m/s^2$

Objects on Earth accelerate at a rate of 9.8 m/s² when gravity is the only force acting on the object. So, if you drop an object, after 1 second it's falling at a speed of 9.8 meters per second ($\approx$ 22 miles per hour).

To calculate the force required to lift a 1 kg object against the force of gravity
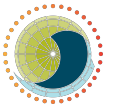
$force = mass\ x\ acceleration$

$force = 1kg\ x\ acceleration\ due\ to\ gravity$

$force = 1kg\ x\ 9.8\ m/s^2$

$force = 9.8\ kg \cdot m/s^2 = 9.8\ N$

$power = \frac{work}{time}$

$1\ joule = 1\ N \cdot m$
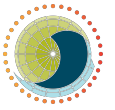
$$1 \; watt \; = \; \frac{1 \; joule}{1 \; second}$$

$$1,000 \; calories \; = \; 1 \; kilocalorie \; = \; 1 \; Calorie \; = \; 4,184 \; joules$$

$$1 \; watt \; = \; 1,000 \; kilowatts \; = \; 1,000,000 \; megawatts \; = \; 0.00134102 \; horsepower$$

$$1 \; meter \; \approx 3.3 \; feet$$

SOLUTIONS TO PROBLEMS

Procedure 1.c. How much **work** (energy) is being done each time you lift 1 liter of water up 1 meter? (1 liter of water has a mass of 1,000 grams = 1 kilogram)

So, for this question we know: $distance\ =\ 1\ meter$ $mass\ =\ 1\ kg$

We want to use the equation: $work\ =\ force\ x\ distance$

We know the distance is 1 meter, but we need to calculate the force required to lift the 1 kg bottle against the force of gravity. Acceleration due to gravity is 9.8 m/s^2.

$$force\ =\ mass\ x\ acceleration$$

$$=\ 1kg\ x\ acceleration\ due\ to\ gravity$$

$$=\ 1kg\ x\ 9.8\ m/s^2$$

$$=\ 9.8\ kg \cdot m/s^2 = 9.8\ N$$

So, a force of 9.8 Newtons is required to lift the 1 kg bottle against the force of gravity.

Now, back to the *work* equation:

$$work\ =\ force\ x\ distance$$

$$=\ 9.8\ N\ x\ 1\ m\ =\ 9.8\ N \cdot m\ =\ 9.8\ joules\ \approx 10\ joules$$

So, each time you lift the one-liter bottle up one meter, you are doing **about 10 joules of work**.