4.2 Potential Energy

What is Potential Energy?
- Potential energy (PE) is the energy stored inside of objects because of their position, stresses inside of the object, or their charge.
- The name means that PE stored inside of an object is not useful until it is released and transformed into another type of energy (motion, heat); in other words, it is the "potential" to create other types of energy.
- Example: a stretched bow contains potential energy that is released when the archer releases the bowstring, this becomes kinetic energy in the arrow.
- There are several kinds of PE, in Science 10 we will focus on the PE of objects in Earth’s gravity.
- The SI unit of potential energy is the joule, abbreviated J.

Acceleration
- "Let's go faster!"
- Newton's First Law: Objects cannot instantly change their velocities due to inertia (which is the resistance of objects against changes in motion, remember).
- Instead, their velocities must change by increasing or decreasing the change in velocity over time, called acceleration, measured in meters per second squared (m/s²).

Example: as a rollercoaster climbs up its velocity decreases, when it rides down its velocity increases, and when it coasts its velocity is constant.

\[ \dot{a} = \frac{\Delta v}{\Delta t} \]
\[ a = \frac{v}{s} \]
Brian Cox visits the world’s biggest vacuum chamber

Human Universe: Episode 4

Preview

BBC Two

https://www.wired.com/2014/11/dropping-objects-worlds-largest-vacuum-chamber/

Apollo 15 Proves Galileo Correct

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Calculating Potential Energy

- The formula for potential energy is: \( PE = mgh \) 

What Does the Formula Mean?

- On Earth, the acceleration of gravity is a constant (it never changes).
- PE changes linearly with the height of the object, so an object with double the height has double the PE, \( \frac{h}{2} \) the height has \( \frac{1}{2} \) the PE, and so on:

\( n=0 \rightarrow PE = 0 \text{ J} \)

\( n=1 \rightarrow PE = 10 \text{ J} \)

\( n=2 \rightarrow PE = 40 \text{ J} \)

\( n=3 \rightarrow PE = 90 \text{ J} \)

- PE also changes linearly with the mass, so an object with double the mass has double the PE, triple the mass has triple the PE, and so on:

\( PE = 0 \text{ J} \)

\( PE = 25 \text{ J} \)

\( PE = 50 \text{ J} \)

\( PE = 150 \text{ J} \)
**Tips for Using the Formula**
- There is only one operation (multiplication) in this formula, so there is no order of operations to worry about.
- Remember that the acceleration of gravity is always 9.81 m/s² on Earth; so this is not something that you need to calculate.

**Practice:** What is the potential energy of a 62 kg man who is a 1.8 m tall tightrope walker?

\[ m = 62 \text{ kg}, \quad h = 1.8 \text{ m}, \quad g = 9.81 \text{ m/s}^2, \quad \text{PE} = ? \]

\[ \text{PE} = mgh = (62 \text{ kg})(9.81 \text{ m/s}^2)(1.8 \text{ m}) = 1121.5 \text{ J} \]

**Practice:** What is the PE of a penny with mass 0.000235 kg held at 276 m on the top deck of the Eiffel Tower?

\[ m = 0.000235 \text{ kg}, \quad h = 276 \text{ m}, \quad g = 9.81 \text{ m/s}^2, \quad \text{PE} = ? \]

\[ \text{PE} = mgh = (0.000235 \text{ kg})(9.81 \text{ m/s}^2)(276 \text{ m}) = 0.636 \text{ J} \]

**Other Versions of the Same Formula**
- The formula can be changed around to solve for mass or height like this:

\[ \frac{\text{PE}}{gh} = m \quad \text{and} \quad \frac{\text{PE}}{mg} = h \]

- For both of these formulas, you will find it easiest to solve the denominator (bottom of the fraction) first, and then divide the PE by that result.

**Practice:** A 6.21 kg eagle has a potential energy of 4.4 x 10⁶ J. How high is it soaring?

\[ m = 6.21 \text{ kg}, \quad \text{PE} = 4.4 \times 10^6 \text{ J} \]

\[ h = \frac{\text{PE}}{mg} = \frac{4.4 \times 10^6 \text{ J}}{(6.21 \text{ kg})(9.81 \text{ m/s}^2)} = 7.2 \times 10^3 \text{ m} \]

**Practice:** What is the mass of a skydiver waiting to jump at 3800 m with a potential energy of 3.26 x 10⁷ J?

\[ h = 3800 \text{ m}, \quad \text{PE} = 3.26 \times 10^7 \text{ J} \]

\[ m = \frac{\text{PE}}{gh} = \frac{3.26 \times 10^7 \text{ J}}{(3800 \text{ m})(9.81 \text{ m/s}^2)} = 87 \text{ kg} \]

**SUMMARY of POTENTIAL ENERGY PROBLEMS**

Gravitational potential energy (PE) is the energy of a mass due to its position in a gravitational force field. For example: when you hike up a hill, you are moving your mass away from the center of the Earth. You are lifting your mass up inside Earth’s gravitational force field, and that means that you could fall back down in the future. Because your mass now has the ability to make things move (you falling), you have more potential energy. You gain PE as you climb.

To calculate the PE of an object (relative to a place where h = 0), use the following formula:

\[ \text{PE} = mgh \]
To calculate the potential energy (\(E_p\)) of a body at a height \(h\) above the ground, use the following formula:

\[ PE = mgh \]

Where:
- Mass \((m)\) is measured in kilograms (kg)
- Gravitational field strength \((g)\) is measured in newtons per kilogram (N/kg)
- Height \((h)\) is measured in metres (m), [note: height is measured from some place where we have decided the height is zero]
- \(E_p\) is measured in joules (J)

**Note:** To earn full marks when solving science word problems, you must **Show your work**. Please refer to the problem solving steps given in class. Don’t forget to convert units into the proper base units before calculating.

**Example Problem:**

A ball of mass 1.30 kg is thrown upward and reaches a height of 24.0 m above the ground. What is the potential energy \((E_p)\) of the ball relative to the ground?

**Known Values:**
- \(m = 1.30\) kg
- \(h = 24.0\) m
- \(g = 9.80\) N/kg (on Earth)
  - [we can assume we are on Earth unless otherwise mentioned]

**Formula:**

\[ E_p = mgh \]

\[ = (1.30)(9.80)(24.0) \]

\[ = 305.76 \text{ (not rounded)} \]

\[ = 305 \text{ J (rounded, with units)} \]