



# ENERGY

itp  
CAMP

14 week course notes:  
[fddrsn.net/teaching/  
energy](http://fddrsn.net/teaching/energy)



# Agenda:

30 minutes

- **Quick energy recap from last week**

- **Kinetic energy concepts**

30 minutes

- **Experimentation**

30 minutes

- **Reconvene and compare notes**



## Conclusions:

- Energy (joule or watt-hour) is important, but surprisingly tricky to pin down in everyday terms.
- Power (watt) is the rate of energy conversion (*informally: "consumption"*).
- Power is more familiar from every day life, especially electronics.
- Power = Energy/Time, and
- Energy = Power x Time



*Review*



# 18TW

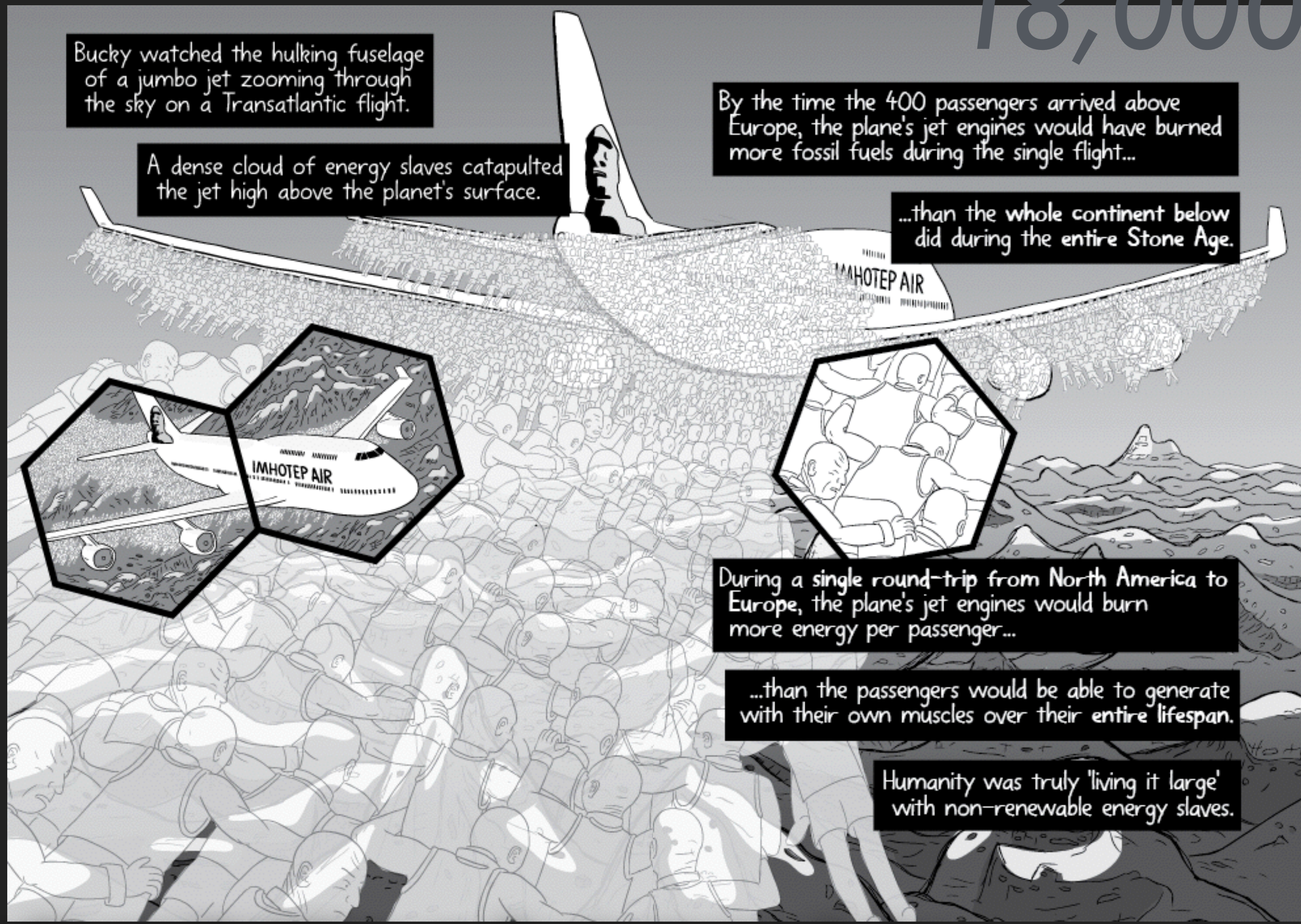
Source: EIA Total World Primary Energy Production  
~550 Quadrillion BTUs / 1 year =  $1.8 \times 10^{13}$  Watts



TW GW MW kW W  
18,000,000,000,100<sup>W</sup>

Review

Human  
2000 kilocalories / 1 day =  
**~100 Watts**



Bucky watched the hulking fuselage of a jumbo jet zooming through the sky on a Transatlantic flight.

A dense cloud of energy slaves catapulted the jet high above the planet's surface.

By the time the 400 passengers arrived above Europe, the plane's jet engines would have burned more fossil fuels during the single flight...

...than the whole continent below did during the entire Stone Age.

During a single round-trip from North America to Europe, the plane's jet engines would burn more energy per passenger...

...than the passengers would be able to generate with their own muscles over their entire lifespan.

Humanity was truly 'living it large' with non-renewable energy slaves.

• **Stuart McMillan on Buckminster Fuller**

<https://www.stuartmcmillen.com/comic/>



*Definitions (from Oxford Dictionary of Physics):*

## Energy

**A measure of a system's ability to**

**do work.** Like work itself, it is measured in joules. Energy is conveniently classified into two forms: potential energy is the energy stored in a body or system as a consequence of its position, shape, or state (this includes gravitational energy, electrical energy, nuclear energy, and chemical energy); kinetic energy is energy of motion and is usually defined as the work that will be done by the body possessing the energy when it is brought to rest. For a body of mass  $m$  having a speed  $v$ , the kinetic energy is  $mv^2/2$  (classical) or  $(m-m_0)c^2$  (relativistic). The rotational kinetic energy of a body having an angular velocity  $\omega$  is  $I\omega^2/2$ , where  $I$  is its moment of inertia.

The internal energy of a body is the sum of the potential energy and the kinetic energy of its component atoms and molecules.

It is a fundamental feature of physics that energy is always conserved in any process. It has occasionally been suggested in various contexts that energy is not conserved, but these suggestions have always turned out to be incorrect.

## Work

The work done by a force acting on a body is **the product of the force and the distance**

**moved** by its point of application in the direction of the force. If a force  $F$  acts in such a way that the displacement  $s$  is in a direction that makes an angle  $\theta$  with the direction of the force, the work done is given by:  $W = F \cdot s \cos \theta$ . Work is the scalar product of the force and displacement vectors. It is measured in joules.



*Review*

1 Volt \* 1 Amp



1 Watt  
Rate



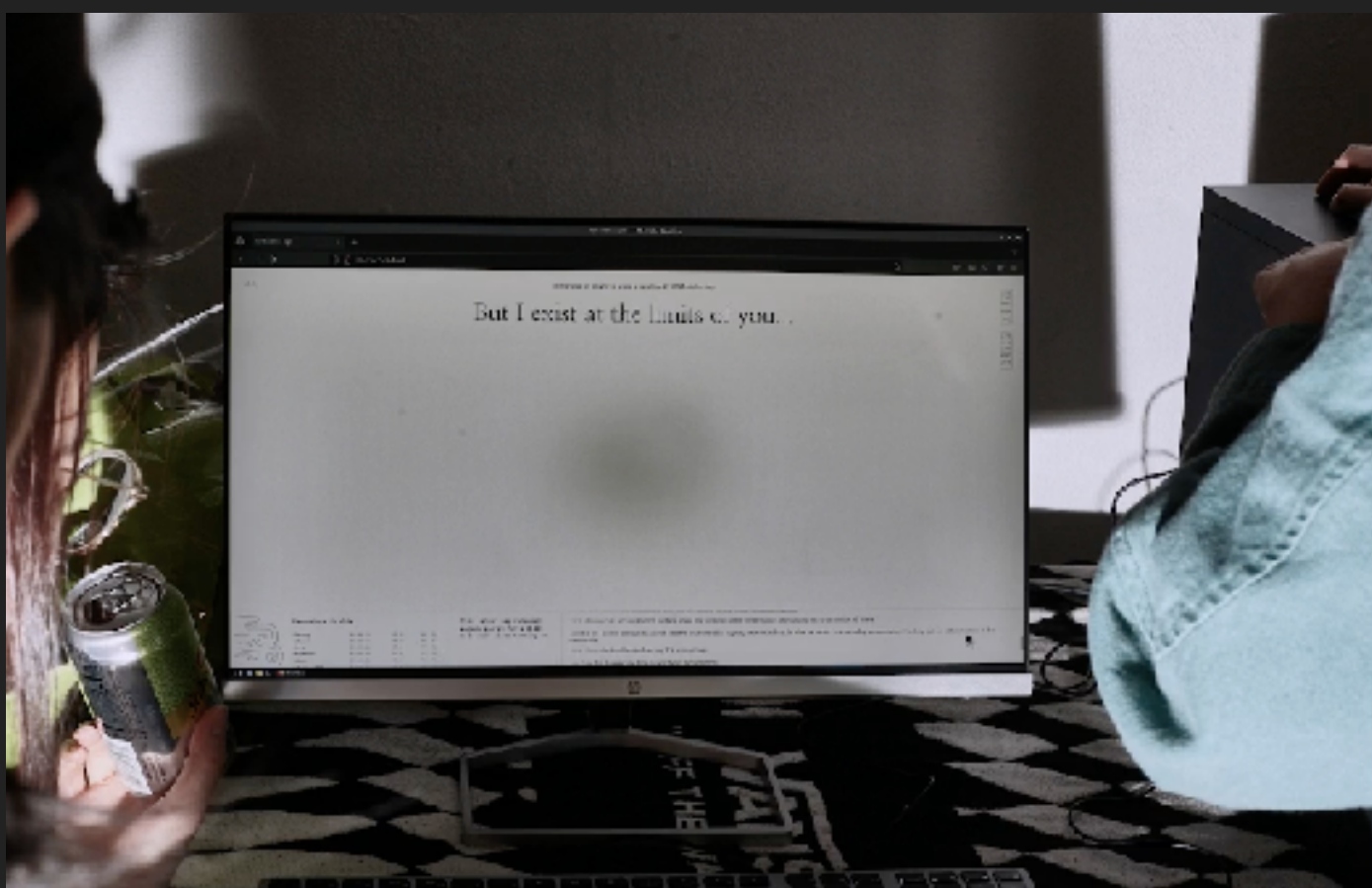
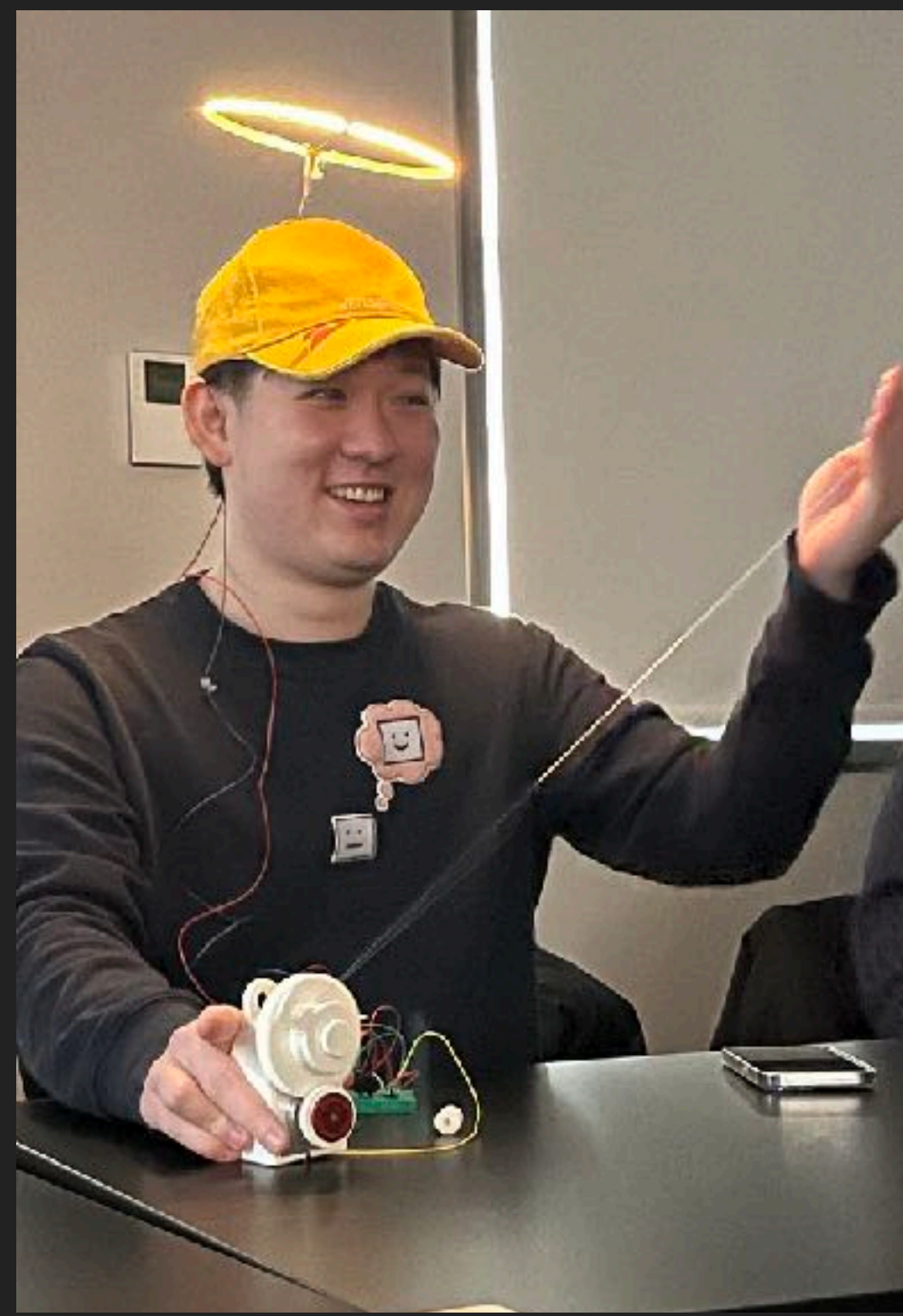
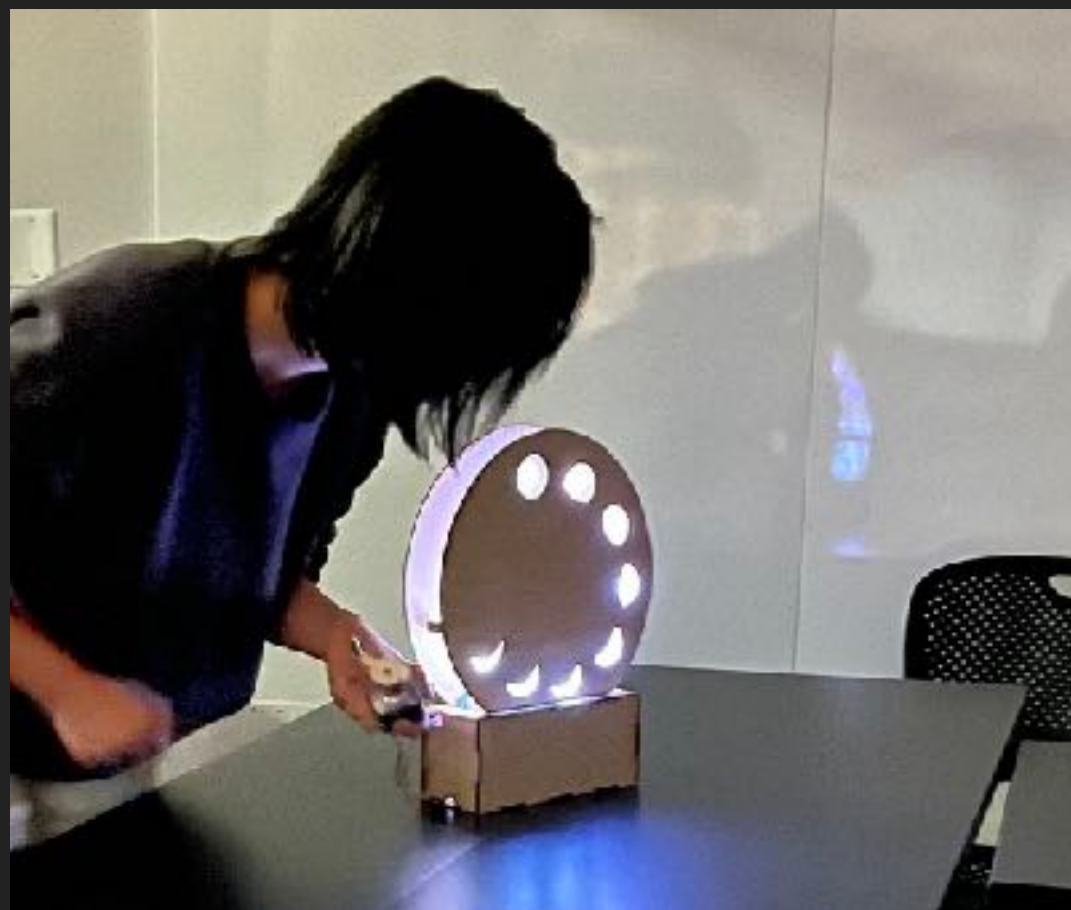
1 Joule / second  
SI Energy Unit!                      Time

What this means: We have a way to measure things with our multimeters that share units with every energy phenomenon in the universe





# Some recent kinetic assignments











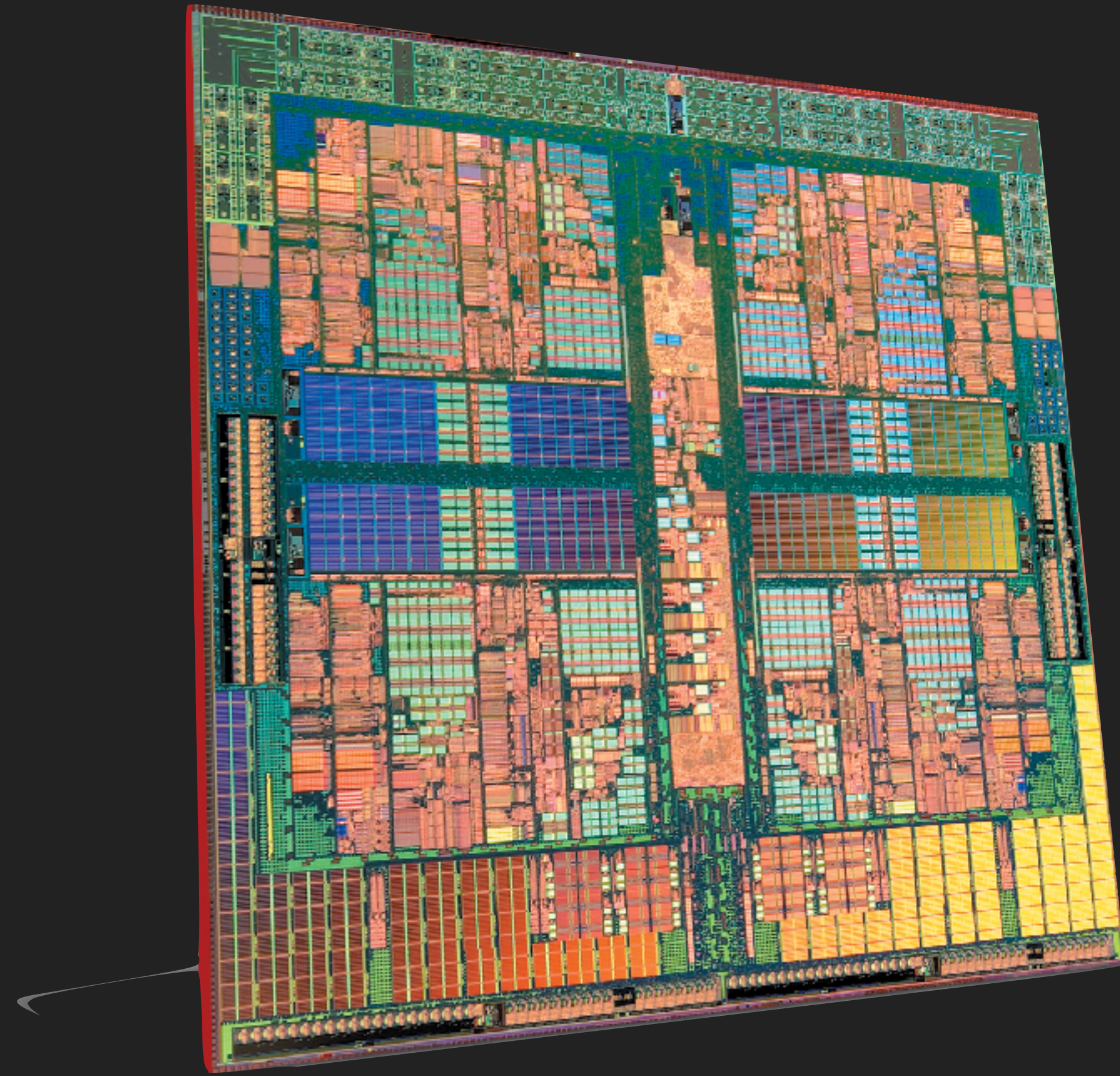


Humans move things



moving rocks





moving electrons



**To get anything moving\*, we need to exert a force.**

Newton's second law:

**Force = mass \* acceleration**

**(F = ma)**

so also

acceleration = force / mass

**SI Units:**

1 Newton force = 1 kg mass \* 1 m/s/s acceleration

**Note:**

- “Lbs” or “pounds mass” is mass in English measure
- “Pounds force” is force in English measure

From google (you can type in equations and google handles the units):



**(1 kg) \* 1 ((meter / second) / second) = 1 newton**



**This leads to definitions for energy and work in physics:**

**Work** is done when a force is applied through a distance. **Energy** is evidenced by the **capacity for doing work\***. So:

$$\text{Energy} = \text{force} * \text{distance}$$

**SI Units:**

$$1 \text{ Joule energy} = 1 \text{ Newton force} * 1 \text{ Meter distance}$$

(Since a newton is a unit of force, and  $F=ma$ , we can reduce this to:

$$1 \text{ joule} = \text{kg} * 1 \text{ m} / \text{s} / \text{s} * 1 \text{ m})$$



$$(1 \text{ newton}) * 1 \text{ meter} = 1 \text{ joule}$$



$$((1 \text{ kg}) * (1 \text{ (m}^2))) / (1 \text{ (s}^2)) = 1 \text{ joule}$$



**Power is the rate of work.**

$$\mathbf{Power = Energy / Time}$$

**SI Units:**

1 **Watt** power = 1 Joule energy / 1 second time

*so also*

1 Joule = 1 Watt \* 1 second



$$(1 \text{ joule}) / (1 \text{ second}) = 1 \text{ watt}$$



**We can perform work against the force of gravity to store energy in the position of objects in a gravitational field.**

$$\text{Gravitational Potential Energy} = mgh$$

m = mass

g = gravitational acceleration = 9.8 m/s/s

h = height

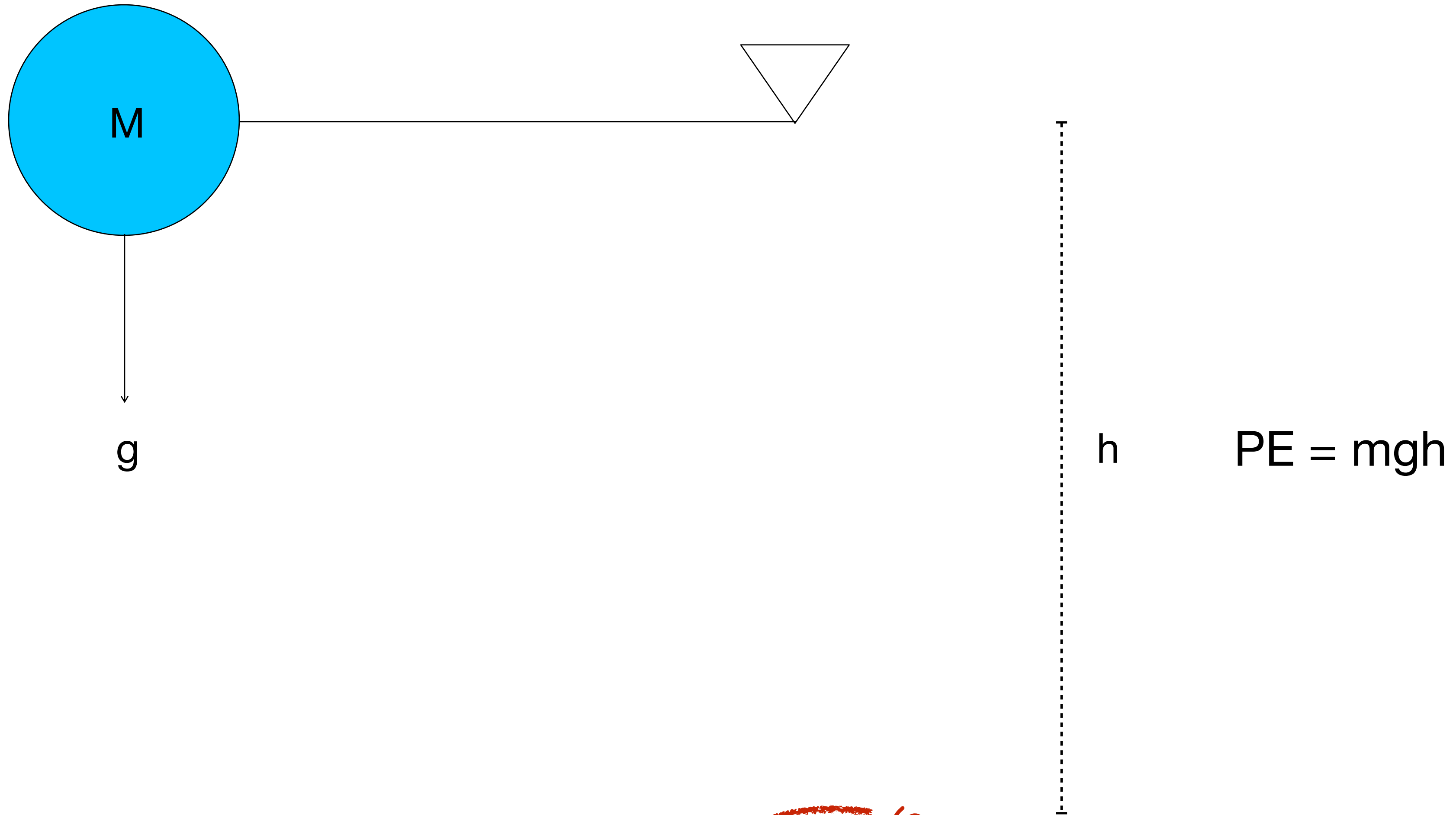
*Google Calculator handles units!*



$$(1 \text{ kg}) * (9.8 ((\text{m} / \text{s}) / \text{s})) * (1 \text{ meter}) = 9.8 \text{ joules}$$

**Note:** 9.8 is pretty close to 10! Rounding makes the math easy.





example:

$$(10 \text{ kg}) * (9.8 \text{ (m / (s^2))}) * (1 \text{ m}) =$$

**98 joules**

*(9.8 is pretty close to 10...)*



**Kinetic energy is the energy of objects in motion:**

$$\text{Kinetic Energy} = \frac{1}{2} mv^2$$

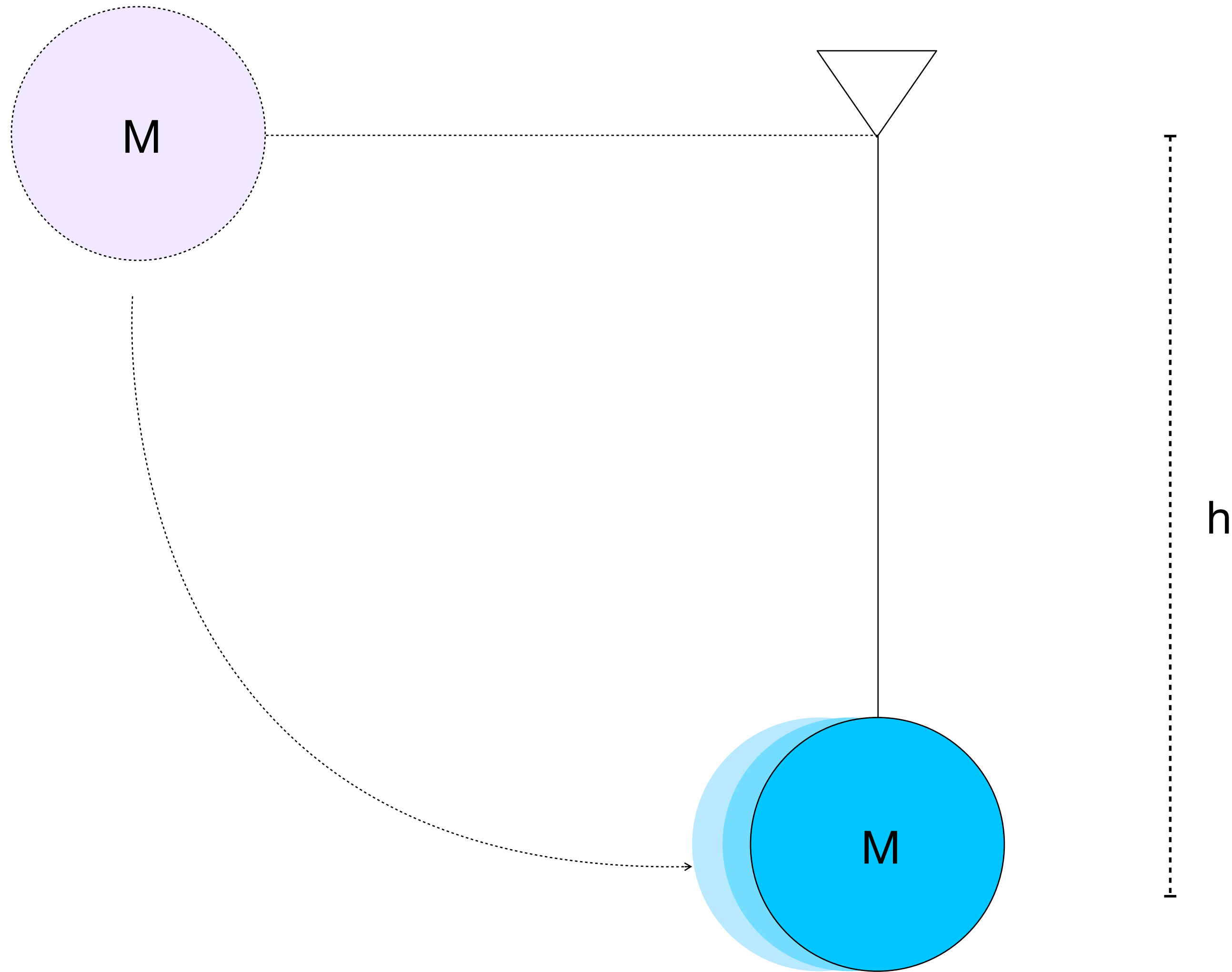
m = mass in kg

v = velocity in meters/second



$$\frac{1}{2} * (1 \text{ kg}) * ((1 \text{ m / s}))^2 = 0.5 \text{ joules}$$





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



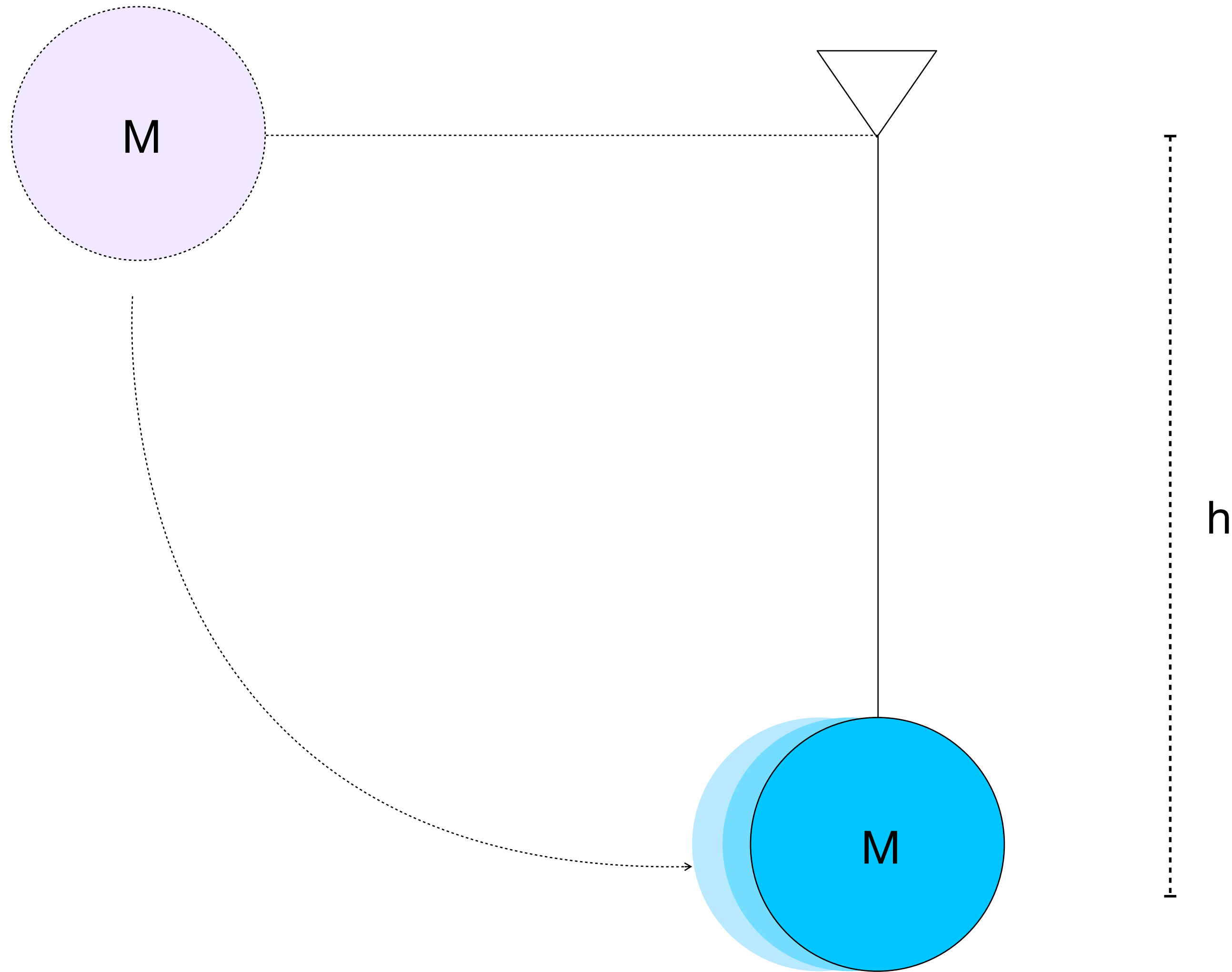
Thermodynamics:

We can't get work out of a system that isn't in the  
system in the first place.

aka 1st law, "*Conservation of energy*"

*aka "You can't win"*





On first swing, from 1st Law we can guess that:

$$\text{KE} \approx \text{PE} \text{ (energy is conserved)}$$



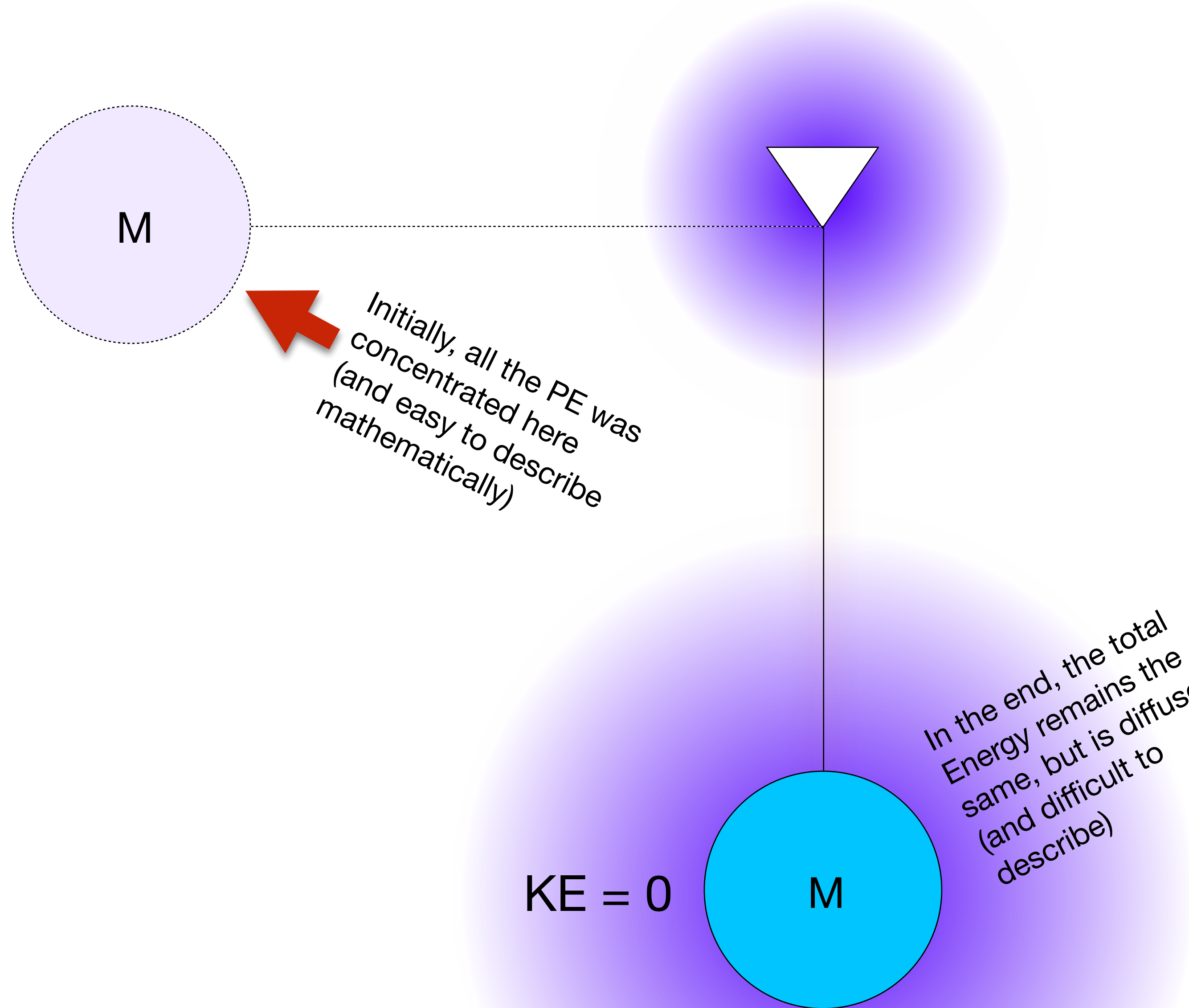
The 2nd law of thermodynamics:

Not all of the energy in a system will be available to do  
the work we want.

aka 2nd law, "*Entropy increases over time*"

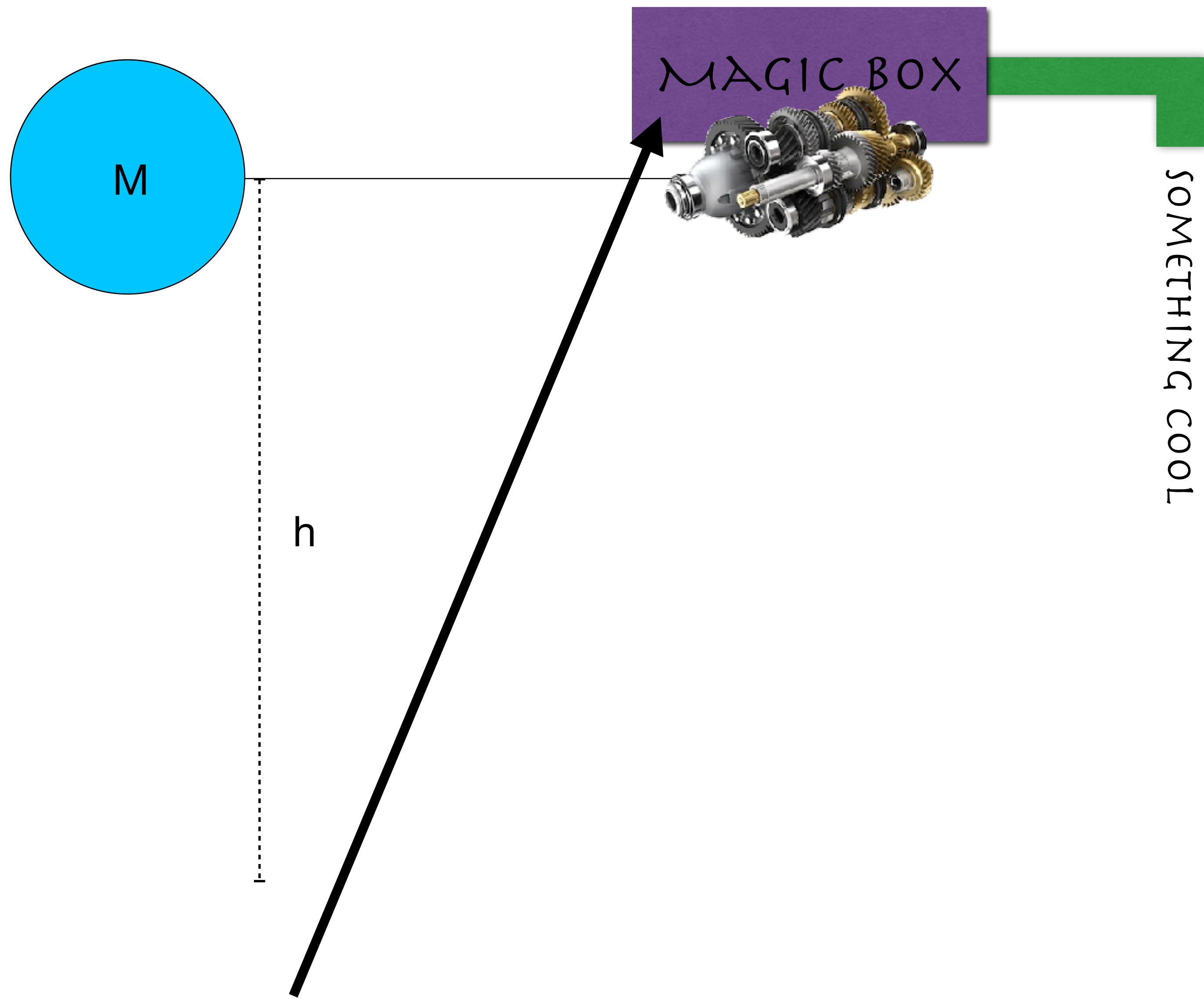
aka "You can't break even"





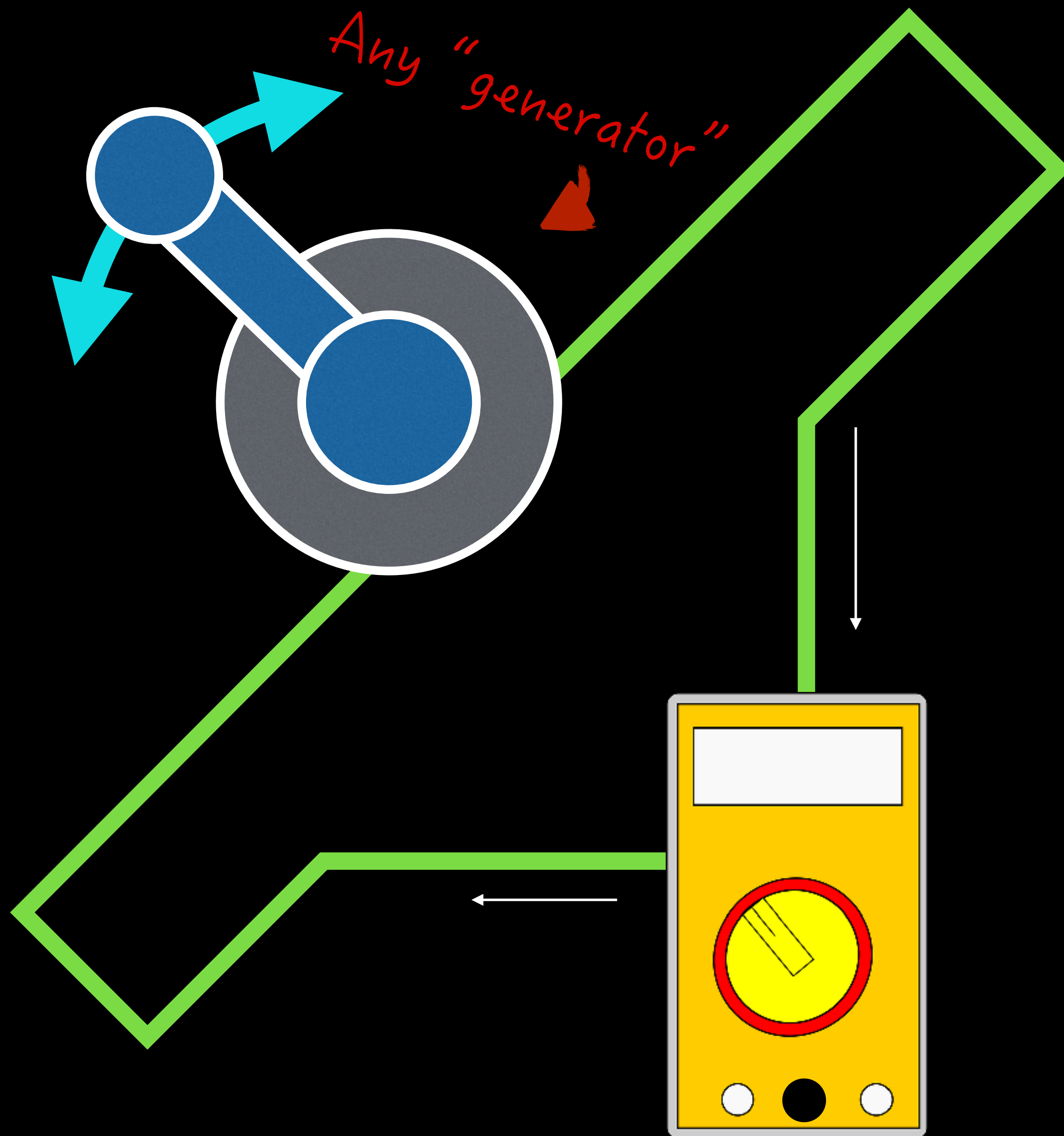
At end, we note 1st and 2nd laws. All of the original PE is *somewhere* (heat, noise, etc.), but is *more diffuse and less useful* to us.





This machine can't get do more work than initial energy input to the system (in this case, bound by  $PE = mgh$ ).





$$1\text{W (electric)} = 1\text{V} * 1\text{A}$$

We can measure

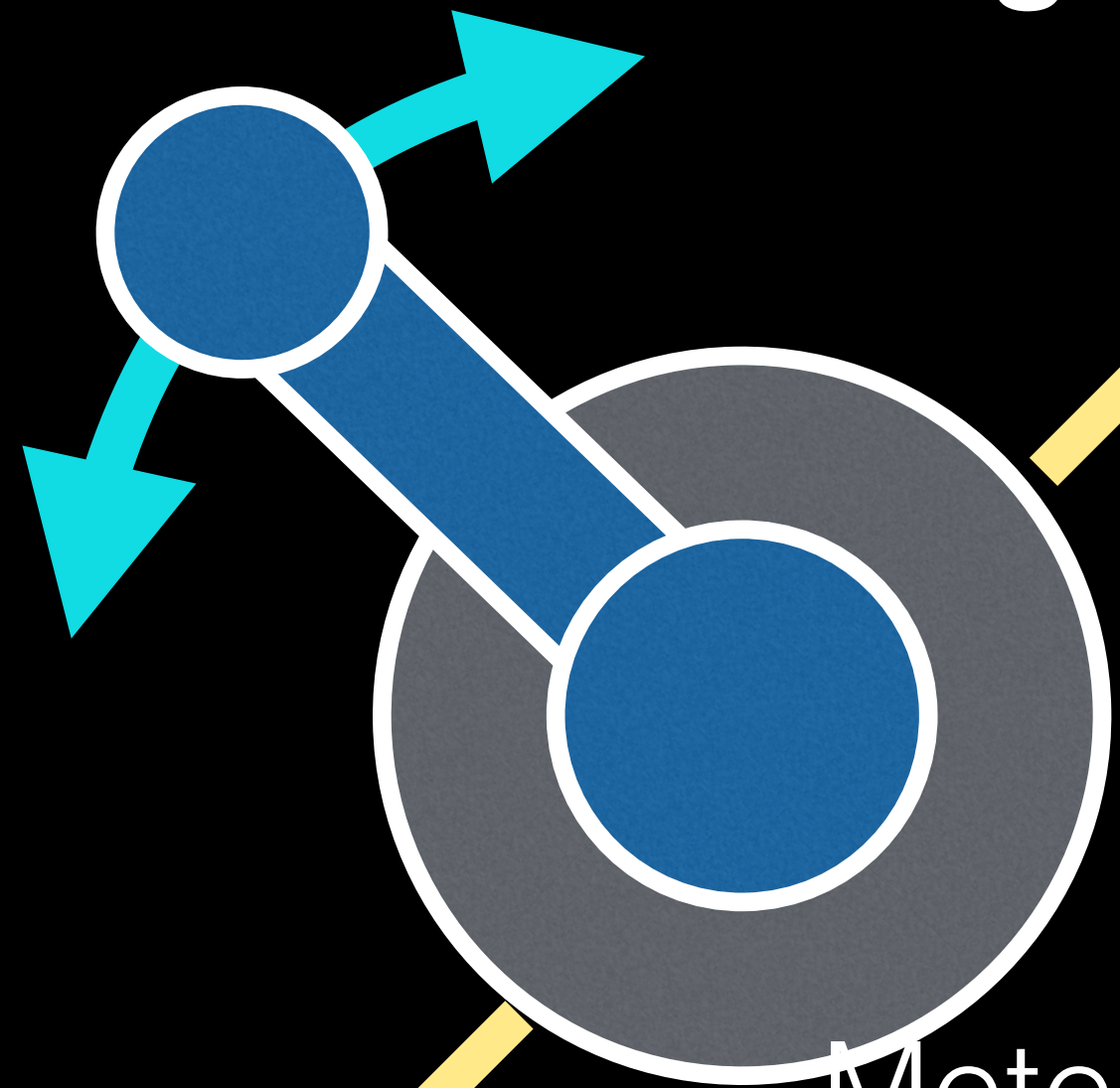
**Open Circuit Voltage**

and

**Short Circuit Current**

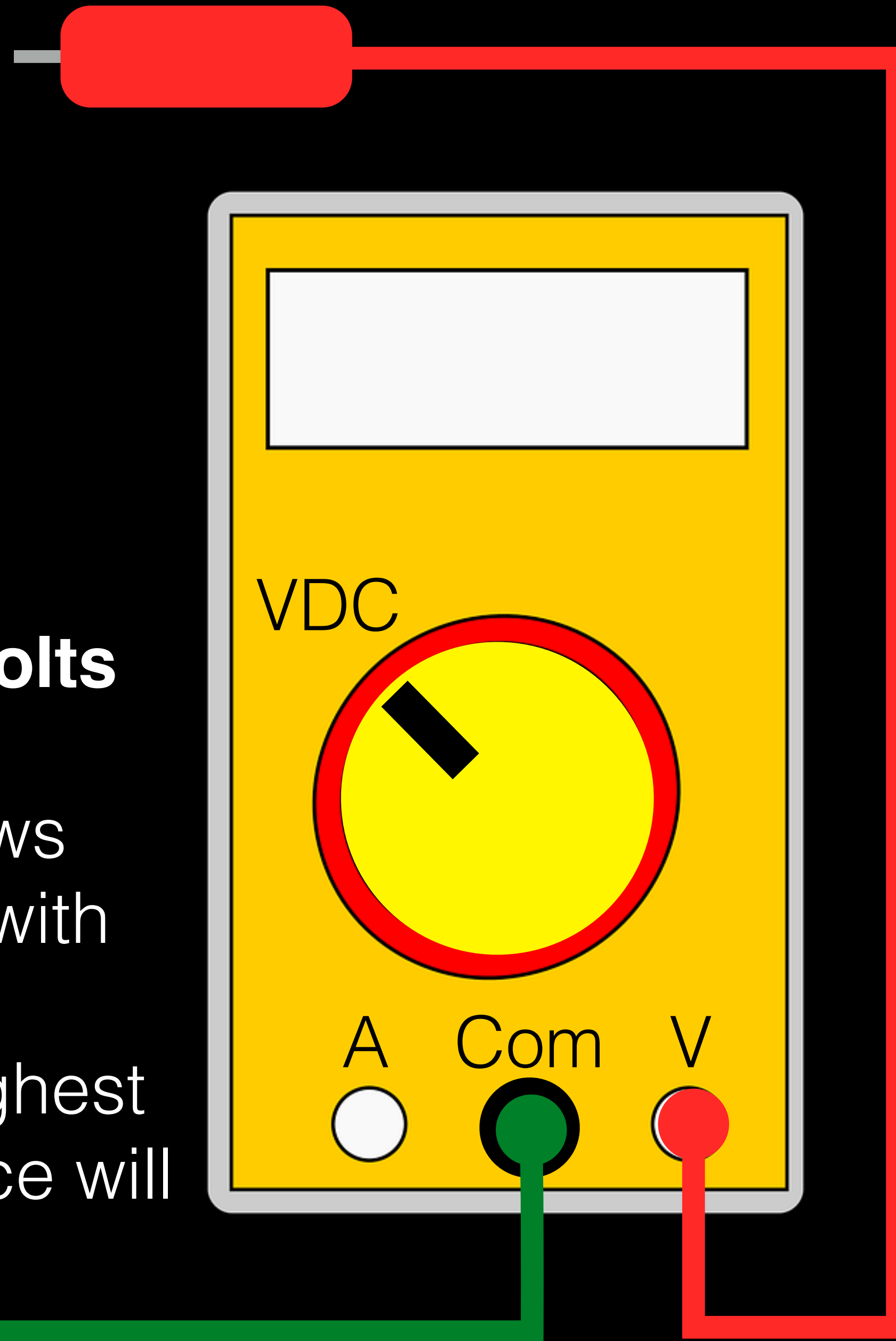


Open Circuit Voltage (OCV)<sup>+</sup>



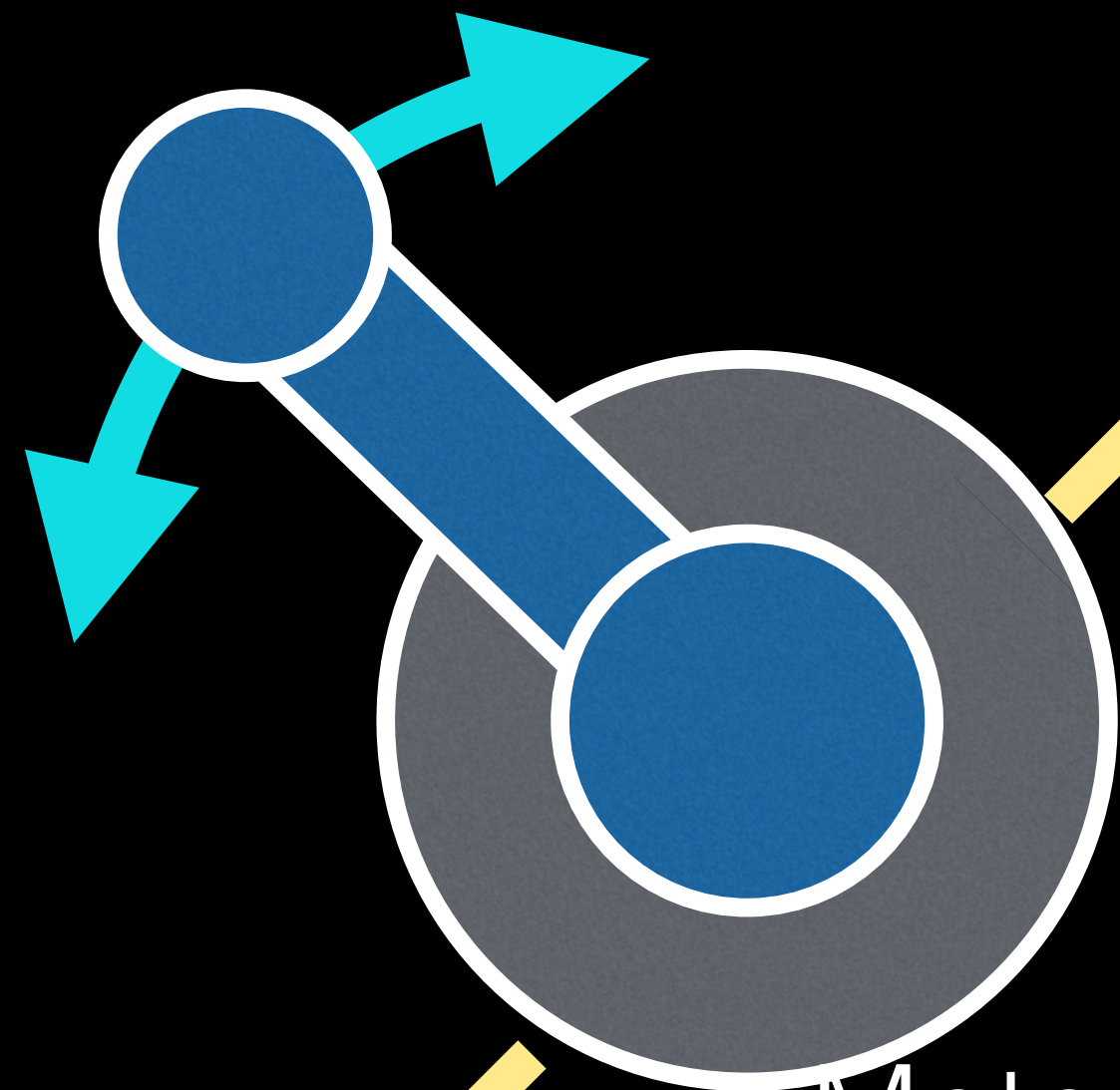
Meter on **DC Volts**

Reading shows panel voltage with **No Load** and thus the highest voltage the device will produce



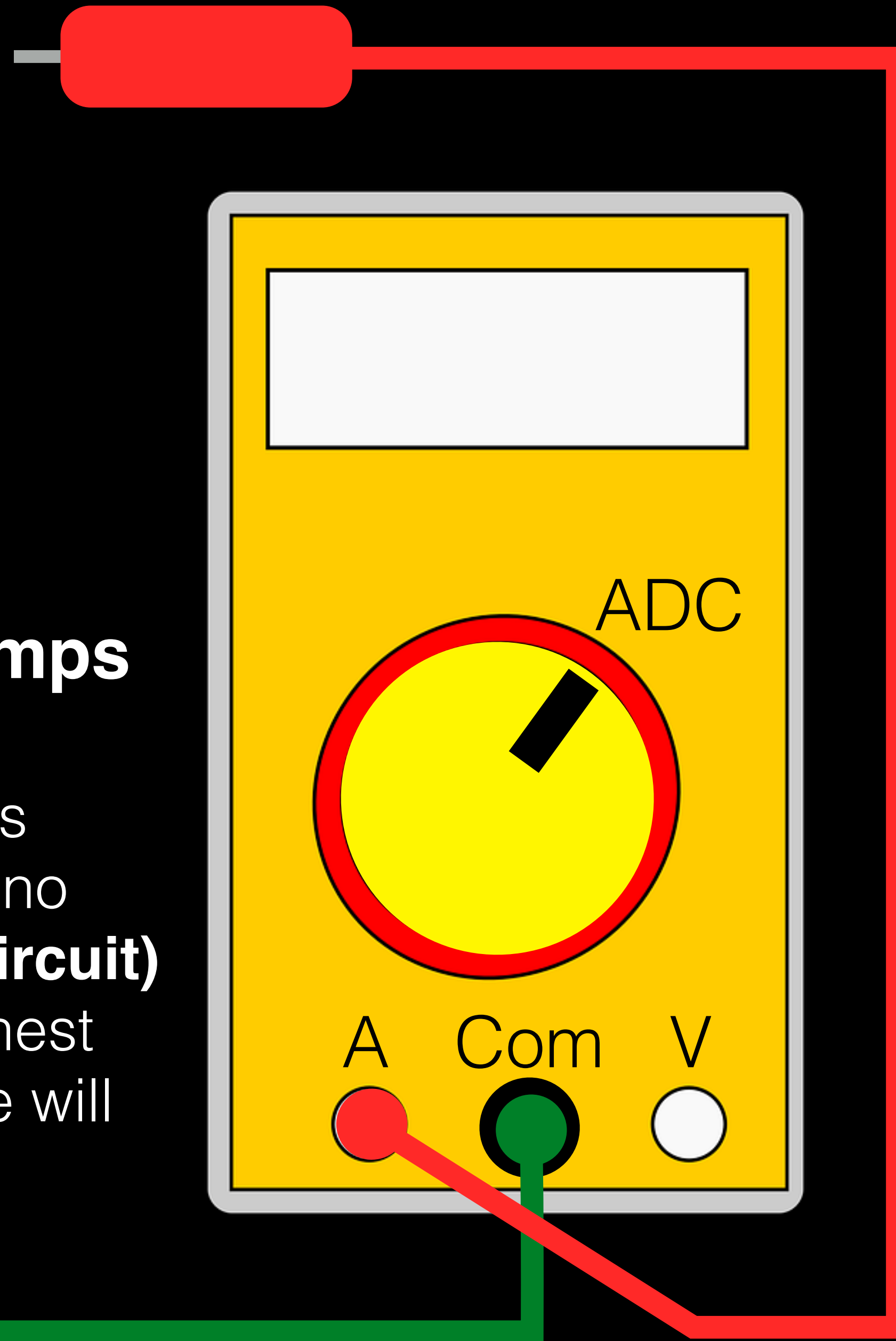


# Short Circuit Current (SCC)



Meter on **DC Amps**

Reading shows current through no resistance (**short circuit**) and thus the highest current the device will produce





**Hands-on activity:** Find magnets and coils and try to measure OCV and SCC. Then try lighting LEDs.

**If small DC motor:** Challenge is spinning fast enough, long enough, to measure. Improvise a mechanism (e.g. pull-cord wound around motor shaft), try using scope for voltage measurements.



**If DC gearmotor:** Gearbox solves issue above, so this is the easiest. Create handle for shaft



**If stepper motor:** Output is AC. Find coil pairs. Measure with Meter set to AC Volts and AC current if it has that, or use scope to see voltage waveform.

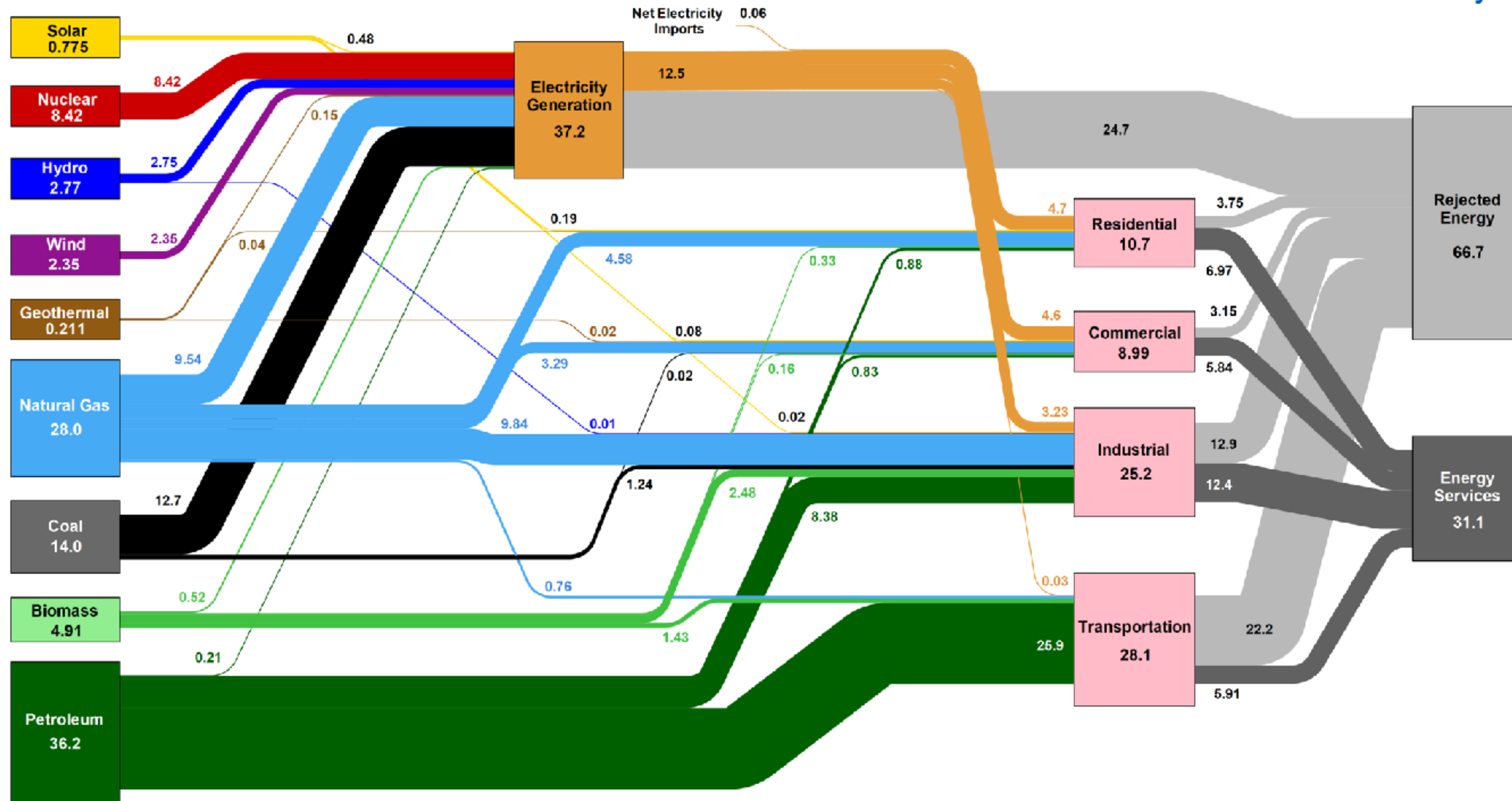








# Estimated U.S. Energy Consumption in 2017: 97.7 Quads



Source: LLNL April, 2010. Data is based on DOE/EIA MBR (2017). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration's analysis methodology and reporting. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector, and 49% for the industrial sector which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

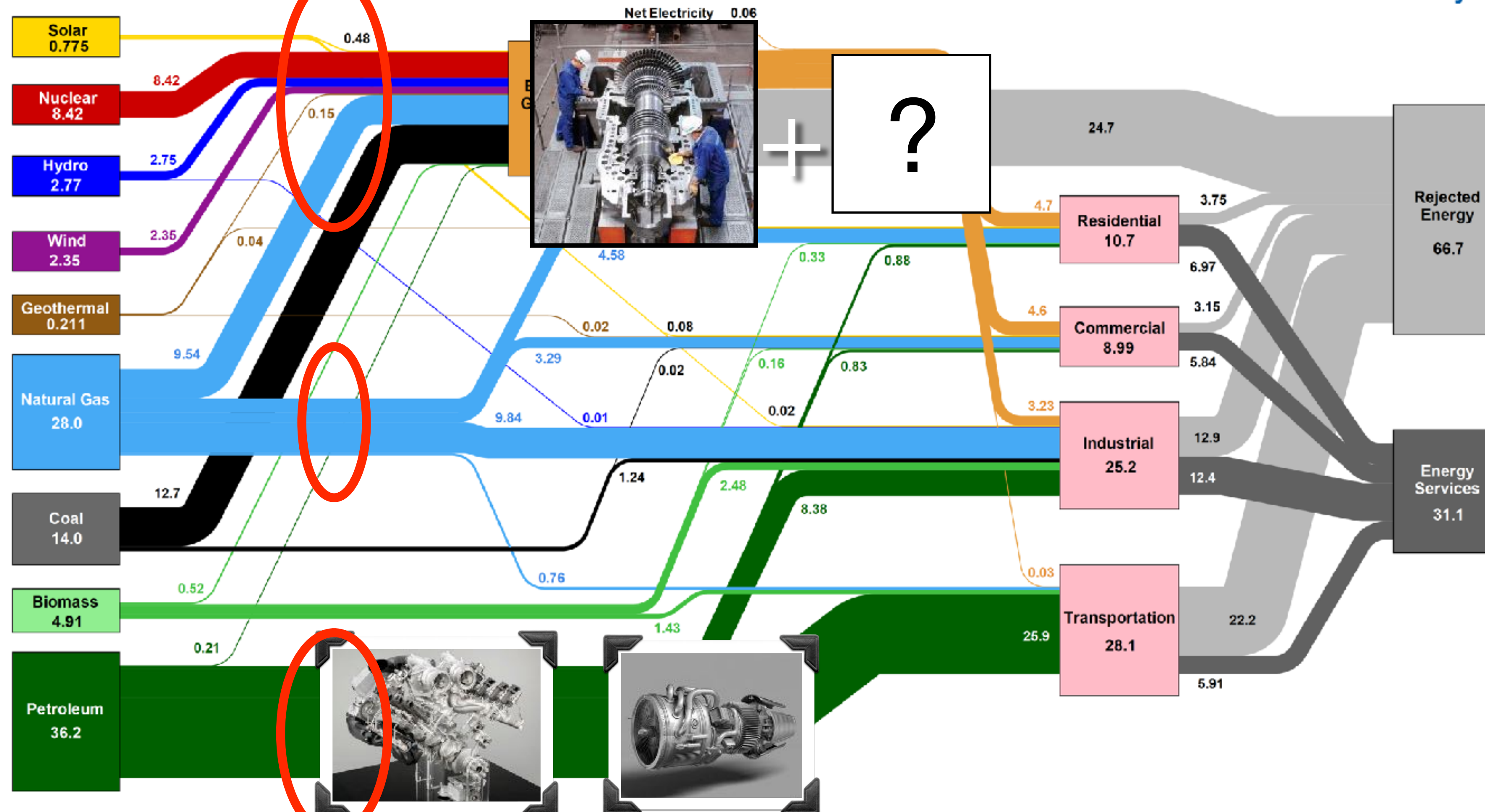
\*for more on Rejected Energy, see

\*\*for more on comparing energy quantities, see

and



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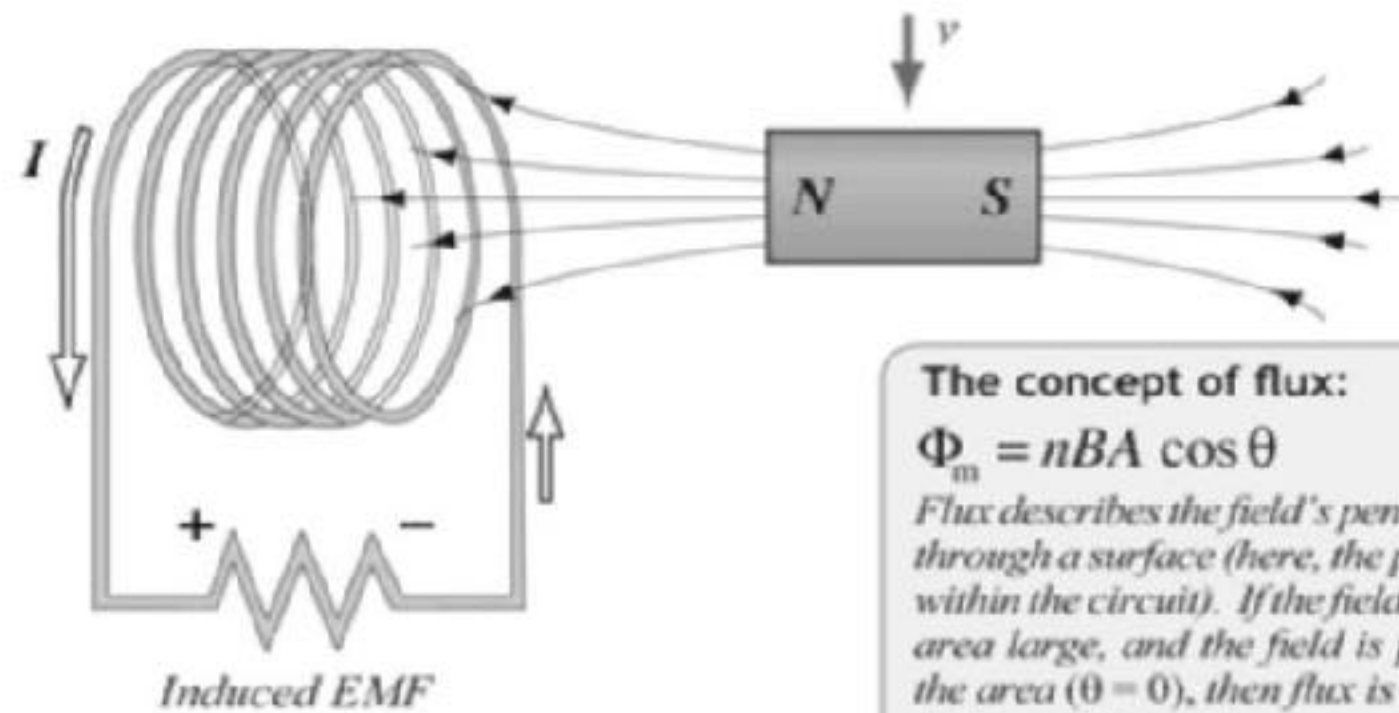
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# FARADAY'S LAW

$$\epsilon = - \frac{\Delta\Phi_m}{\Delta t}$$

$\epsilon$  = induced emf  
 $\frac{\Delta\Phi_m}{\Delta t}$  = rate of change of magnetic flux through the circuit



The concept of flux:

$$\Phi_m = nBA \cos \theta$$

Flux describes the field's penetration (or flow) through a surface (here, the plane of the loops within the circuit). If the field is strong and the area large, and the field is perpendicular to the area ( $\theta = 0$ ), then flux is high. Each turn in the coil ( $n$ ) adds more area.

Image Source: <http://wikipremid.com/01physicscards000/379a.gif>

