TYPES OF ENERGY

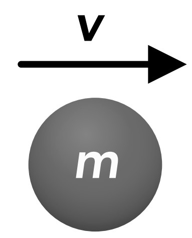
Kinetic Energy

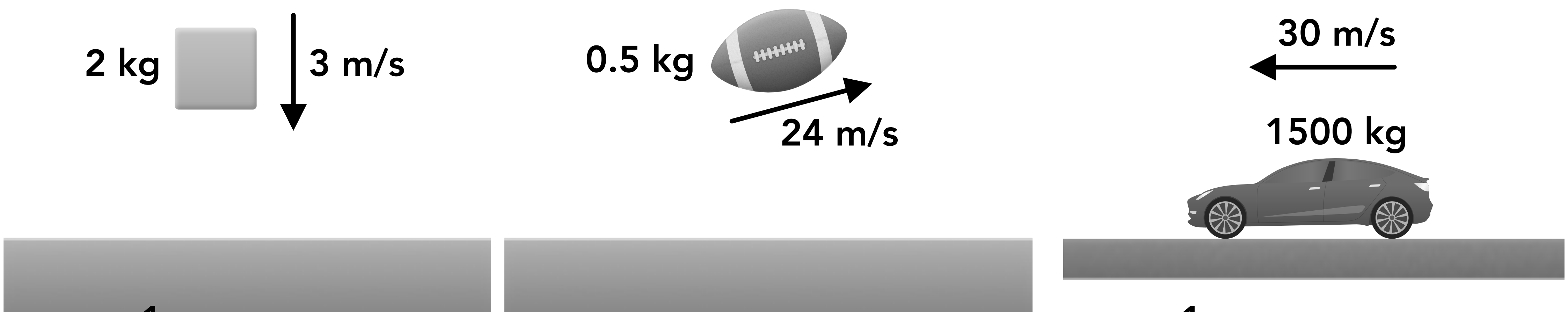
- **Kinetic energy** is the energy of an object or system due to its motion. There are two types: translational kinetic energy and rotational kinetic energy. Both of these are types of **mechanical energy**.
- Kinetic energy is a **scalar quantity** (not a vector quantity) so it's always positive, it does not have a direction and it does not depend on the direction of the object's or system's velocity.
- **Translational kinetic energy** or linear kinetic energy (often just referred to as kinetic energy) is the energy of an object or system due to its linear motion and depends on its mass and linear speed.

Variables		SI Unit
K	kinetic energy	J
m	mass	kg
v	speed	$\frac{m}{s}$

Kinetic energy

$$K = \frac{1}{2}mv^2$$





$$K = \frac{1}{2}(2\text{ kg})(3\text{ m/s})^2$$
$$K = 9\text{ J}$$

$$K = \frac{1}{2}(0.5\text{ kg})(24\text{ m/s})^2$$
$$K = 144\text{ J}$$

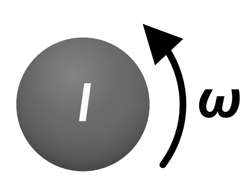
$$K = \frac{1}{2}(1500\text{ kg})(30\text{ m/s})^2$$
$$K = 675{,}000\text{ J}$$

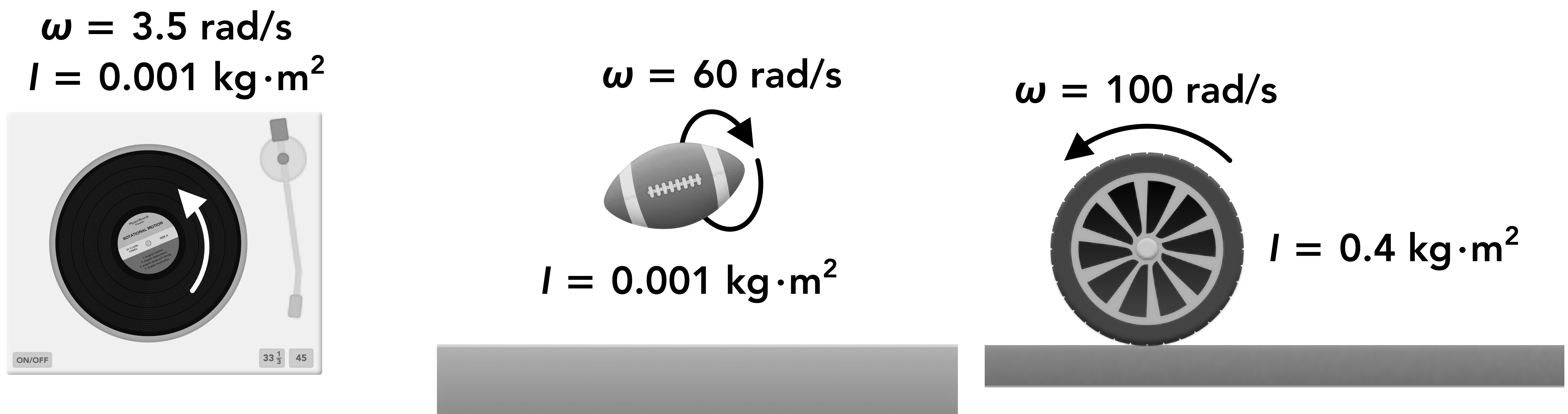
- **Rotational kinetic energy** is the energy of an object or system due to its rotational motion and depends on its rotational inertia and angular speed.

Variables		SI Unit
K_{rot}	rotational kinetic energy	J
I	rotational inertia	$kg \cdot m^2$
ω	angular speed	$\frac{rad}{s}$

Rotational kinetic energy

$$K_{rot} = \frac{1}{2}I\omega^2$$





$$K_{rot} = \frac{1}{2}(0.001)(3.5)^2$$
$$K_{rot} = 0.006\text{ J}$$

$$K_{rot} = \frac{1}{2}(0.001)(60)^2$$
$$K_{rot} = 1.8\text{ J}$$

$$K_{rot} = \frac{1}{2}(0.4)(100)^2$$
$$K_{rot} = 2{,}000\text{ J}$$

Gravitational Potential Energy

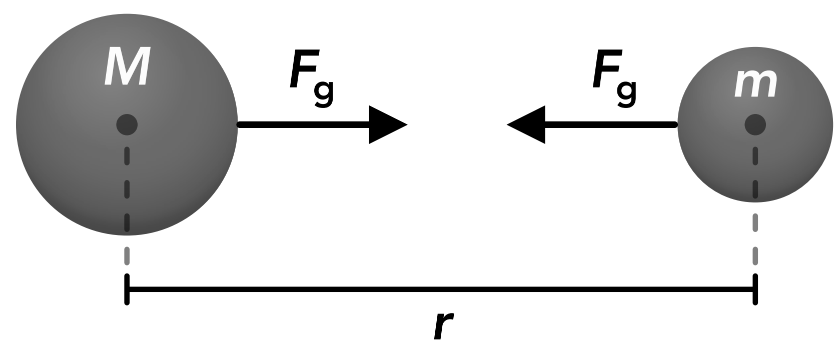
Constants		Unit	Name
G	6.67×10^{-11}	$\frac{m^3}{kg \cdot s^2}$	gravitational constant

Variables		SI Unit
U_g	gravitational potential energy	J
M	planet mass	kg
m	object mass	kg
r	distance between centers	m
y	height	m
g	gravitational acceleration	$\frac{m}{s^2}$

- **Gravitational potential energy** is the energy of a system of two masses due to the gravitational force pulling them together. The two masses are usually an object and the earth. This is a type of **mechanical energy**.
- It's important to remember that gravitational potential energy is a property of **a system** of two masses. A single object can't have gravitational potential energy on its own, although it is very common to say that it does. When you see "the potential energy of the ball", replace that with "the potential energy of the ball-earth system".
- There are usually two equations that are used to calculate gravitational potential energy. One is used for planet-sized distances and one is used for changes in height near the surface of a planet. These are actually the same equation, the second one is derived from the first using approximations.
- The SI unit of gravitational potential energy is a joule (J), the same as all types of energy.

- The gravitational potential energy of a two-mass system is derived from the gravitational force given by Newton's law of universal gravitation which is shown below. Note that when the two masses are an infinite distance apart the gravitational force between them approaches zero.

$$F_g = \frac{GMm}{r^2} \qquad F_g = 0 \text{ at } r = \infty$$

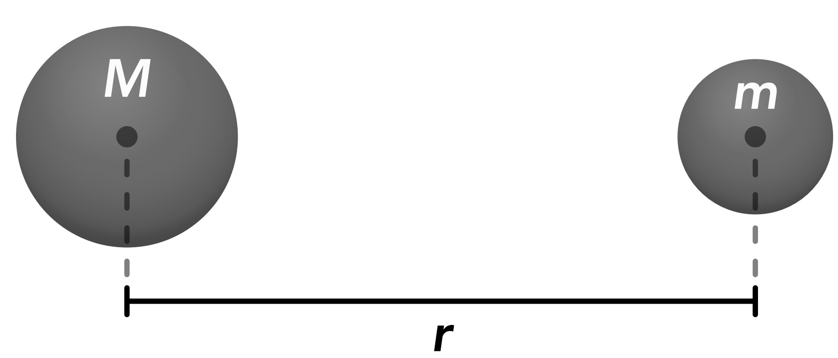


- The gravitational potential energy of a two-mass system exists because of the gravitational force between them. If the gravitational force is zero when the objects are an infinite distance apart, **the gravitational potential energy is also zero when the objects are an infinite distance apart**.
- The gravitational force between the two masses is attractive and each mass "wants" to move towards the other, so **energy must be added to the system (work must be done on the system) in order to move them apart** and increase the distance r between them.
- For those two reasons, the gravitational potential energy of a two-mass sytem is negative instead of positive. An increase in r must increase U_g (which changes from a bigger negative value to a smaller negative value, a positive increase) and U_g must be zero when $r = \infty$.

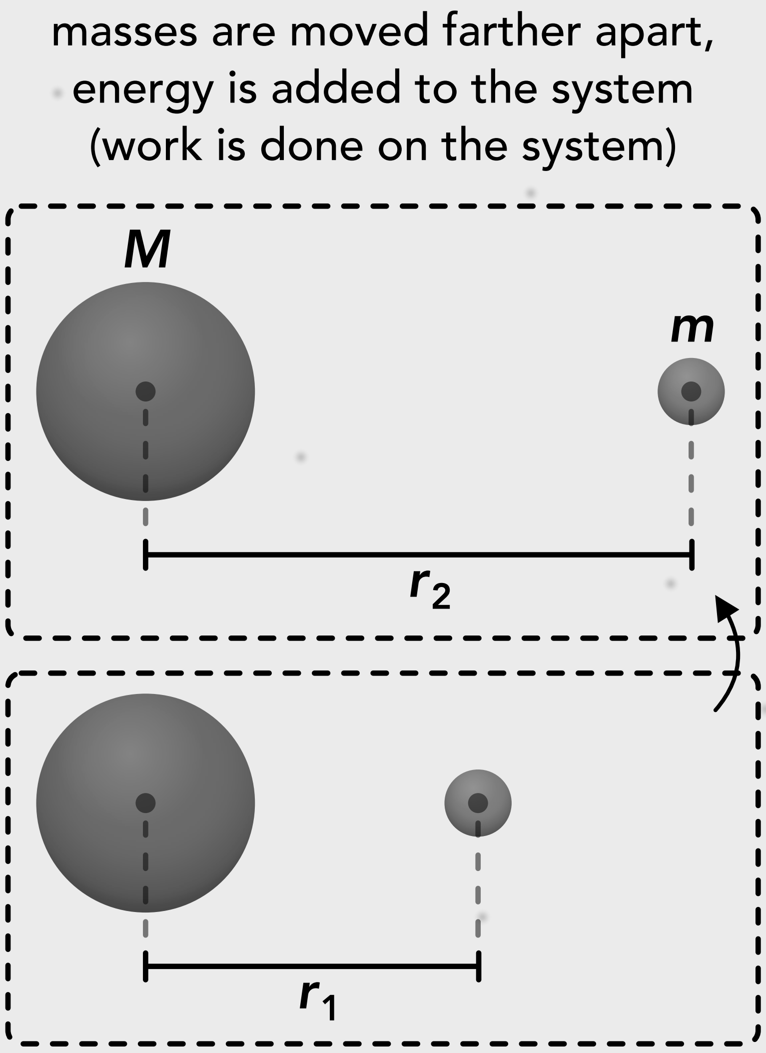
Gravitational potential energy of a two-mass system

$$U_g = -\frac{GMm}{r}$$

$$U_g = 0 \text{ at } r = \infty$$



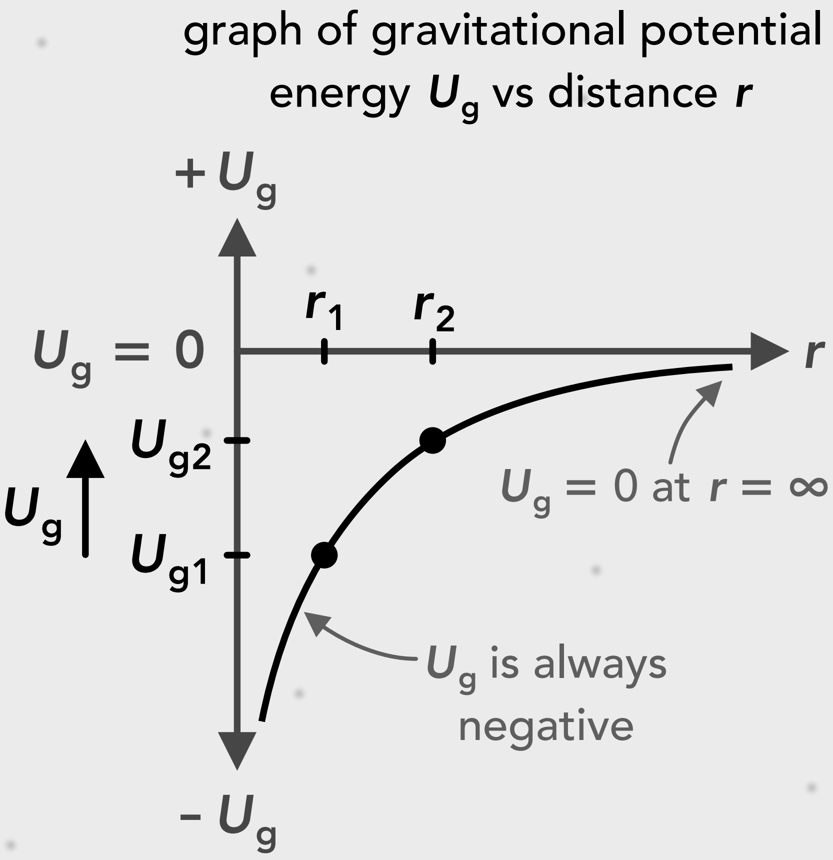
The change in the gravitational potential energy of a two-mass system is positive as the distance between the masses increases



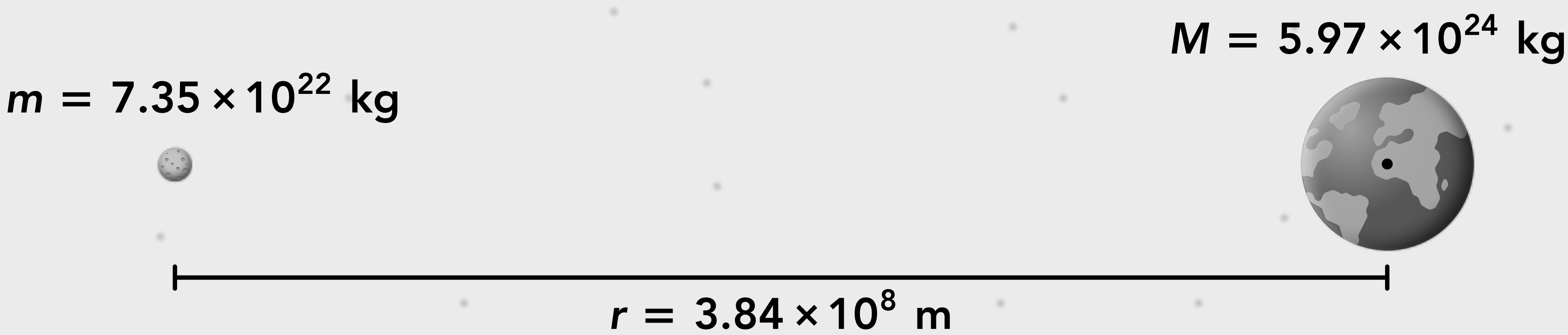
$$U_{g2} = -\frac{GMm}{r_2}$$

$$U_{g2} - U_{g1} = +\Delta U_g$$

$$U_{g1} = -\frac{GMm}{r_1}$$



Example: Gravitational potential energy of the earth-moon system

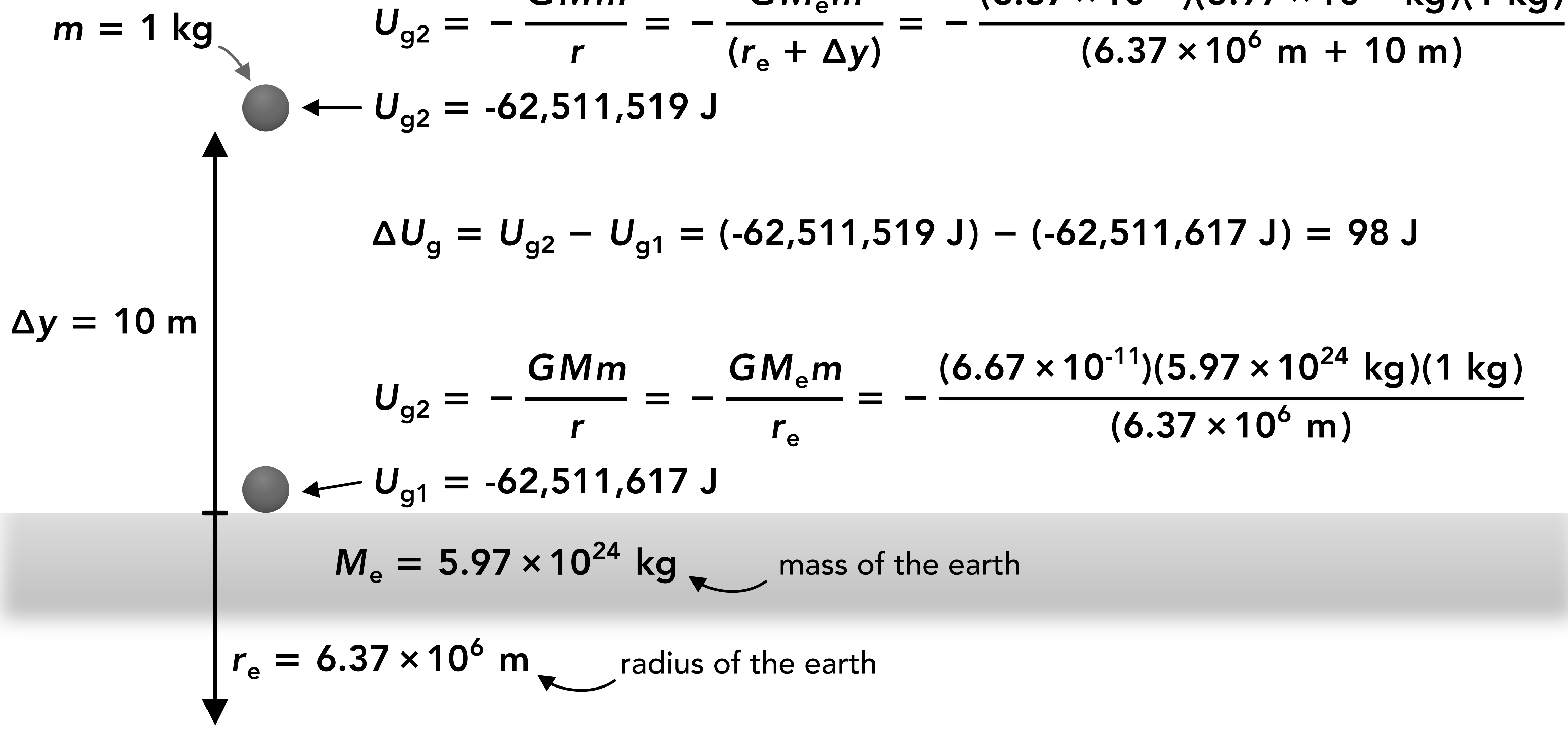


$$U_g = -\frac{GMm}{r} = -\frac{(6.67\times10^{-11})(5.97\times10^{24}\text{ kg})(7.35\times10^{22}\text{ kg})}{(3.84\times10^{8}\text{ m})} = -7.62\times10^{28}\text{ J}$$

- What if we're working with an object at a relatively small height above the ground and we want to know the gravitational potential energy of the object-earth system?
- The equation given above still represents the gravitational potential energy of the object-earth system, but we're going to get very large (negative) values for the potential energy. We'll also find that it's more useful to focus on the **change** or the **difference** in the potential energy between two heights.
- Below is an example of the gravitational potential energy of a ball-earth system at two different heights, then how we can simplify the equation for relatively small changes in height near the surface of the earth.

Calculating the change in gravitational potential energy of the ball-earth system between two different heights, using the original equation for gravitational potential energy

U_g: gravitational potential energy of **ball-earth system**



$$U_{g2} = -\frac{GMm}{r} = -\frac{GM_em}{(r_e + \Delta y)} = -\frac{(6.67 \times 10^{-11})(5.97 \times 10^{24}\ \text{kg})(1\ \text{kg})}{(6.37 \times 10^{6}\ \text{m} + 10\ \text{m})}$$

$$U_{g2} = \text{-62,511,519 J}$$

$$\Delta U_g = U_{g2} - U_{g1} = (\text{-62,511,519 J}) - (\text{-62,511,617 J}) = 98\ \text{J}$$

$$U_{g2} = -\frac{GMm}{r} = -\frac{GM_em}{r_e} = -\frac{(6.67 \times 10^{-11})(5.97 \times 10^{24}\ \text{kg})(1\ \text{kg})}{(6.37 \times 10^{6}\ \text{m})}$$

$$U_{g1} = \text{-62,511,617 J}$$

$$M_e = 5.97 \times 10^{24}\ \text{kg}$$

$$r_e = 6.37 \times 10^{6}\ \text{m}$$

We can simplify the equation for the change in gravitational potential energy using some approximations when working with relatively small changes in height above the surface of the earth

M_e : mass of the earth
r_e : radius of the earth
m : object mass
Δy : object's change in height

$$\Delta U_g = U_{g2} - U_{g1}$$

simplify

$$\Delta U_g = \left(\frac{-GM_e m}{(r_e + \Delta y)}\right) - \left(\frac{-GM_e m}{r_e}\right)$$

$$\Delta U_g = \frac{GM_e m}{r_e} - \frac{GM_e m}{(r_e + \Delta y)}$$

$$\Delta U_g = GM_e m\left(\frac{1}{r_e} - \frac{1}{(r_e + \Delta y)}\right)$$

$$\Delta U_g = GM_e m\left(\frac{(r_e + \Delta y)}{r_e(r_e + \Delta y)} - \frac{r_e}{r_e(r_e + \Delta y)}\right)$$

$$\Delta U_g = GM_e m \frac{\Delta y}{r_e(r_e + \Delta y)}$$

if the object's change in height is much less than the radius of the earth, the radius plus the change in height is approximately equal to the radius

$$\Delta y \ll r_e$$

$$(r_e + \Delta y) \approx r_e$$

$$\Delta U_g = GM_e m \frac{\Delta y}{r_e^2}$$

$$\Delta U_g = \frac{GM_e}{r_e^2} m\Delta y$$

if we assume the acceleration due to gravity is constant for this change in height

$$g = \frac{GM_e}{r_e^2}$$

$$\Delta U_g = gm\Delta y$$

Calculating the change in gravitational potential energy of the ball-earth system between two different heights, using the simplified equation for the change in gravitational potential energy

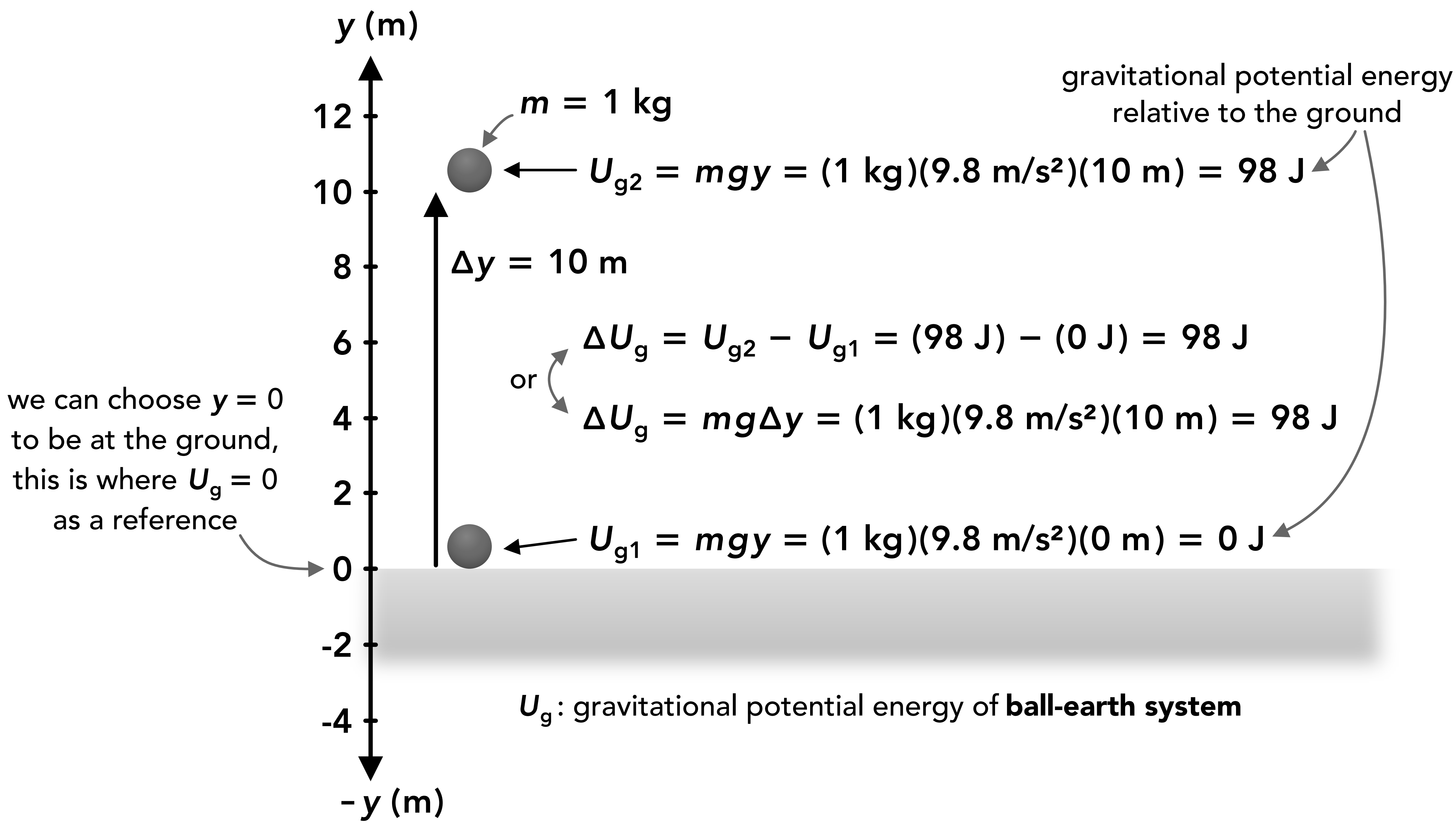
Change in gravitational potential energy of an object-earth system

$$\Delta U_g = mg\Delta y$$

Gravitational potential energy of an object-earth system *relative to a reference point

$$U_g = mgy \qquad U_g = 0 \text{ at } y = 0$$

these mean the same thing, they're just two different ways to represent changes in the gravitational potential energy

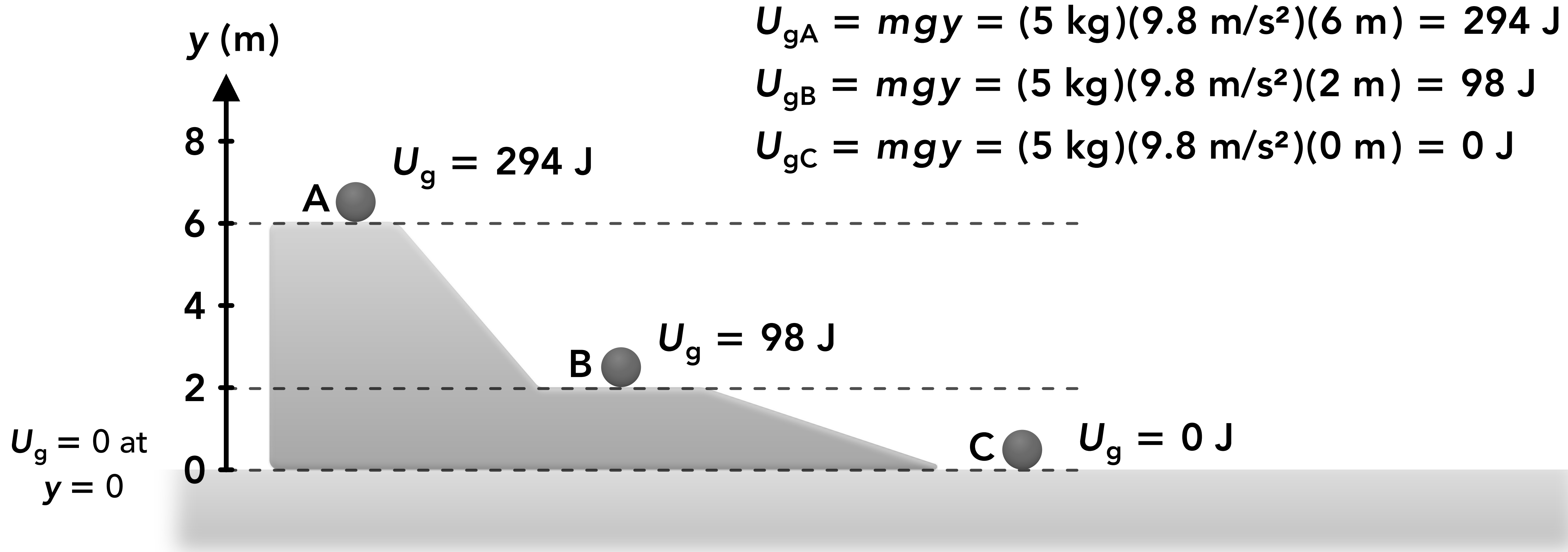


- Above we use the simplified equation for the change in gravitational potential energy for the ball-earth system. The change in height is small relative to the radius of the earth, and the acceleration due to gravity is constant. **We get the same value for the change in potential energy as before: 98 J**. This is the change in the potential energy of the system regardless of which equation we use.
- Instead of calculating the change in potential energy **we can establish a reference point where $y = 0$ and $U_g = 0$**. Then we can calculate the potential energy when the object is at different heights **relative to that reference point**.
- Remember that this value is not the actual, absolute gravitational potential energy of the sytem, **this is just a different way to represent changes in the gravitational potential energy**, which will be helpful when using the conservation of energy and work.
- Also, notice that the change in potential energy only depends on the change in height, **it does not depend on the path that the object takes between the two heights**.

Example: A 5 kg ball rolls down a ramp with multiple sections and reaches the ground. What is the ball's gravitational potential energy (technically the energy of the ball-earth system) at points A, B and C if:

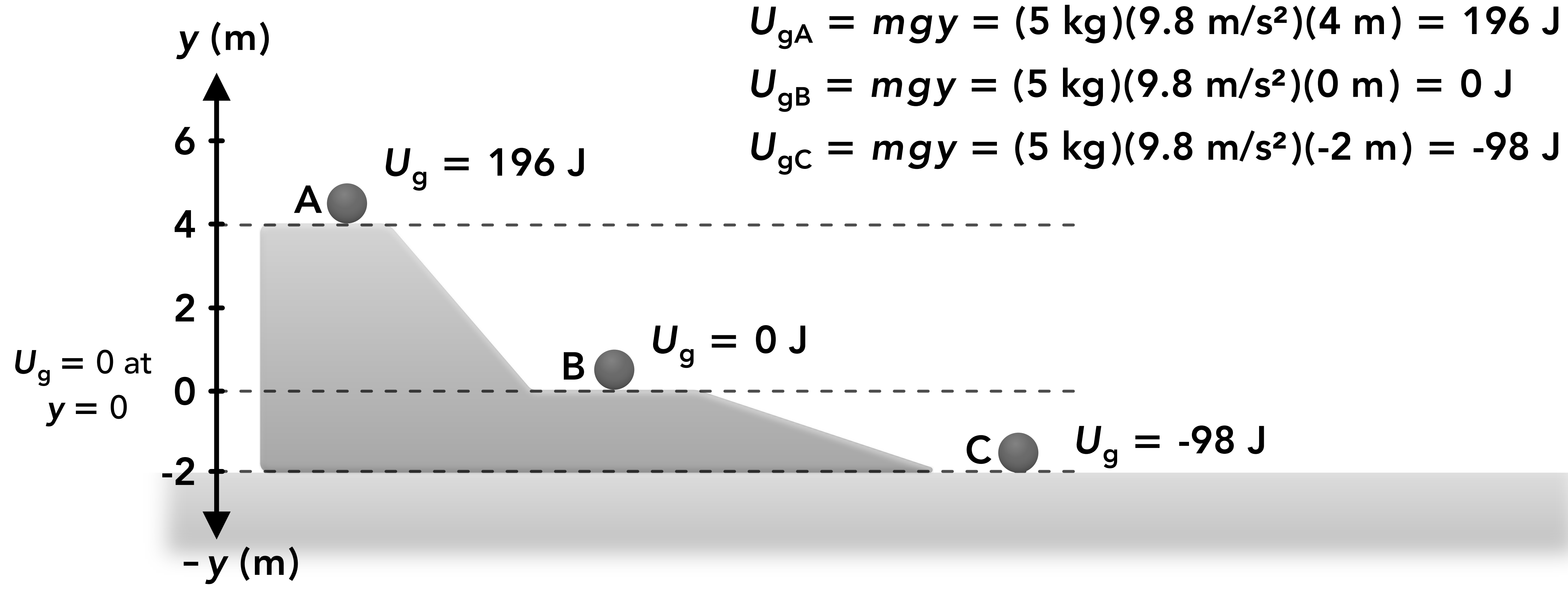
the reference point ($y = 0$) is at the ground

$$U_{gA} = mgy = (5\text{ kg})(9.8\text{ m/s}^2)(6\text{ m}) = 294\text{ J}$$
$$U_{gB} = mgy = (5\text{ kg})(9.8\text{ m/s}^2)(2\text{ m}) = 98\text{ J}$$
$$U_{gC} = mgy = (5\text{ kg})(9.8\text{ m/s}^2)(0\text{ m}) = 0\text{ J}$$



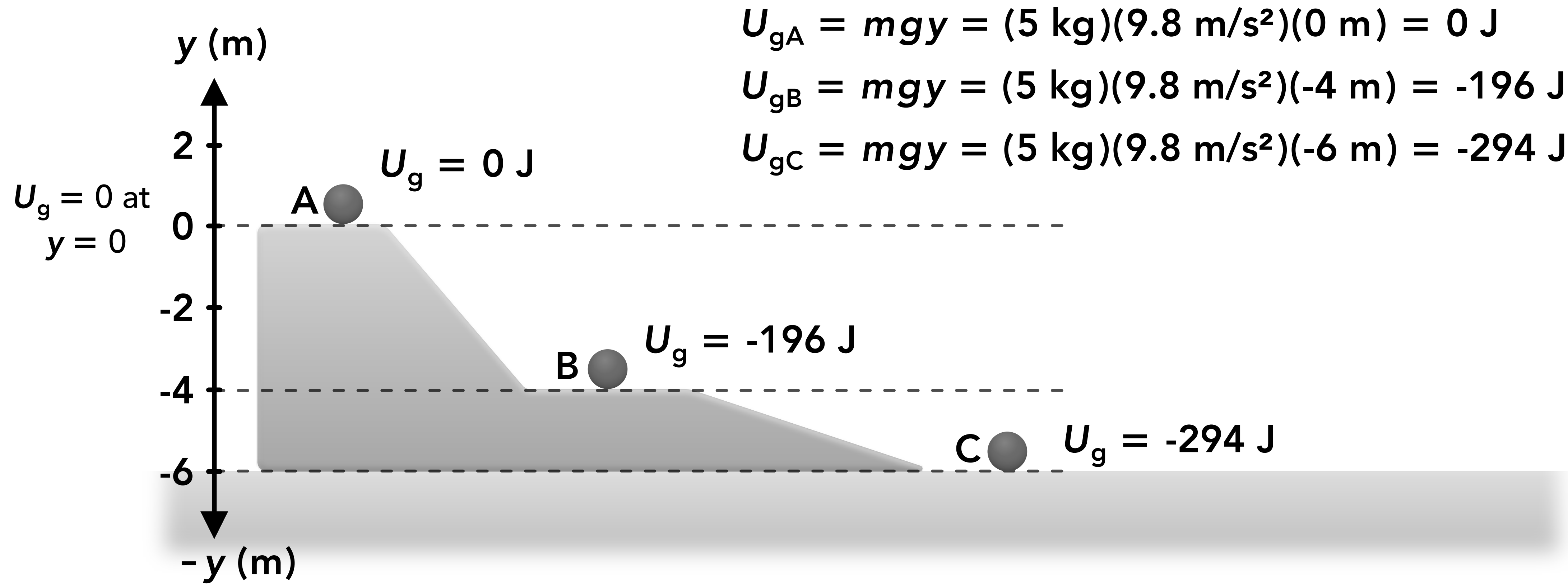
the reference point ($y = 0$) is at the height of point B

$$U_{gA} = mgy = (5\text{ kg})(9.8\text{ m/s}^2)(4\text{ m}) = 196\text{ J}$$
$$U_{gB} = mgy = (5\text{ kg})(9.8\text{ m/s}^2)(0\text{ m}) = 0\text{ J}$$
$$U_{gC} = mgy = (5\text{ kg})(9.8\text{ m/s}^2)(-2\text{ m}) = -98\text{ J}$$



the reference point ($y = 0$) is at the height of point A

$$U_{gA} = mgy = (5\text{ kg})(9.8\text{ m/s}^2)(0\text{ m}) = 0\text{ J}$$
$$U_{gB} = mgy = (5\text{ kg})(9.8\text{ m/s}^2)(-4\text{ m}) = -196\text{ J}$$
$$U_{gC} = mgy = (5\text{ kg})(9.8\text{ m/s}^2)(-6\text{ m}) = -294\text{ J}$$



Other Types of Energy

- Kinetic energy, gravitational potential energy and spring potential energy are all types of **mechanical energy**.
- There are other types of energy that are categorized as **non-mechanical energy** such as thermal energy, sound energy, light energy, chemical energy and electrical energy.

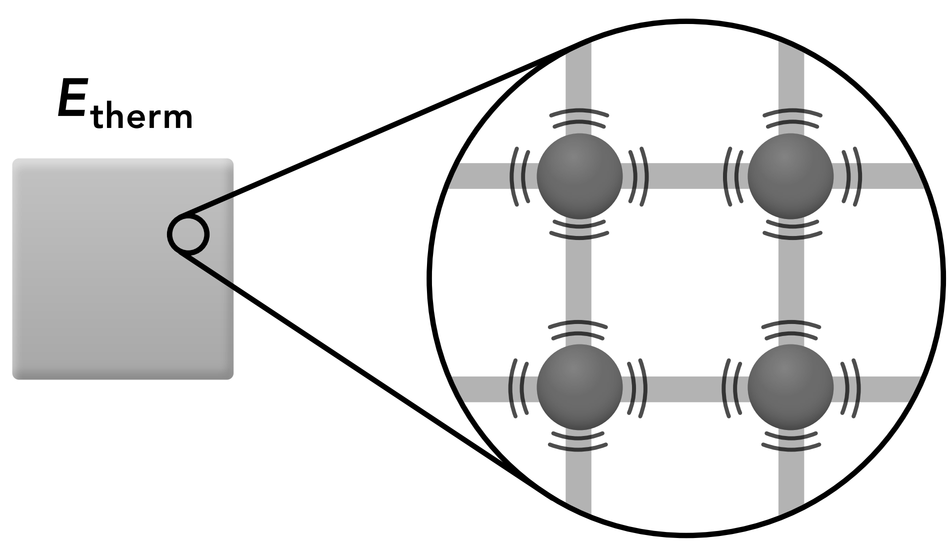
Mechanical energy

- K - Kinetic energy
- U_g - Gravitational potential energy
- U_{sp} - Spring (elastic) potential energy

Non-mechanical energy

- E_{therm} - Thermal energy
- E_{sound} - Sound energy
- E_{light} - Light energy
- E_{chem} - Chemical energy
- E_{elec} - Electrical energy

- **Thermal energy** is the energy of an object or system due to the vibrations of the atoms in the material.
- The thermal energy of an object is really the total kinetic energy of all of its atoms, and an object's temperature is the average kinetic energy of all of its atoms.
- The atoms in an object with a higher temperaure are vibrating (translating and rotating) more than the atoms in an object with a lower temperature.
- When there is kinetic friction between two objects, some of the kinetic energy of the moving object is converted into the increased thermal energy of both objects, raising their temperatures.



the thermal energy and temperature of the block is due to the vibrational kinetic energy of its atoms

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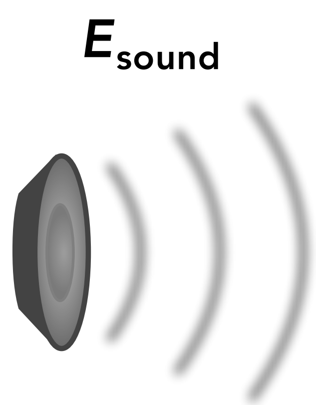
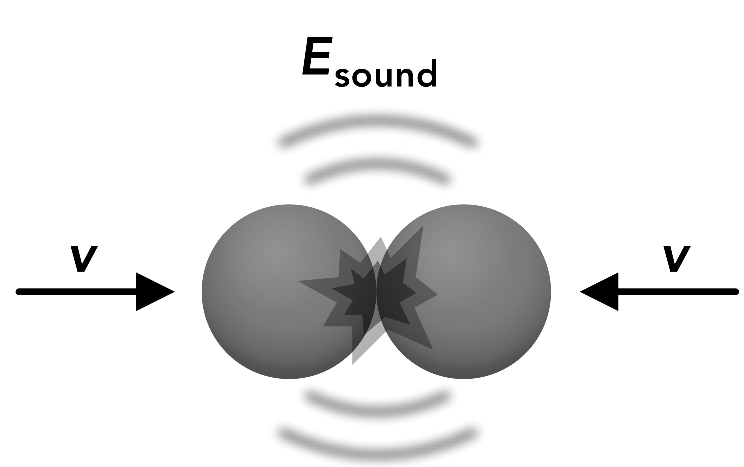
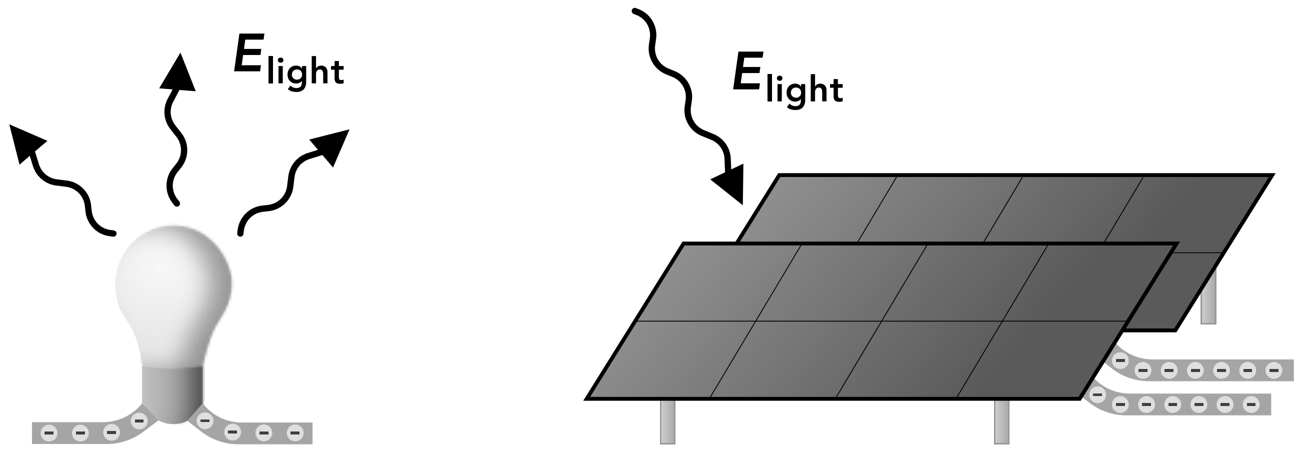
- **Sound energy** is the energy of sound waves traveling through the air or another medium.
- Sound energy is a combination of pressure energy (a form of potential energy) and the kinetic energy of the molecules as they move or vibrate.
- During a collision of two objects, some of the kinetic energy is converted into sound energy, creating the sound that you hear from the collision.





some of the kinetic energy during is a collision is transformed into sound energy

- **Light energy** is the energy of light waves, which is just a form of electromagnetic wave energy.
- The electrical energy in the filament of a lightbulb is converted into light energy (and thermal energy) which is the light emitted from the bulb.
- The light energy from the sun can be converted into electrical energy using solar panels.



energy is converted between electrical energy and light energy in a light bulb and a solar panel

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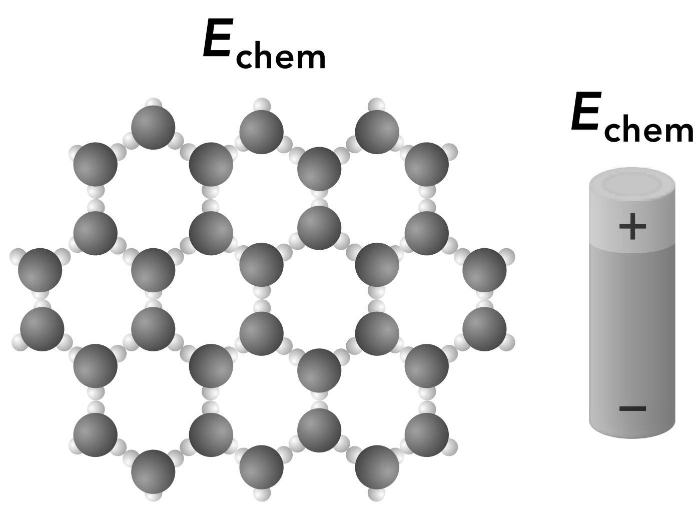
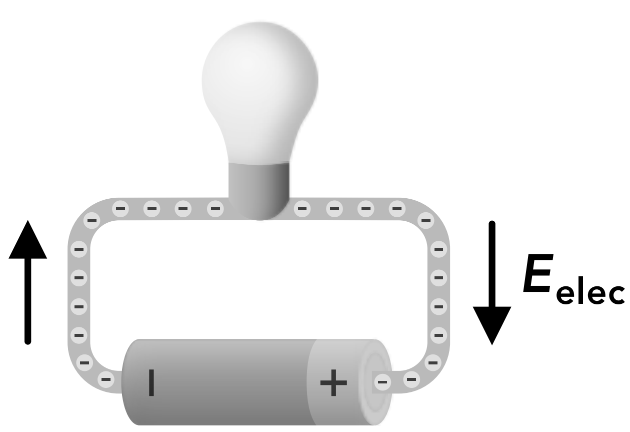
- **Chemical energy** is the energy stored in the chemical bonds in a material.
- Energy is required to form chemical bonds, and chemical energy is released and converted into other forms when those chemical bonds are broken or change in some way during a chemical reaction.
- The chemical energy in the food we eat is converted into other forms of energy that we can use.
- The chemical energy in a battery is converted into electrical energy, which can be converted into other types of energy like light, sound, heat or mechanical energy.

chemical energy is stored in chemical bonds



during chemical reactions the energy is converted into light, thermal, electrical or other forms of energy

- **Electrical energy** is the energy due to the movement of electrons.
- The chemical energy in a battery is converted into electrical energy when connected to a circuit, which can be converted into other types of energy like light, heat, sound or mechanical energy.



the chemical energy in a battery is converted into electrical energy, which is converted into light and thermal energy in the lightbulb