PennState

EGEE 102

Energy Types, Units, and Conversions

Basics

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What is Energy?

- Capacity to perform work

  Practical applications of energy

- Energy must be transferred to an object to move it

  Transportation, wind turbines, football

- Energy must be transferred to an object to heat it

  Cooking, home heating, Sun >> Earth

- Energy must be transferred to an object to light it

  Light bulb, TV, computers

- Energy is needed to “switch things on”

  Processors, chemical reactions, bio-organisms

Most fundamental energy law

!!!

Energy conservation

- Energy cannot be created or destroyed
- Energy can only be converted from one form to another.
- First Law of Thermodynamics:

Probing question

True or False?
Energy is created when we burn a ton of coal

A. True

B. False

Probing question

True or False?
Energy is created when we burn a ton of coal

A. True

B. False

Strictly speaking, energy is not “created” in the combustion process, but rather converted from chemical form (stored in the bonds of hydrocarbon fuel) to heat.

We can say that “heat is generated” in the process.

Energy is diverse

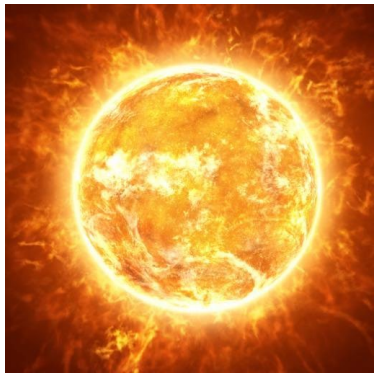
Forms of energy

- Electricity
- Heat
- Mechanical
- Chemical
- Radiation
- Nuclear

- There are many various forms of energy
- Energy can be converted from one form to another
- All forms can be represented in the same units

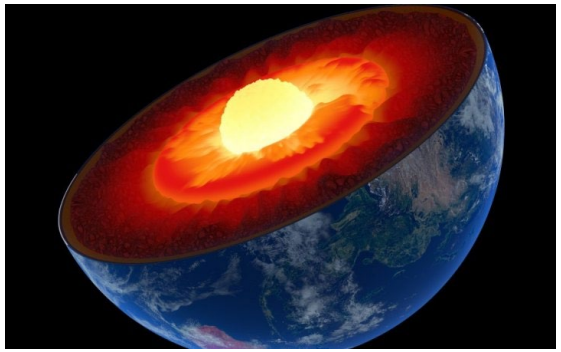
Where does Energy come from?

- From the Sun (99.9% of energy available on Earth)
  - all radiation - light and heat

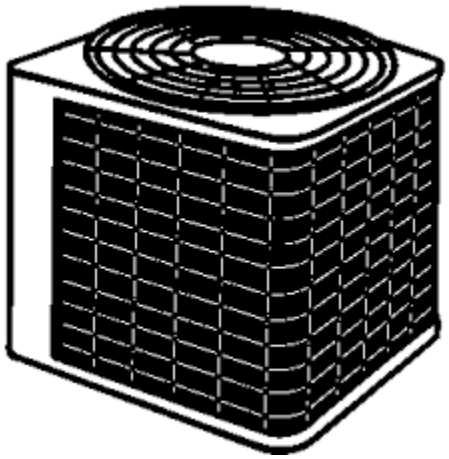


- Visible light (50%)
- Infrared (IR) radiation (40%)
- Ultraviolet (UV) radiation (10%)
- X-rays, gamma rays … - minor quantities

- From underground
  - portion of energy is stored in the Earth's core and mantle
    - Nuclear reactions
    - Liquid metal convection (in outer core)
    - Stored heat (geothermal gradient)



- From Earth and Moon gravity and motion (tides)



If one uses an air conditioner, how is it related to solar energy?

Air conditioning: Electricity to heat and compression

Transmission of electricity

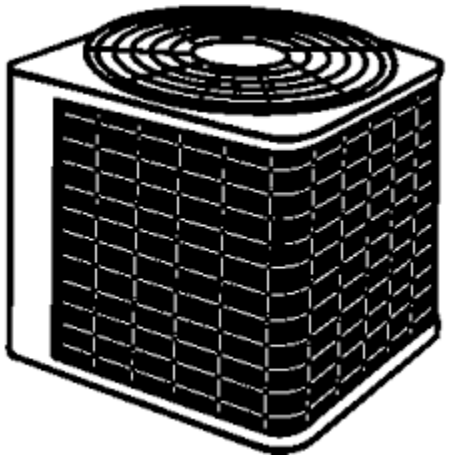
Combustion: Fuel to heat

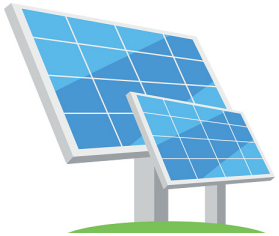
Generation: Turbine motion to electricity

Coal formation: Biomass deposition and metamorphism

Photosynthesis: Light to biomass

.. Or we can by-pass the combustion





Air conditioning:
Electricity to heat and compression

Transmission of electricity

Combustion:
Fuel to heat

Generation:
Turbine motion to electricity

Coal formation:
Biomass deposition and metamorphism

Photosynthesis:
Light to biomass

More Energy Conversion Chains

Sun ⇨ **Light Heat** ⇨ **Ground radiation** ⇨ **Wind** ⇨ **Wind turbine** ⇨ **Electricity**

Sun ⇨ **Light Heat** ⇨ **Evaporation** ⇨ **Rain Wind** ⇨ **Stream River** ⇨ **Hydro Electricity**

Sun ⇨ **Light Heat** ⇨ **Plants Photo Synthesis** ⇨ **Food** ⇨ **Human** ⇨ **Running**

Wow! Almost any type energy we have on the Earth is transformed Solar Energy

Solar flow

Incident sunlight 99.98%

Reflected sunlight 30%

Infrared radiation 70%

70%

Direct conversion to thermal energy 46%

Thermal energy

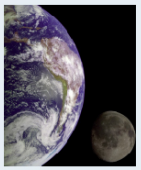
Tidal flow

Tidal energy

0.0017%

Evaporation 23%

Storage in water vapor



Motion of earth and moon

1%

Energy of wind and currents

Decay

0.008%

Geothermal flow 0.025%

Photosynthesis 0.08%

Plants

Animals

Human uses

Energy in Earth's interior

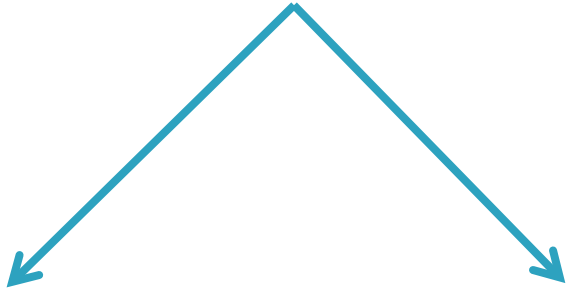
0.0005%

Fossil fuels

0.007%

Nuclear fuels

Energy types can be classified as



Electric or magnetic fields

Brownian motion of molecules (temperature)

Potential

Stored energy, static
Energy that can be potentially converted to work

Energy stored in battery

Compressed spring

Gravitational energy of apple hanging on a tree

Energy stored in chemical bonds (fuel)

or

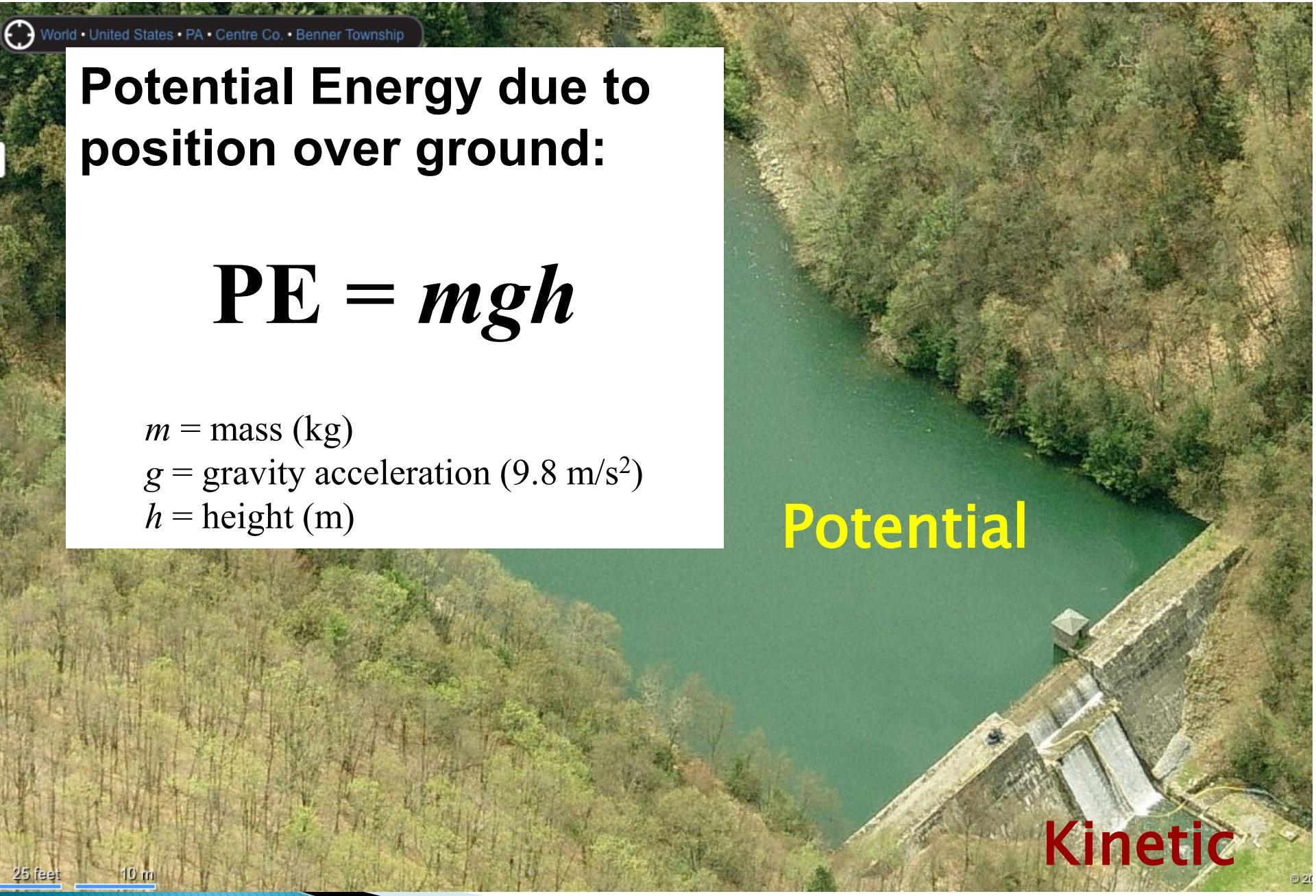
Kinetic

Related to motion, acting, working at the moment

mechanical energy of the moving train

Moving electrons (electric current)

Vibration of molecules (sound)



Potential Energy due to position over ground:

$$PE = mgh$$

m = mass (kg)
g = gravity acceleration (9.8 m/s^2)
h = height (m)

Kinetic Energy

- Kinetic energy is the energy that is possessed by a body due to its motion

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

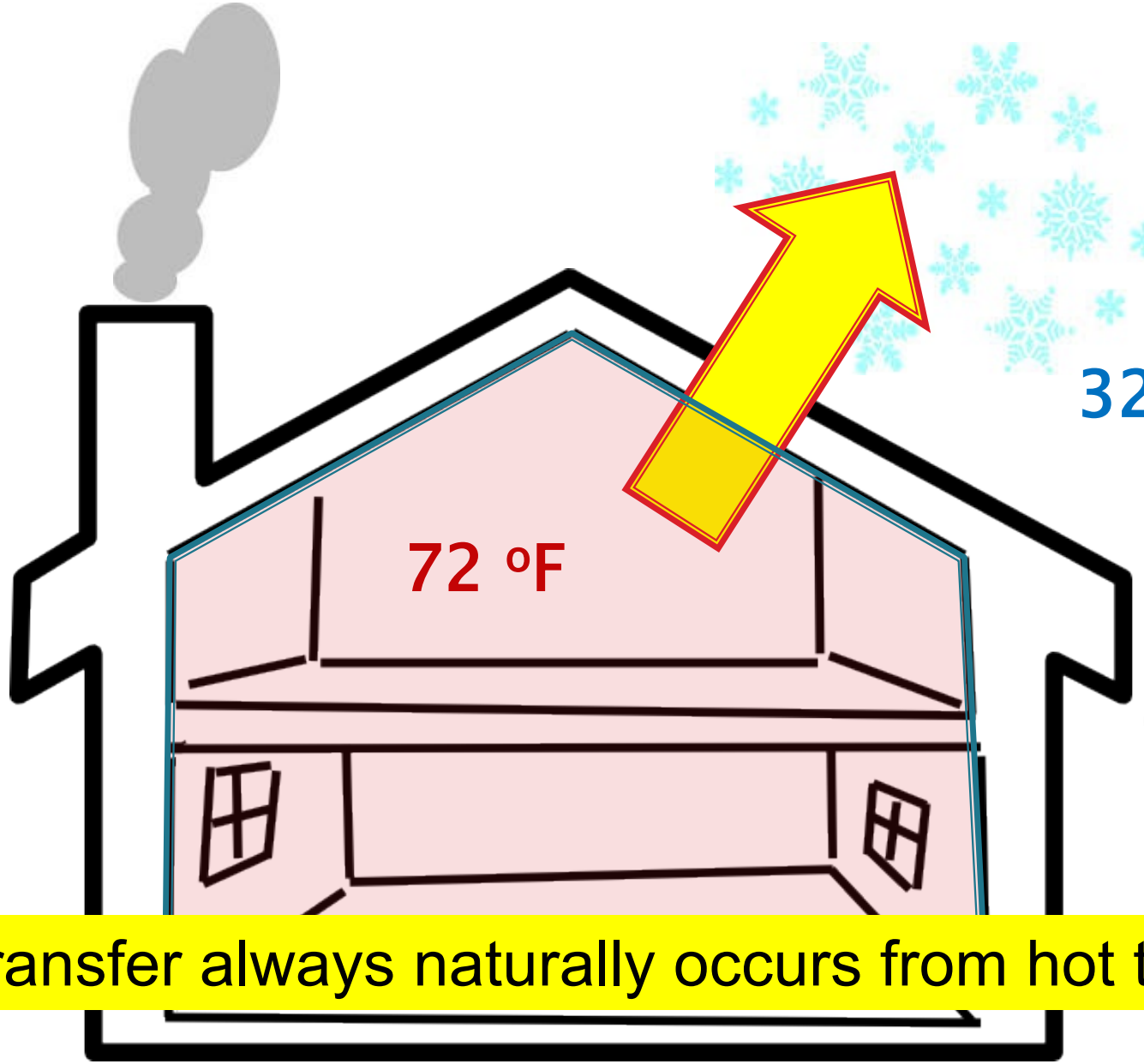
m = mass (kg)
v = velocity or speed (m/s)

Practical!
38% of the energy Americans used in 2011 was for transportation

Heat (Thermal) Energy

- Kinetic energy of random motion of molecules of a substance.
- Temperature is a measure of thermal energy.
- Easier to obtain heat than to produce work.
- Flows from a body at higher temperature (higher thermal energy) to a body at lower temperature (lower thermal energy).

https://www.youtube.com/watch?v=6VdMp46ZIL8



Heat transfer always naturally occurs from hot to cold

Temperature Scales

Scale	melting point of ice	boiling point of water
Fahrenheit (°F)	32	212
Celsius (°C)	0	100
Kelvin (K)	273	373

$$(^{o}C \times 1.8) + 32 = {}^{o}F$$

$$(^{o}F - 32) / 1.8 = {}^{o}C$$

$$^{o}C + 273.15 = K$$

Chemical Energy

- Energy that is **stored** in the chemical bonds that hold molecules together
- A special kind of potential energy
- When chemicals combine or react, energy is released usually in the form of heat, radiation, or electricity (battery)
- Examples?

Natural gas combustion:

https://www.youtube.com/watch?v=6zd1S_LJOlk

Chemical Energy example

Energy is stored in iron powder. Water, salt, activated charcoal, and vermiculite are also present. Oxygen in the air reacts with the iron to make iron oxide, releasing heat.

Probing question:

What energy types are involved in car driving?

1. Gasoline contains **chemical energy** in hydrocarbon bonds

2. Combustion of gasoline produces heat – **thermal energy**

3. Heat results in expansion of gas in the cylinder pushing piston – **mechanical energy**

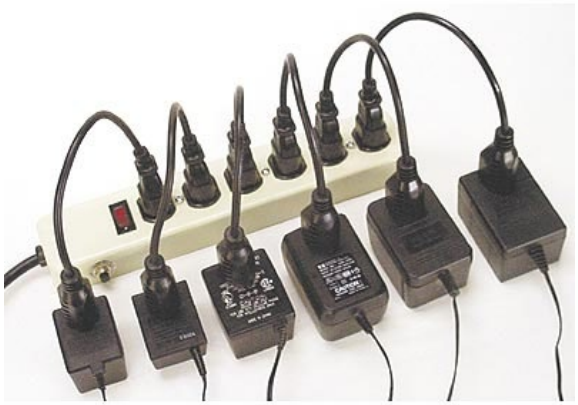
4. Energy from pistons is transferred via gears to rotation wheels and forward motion of car –**mechanical energy**

5. Energy from engine is transferred to generator which makes **electricity** for lights and for charging battery

6. Human drinking coffee and pushing on the gas pedal (conversion of **chemical energy to mechanical**)

Electrical Energy

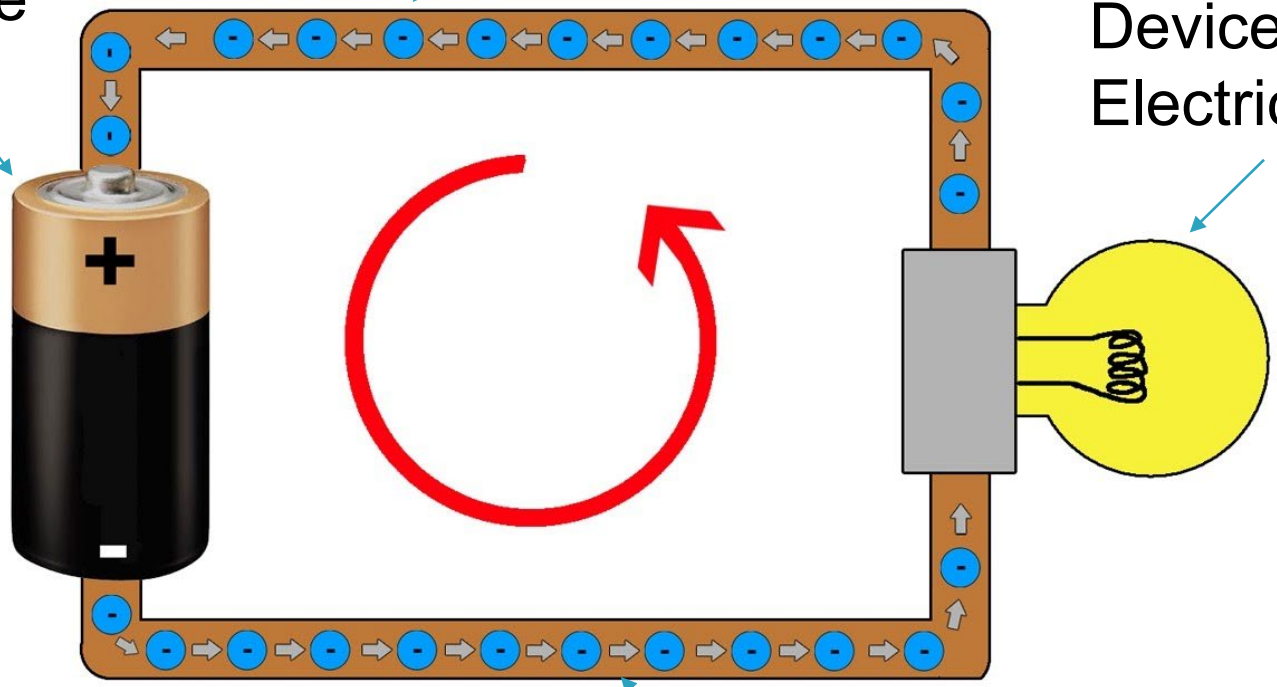
- Special form of kinetic energy.
- Energy of electrons in motion (electric current).
- Intermediate form in which energy is transported and distributed.
- Requires conductors (e.g. metal wires) with free electrons to pass current
- Typically produced under action of electric potentials or magnetic fields
- Easily converted to other forms of energy.



Electrons – negatively charged particles

Electric source

Energy conversion Device – **light bulb**
Electricity >>> Light



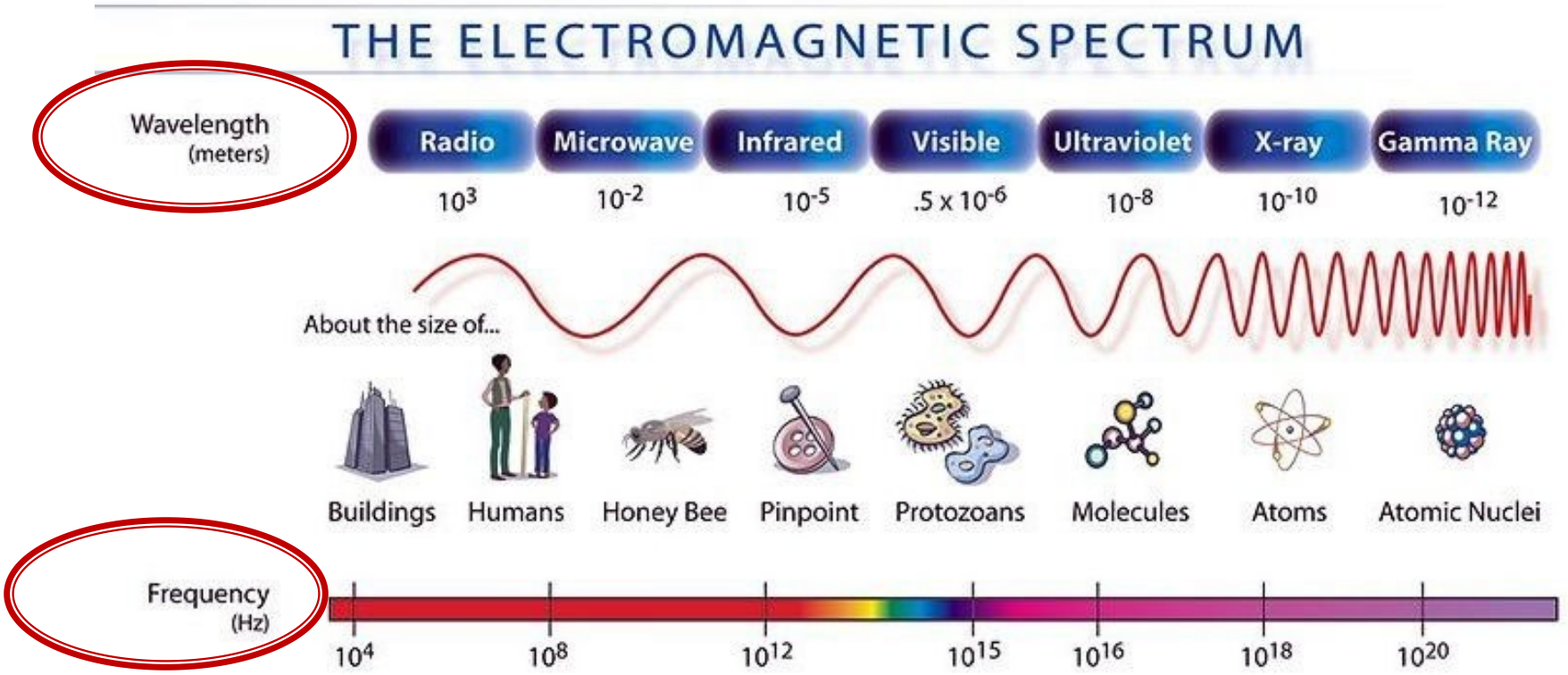
Conductor – metal wire

Radiative energy

All solar energy reaches Earth in the form of electromagnetic radiation.

What is that?

Remember this from your middle school science class?

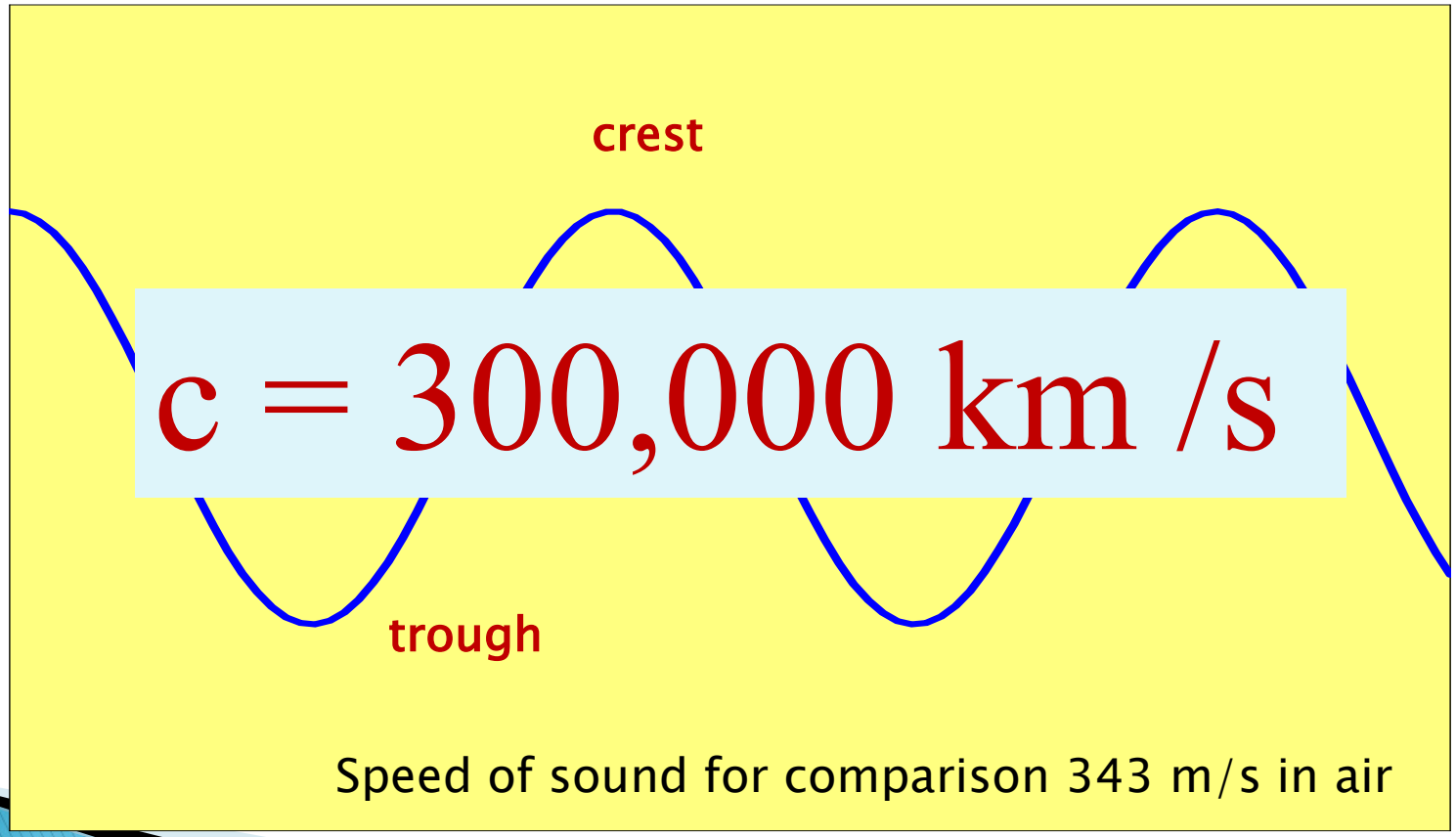


There was a song too:
https://www.youtube.com/watch?v=bjOGNVH3D4Y

Image source: rascan.com

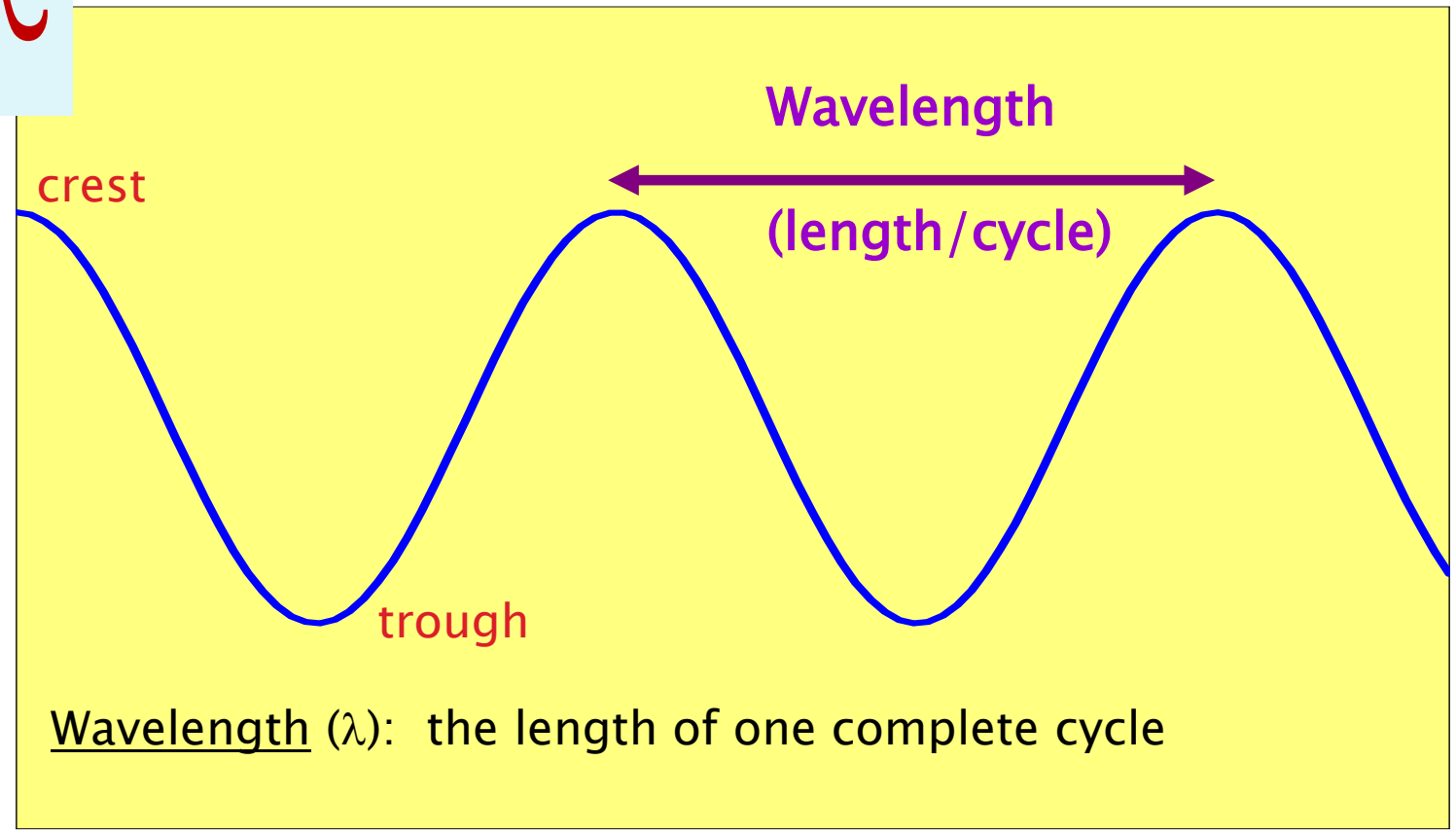
Properties of Electromagnetic Waves

All electromagnetic waves travel at the same speed – the speed of light



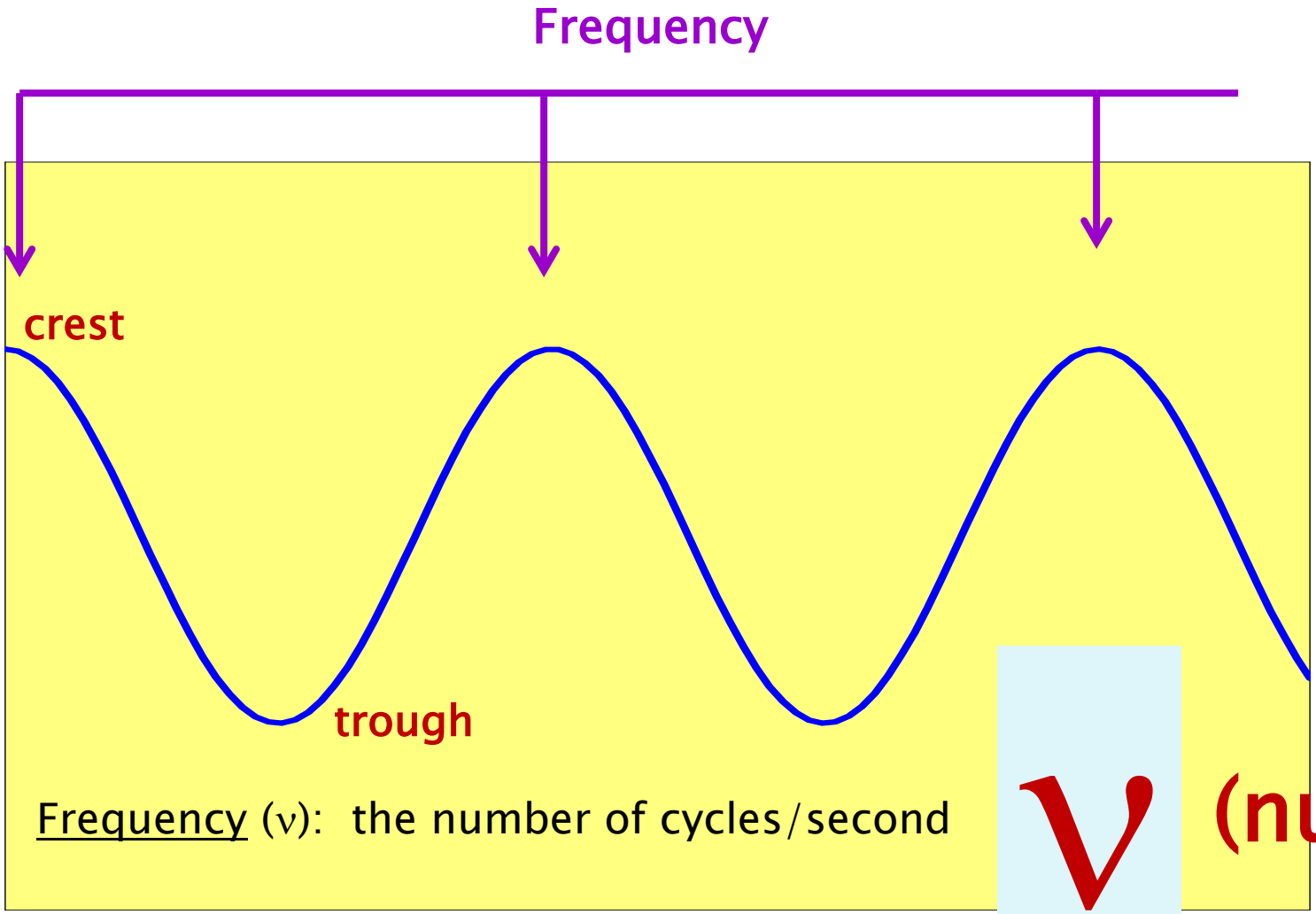
Properties of Electromagnetic Waves

λ (lambda)



Wavelength (λ): the length of one complete cycle

Properties of Electromagetic Waves



Wave parameters connected

Speed = wavelength x frequency

$$c = \lambda \nu$$

Hertz = Hz

Units: (length/second) = (length/cycle) x (cycle/second)

- The higher frequency, the smaller the wave length
- The lower frequency, the greater the wave length

Reversed form: $\lambda = c / \nu$

Energy of Electromagnetic Wave

Energy is proportional to frequency,
and inversely proportional to wavelength

Photon = smallest discrete amount of energy transmitted

$$E = h \nu$$

Energy

Frequency

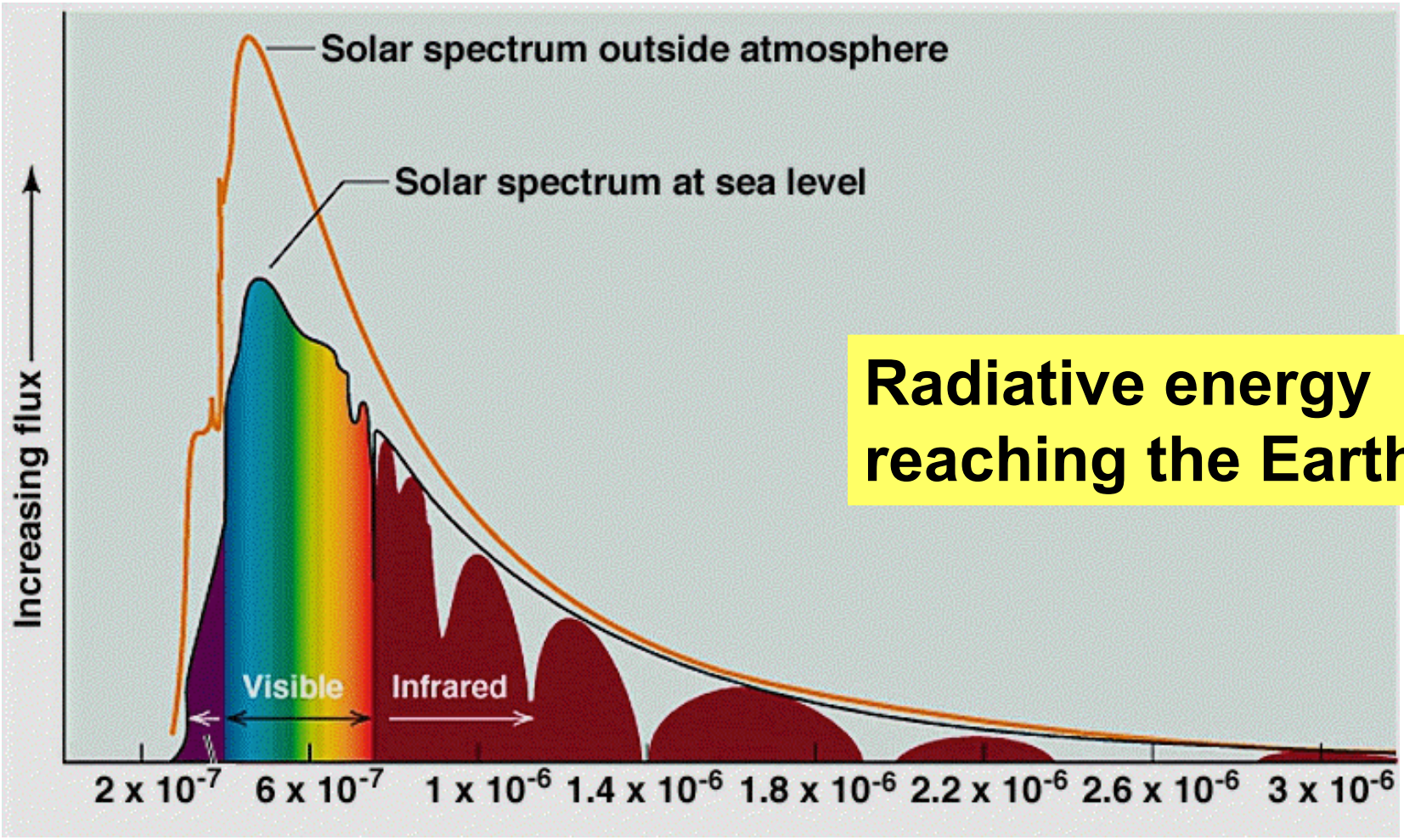
Planck constant

Planck constant $h = 6.63 \times 10^{-34}$ J/s

$$E = h (c/ \lambda)$$

Waves with shorter wavelengths and higher frequency have higher energy !

Solar spectrum



Radiative energy reaching the Earth

Infrared (IR) radiation

An image of a human hand, taken in the infrared, and displayed in false color. Here white and yellow correspond to hot regions, blue and green to cool regions.

Wave length range:
0.7 μm to 1 mm

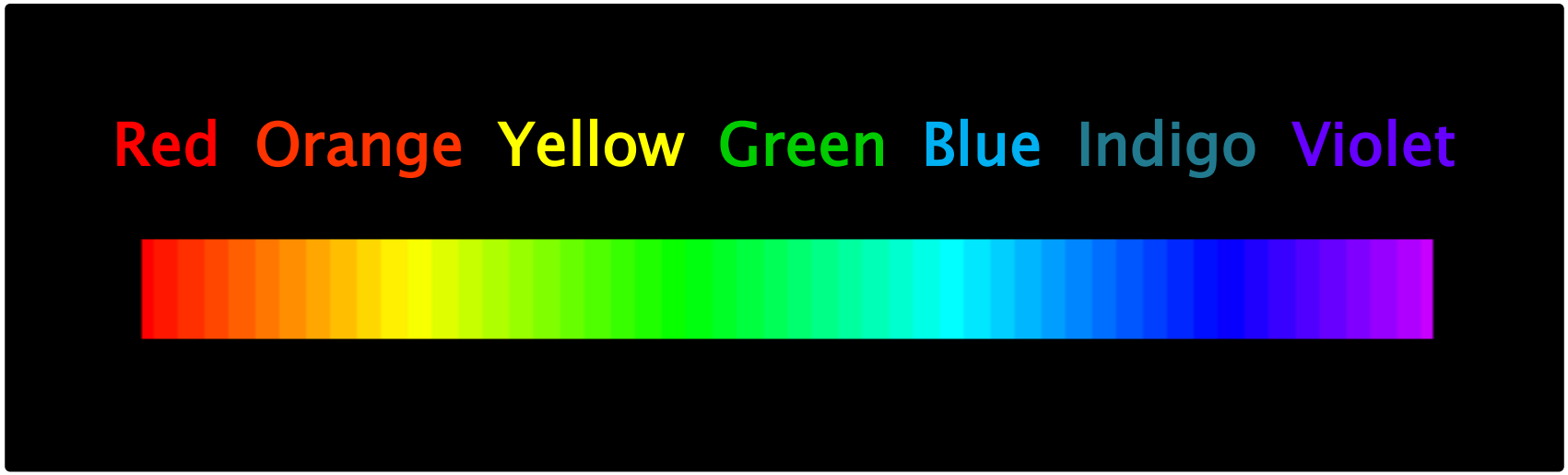
- We cannot see IR, but we can feel it as **radiant heat**
- IR has lower energy than visible light
- Heated objects at normal temperature emit IR (VIS is added at very high T)

Infrared world

Visible Light (VIS)

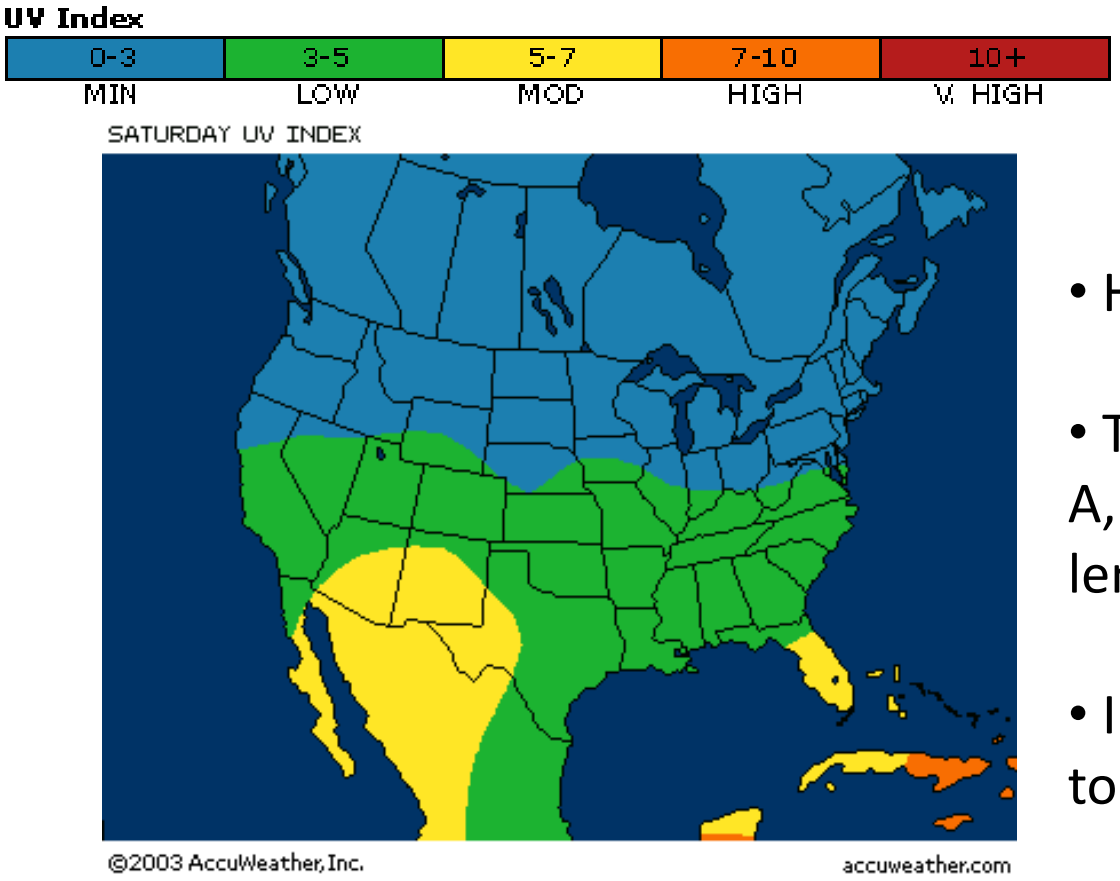
Wave length range: 0.4 to 0.7 μm

Our eyes are sensitive to this region of the spectrum – that is why we can see



Visible light photons have higher energy than IR (higher frequency)

Ultraviolet (UV) radiation



Wave length range:
0.1 μm to 0.4 μm

- Higher energy than visible light
- There three types of UV:
A, B, and C distinguished by wave length
- Invisible to humans, UV-A visible to birds, insects, and fish
- Can burn human skin and damage cells

Self-check question:

Which wave has higher energy?

Ultraviolet Infrared

Self-check question:

Which wave has higher energy?

Visible light Microwave

Energy Units

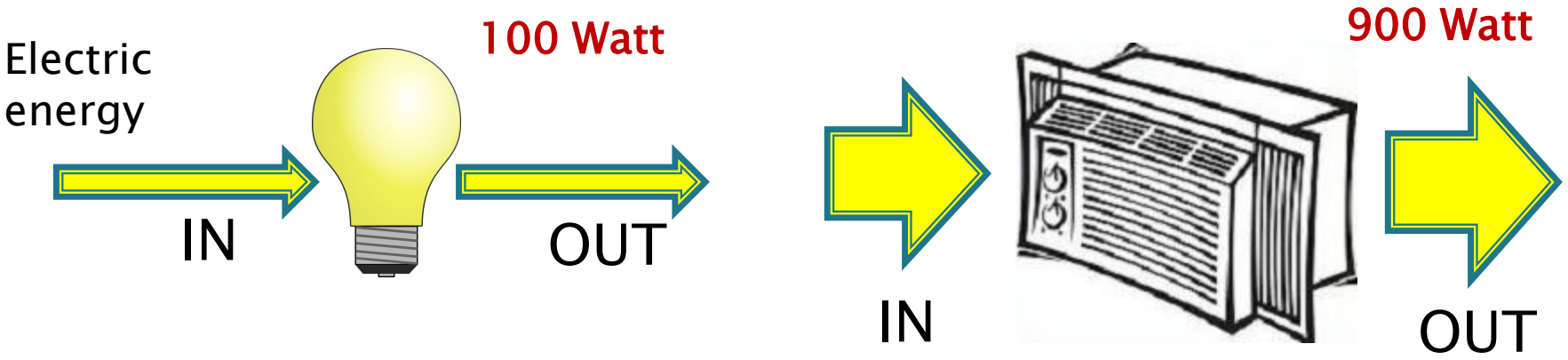
- **Joule** (J) - SI unit for energy – universal for all types of energy. It is rather small compared to other units
- **calorie** - the amount of heat energy needed to raise the temperature of 1 gram (g) of water by 1° Celsius (C). / **1 cal = 4.2 Joules**
- **BTU** – the British Thermal Unit is the amount of energy that is required to raise the temperature of 1 lb. of water by one degree Fahrenheit. **1 BTU = 1055 Joules**
- **Watt-hour (Wh)** – specifically used for measuring electric energy and radiative energy as well. **1 Wh = 3600 Joules**

Online unit converter

http://www.onlineconversion.com/energy.htm

Power

- Power is the **rate of the energy flow**
- Units: 1 Watt = 1 Joule per second



In this example, AC uses more energy per second than light bulb

Energy

Total amount (additive)

Units:
BTU, Calories
Joules, Watt-hrs

Power

Rate of energy flow

Units:
Watts
(J/s)

To find energy used by a device, multiply its power rating by time of usage:
Watt x hours = Watt-hours (Wh)

Answer this question

A 15- watt fluorescent light bulb is operated for 120 hours. How much energy is used?

A. 1800 kWh

B. 120 kWh

C. 15 kWh

D. 1.8 kWh

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Note: 1 kWh = 1000 Wh

kWh are convenient units because we pay for our electricity in $/kWh

For example, living in Pennsylvania I pay **$0.107 per kWh** of used electricity (including support charges), according to my electric bill

Answer this question:

100-watt electric light bulb is operated for 120 hours. How much would it add to your electric bill if the local electricity price is 13 cents per kWh?

A. $1.56

B. $10.8

C. $15.6

D. $1,560

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