Today

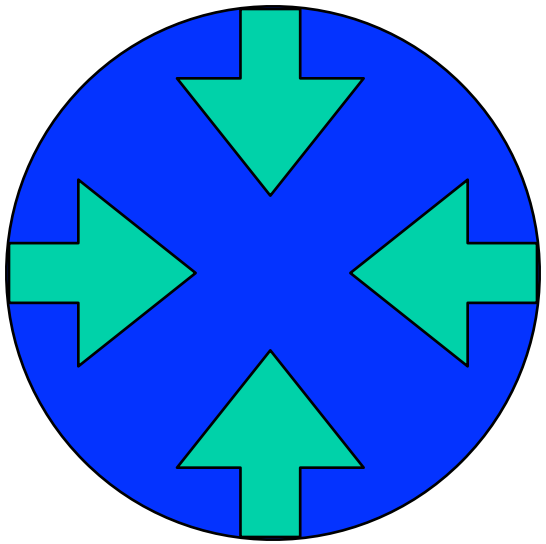
- Tides
- Light
  - the Electromagnetic Spectrum
  - Thermal Radiation

Events

- Homework Due Next time
- Exam I on Feb. 17

Why are stars and planets spherical?

- Gravity pulls - it is an attractive force
- IF self-gravity is the most important force holding an object together, it must be spherical.



Example: Earth

- Diameter of Earth: 12,756 km
- Mt. Everest: 8.848 km above sea level
- Mariana Trench: 10.934 km below
- Maximum variation: 19.782 km

$$\frac{\text{maximum variation}}{\text{diameter}} = \frac{19.782}{12,756}$$

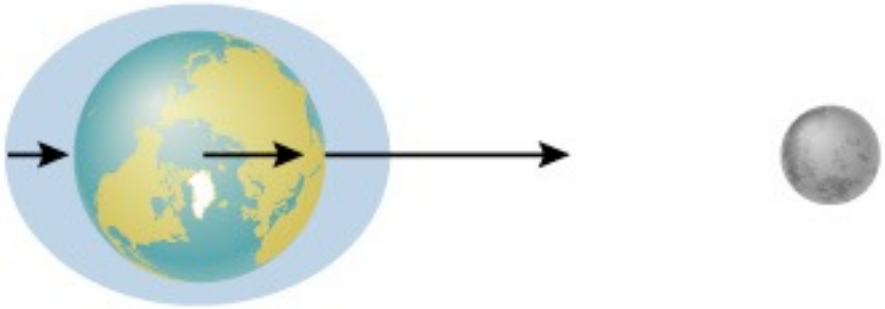
$$= 0.0015$$

- a very smooth sphere!

- Gravity makes individual objects round
  - about 100 km in diameter is where objects start to become dominated by self-gravity
    - planets round
    - asteroids still lumpy

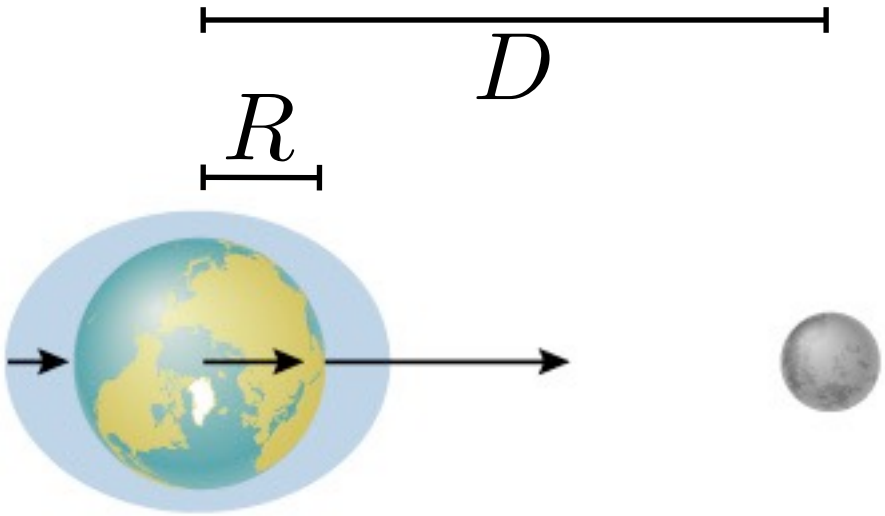
This holds for individual objects.
What about multiple objects?

Tides



Tides are the result of differential gravity

- The Moon's gravity pulls harder on near side of Earth than on far side (inverse square law).
- The difference in the Moon's gravitational pull stretches Earth.



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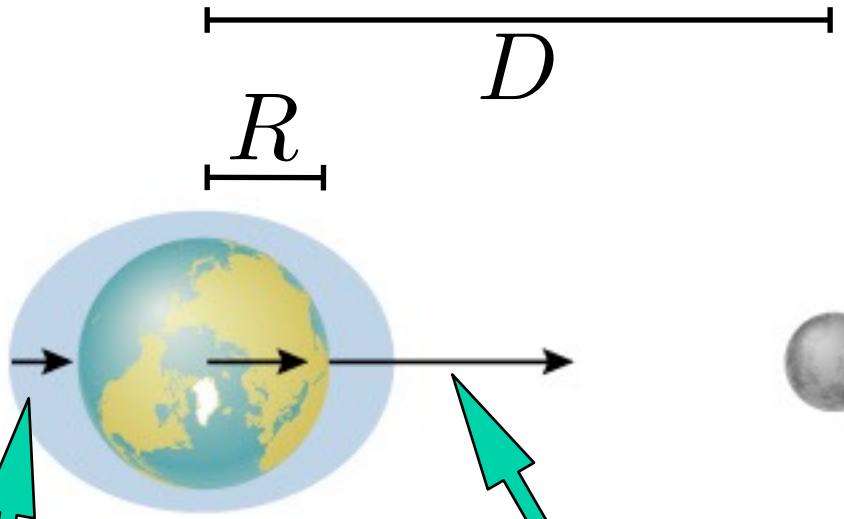


$$F = \frac{GM_E M_m}{(D+R)^2}$$

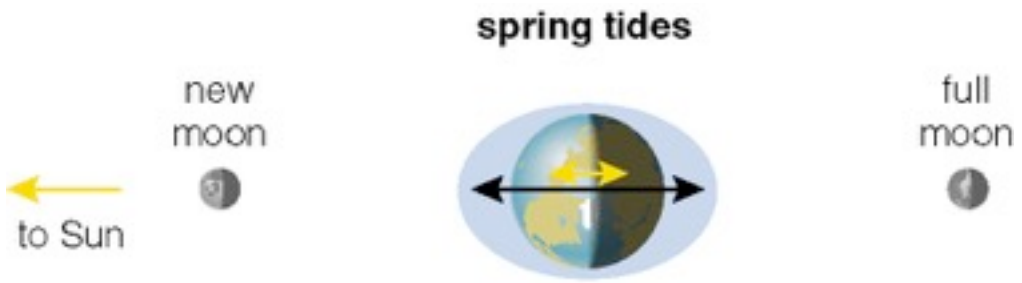
$$F = \frac{GM_E M_m}{(D-R)^2}$$

$D = 384,400$ km

$R = 6,378$ km

So the gravitational attraction towards the moon is about 7% stronger on the near side of the Earth than on the far side.

2 Tides a day



The combined force of the sun and moon causes the ideal gravitational surface to be slightly non-spherical.

Consequently, Earth's oceans to fill a slightly oblate spheroid.

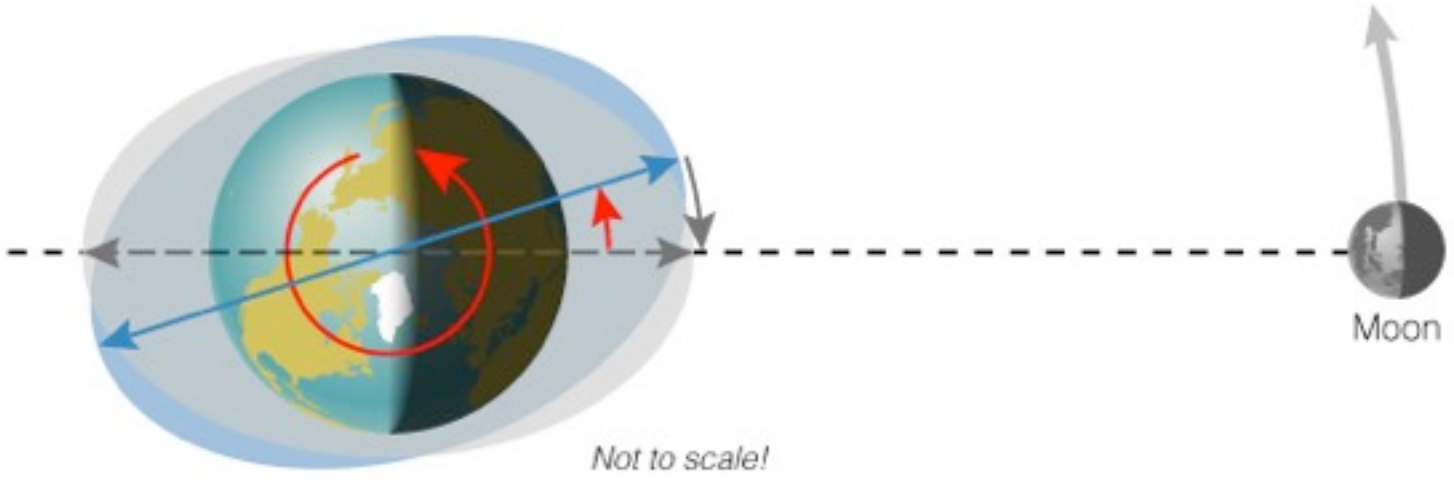
The Earth spins under this spheroid, so we have two pairs of low & high tides a day.

Tides and Phases

Size of tides depends on the phase of the Moon.

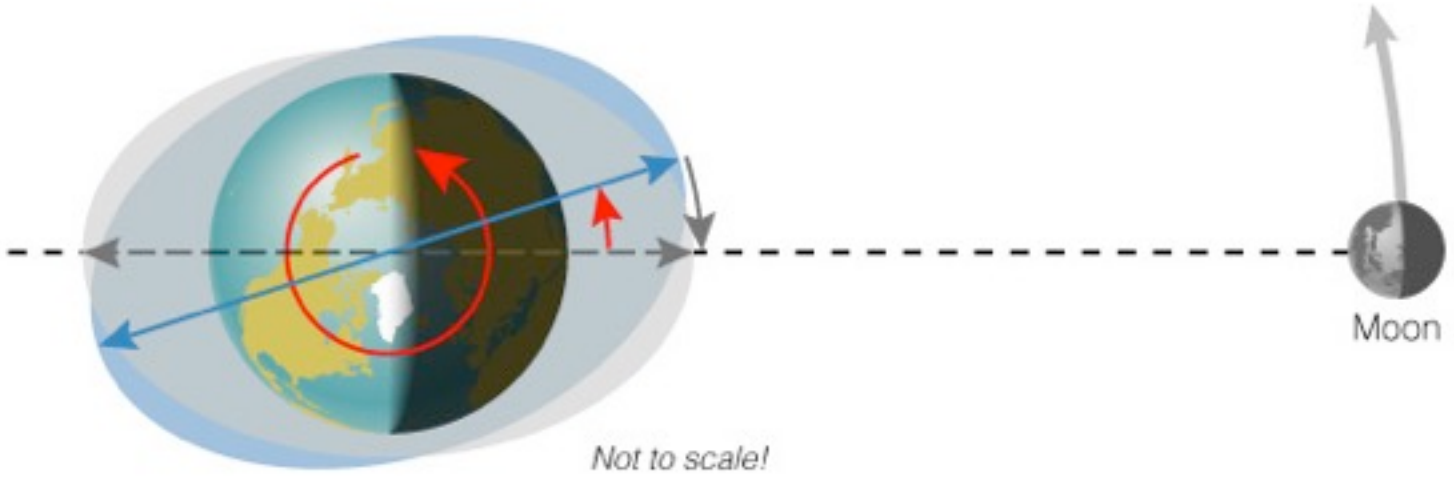
Spring tides are stronger than neap tides because the sun and moon team up at new & full moon.

Tidal Friction



- The spin of the Earth drags the tidal bulge of the ocean ahead of the ideal oblate spheroid, which is aligned with the moon.
- The gravity of the moon pulls back on the leading, near side bulge more strongly than it pulls forward the far side bulge.
- The net result is **tidal friction**, which results in a gradual braking of the spin of the Earth.

Tidal Friction



- Tidal friction gradually slows Earth rotation
  - Moon gradually drifts farther from Earth (3.8 centimeters per year)
  - conservation of angular momentum

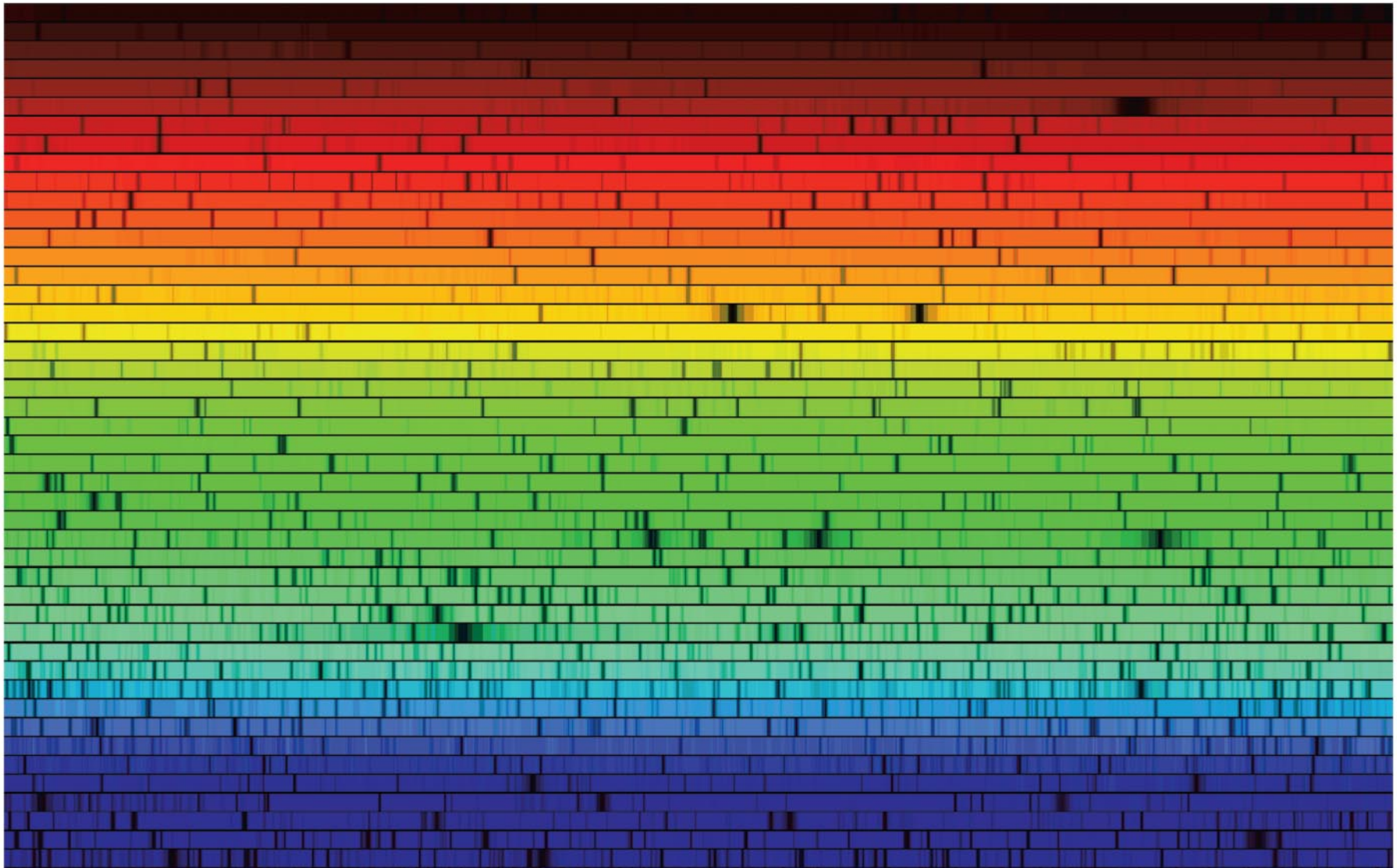
The length of Earth's day increases 2 milliseconds per century

- Moon once spun faster; tidal friction caused it to "lock" in synchronous rotation
  - orbit period:spin period = 1:1
  - keeps same face towards us all the time

Summary of Tides

- Gravitationally bound objects are spherical
  - e.g., planets, stars
- Tides are caused by the differential gravity of the sun and moon
  - Spring tides are cause when the sun and moon are aligned; neap tides when they are perpendicular.
- Tidal friction gradually changes
  - the orbit of the moon and the spin of the earth

Electromagnetic Radiation



Electromagnetic Radiation

aka Light

"Radiation" sounds scary, but there are many benign forms of radiation - including visible light, radio waves, and infrared radiation.

These are all fundamentally the same stuff.

Electromagnetic Radiation

aka Light

- Properties of Light are simultaneously
  - **wave-like** AND
  - **particle-like**

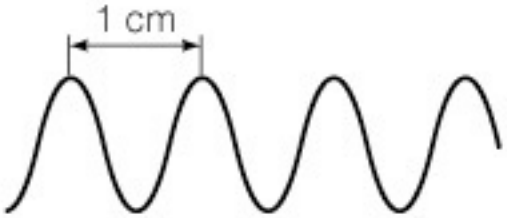
Sometimes it behaves like ripples on a pond (waves).
Sometimes it behaves like billiard balls (particles).

Called the “wave-particle” duality in quantum mechanics.

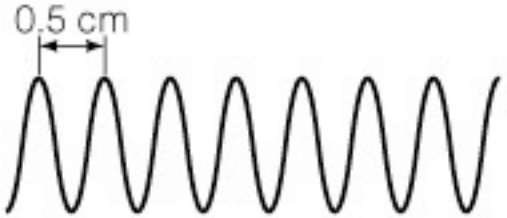
Particles of Light

- Particles of light are called **photons.**
- Each photon has a wavelength and a frequency.
- The energy of a photon depends on its frequency.

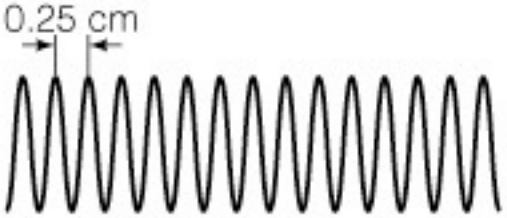
Wavelength and Frequency



wavelength = 1 cm,
frequency = 30 Ghz



wavelength = $\frac{1}{2}$ cm,
frequency = 2 × 30 Ghz = 60 Ghz



wavelength = $\frac{1}{4}$ cm,
frequency = 4 × 30 Ghz = 120 Ghz

Wavelength & Frequency

λ = wavelength (separation between crests)

f = frequency (rate of oscillation)

c = speed of light $= 3 \times 10^8$ m/s

$$\lambda f = c$$

Wavelength, Frequency, and Energy

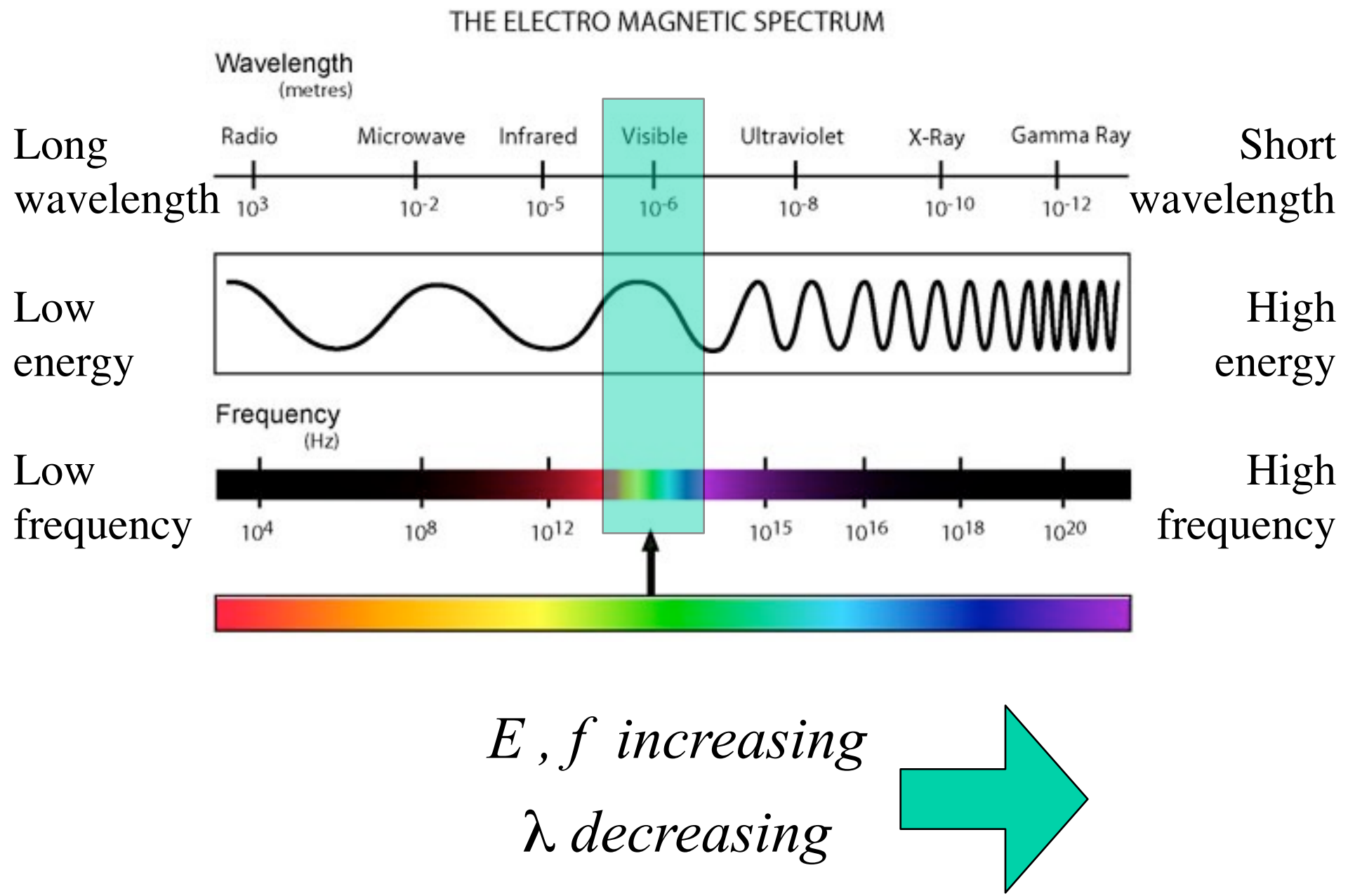
photon energy:

$$E = hf = hc/\lambda$$

$$h = 6.626 \times 10^{-34} \text{ joule} \times \text{s}$$

(Planck's constant)

The frequency f can be arbitrarily high or low, so the energy carried by an individual photon can be arbitrarily high or low. However, the energy always comes in a finite unit of one photon at a time, not continuously.



Long wavelength

Short wavelength

Low energy

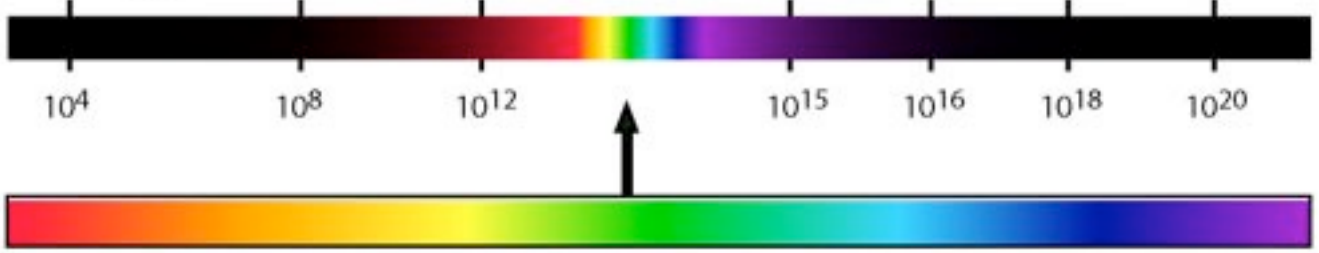
High energy

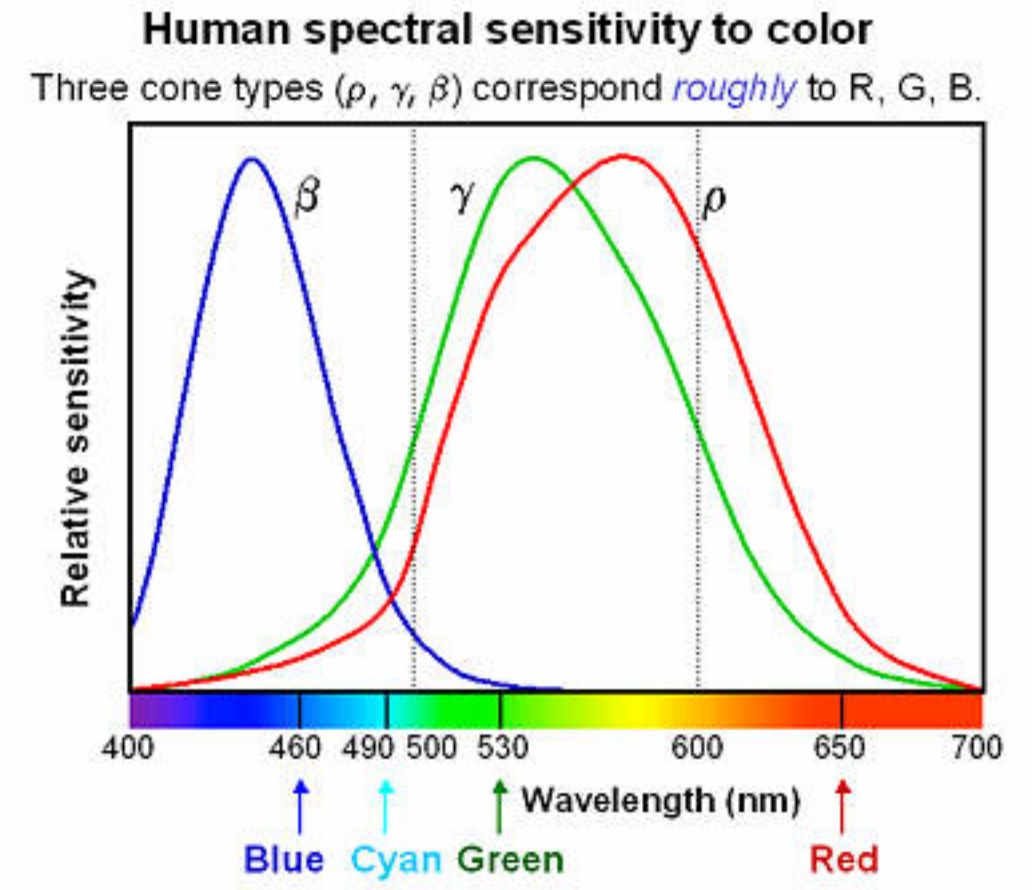
Low frequency

High frequency

E , f increasing

λ decreasing





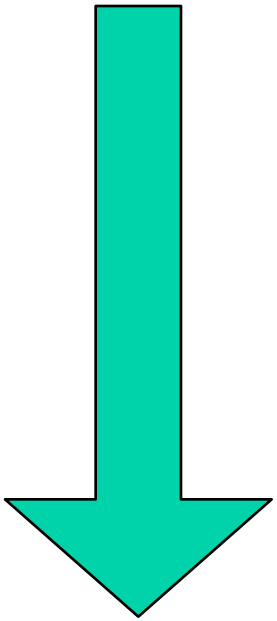
Our eyes are only sensitive to a factor of two range in wavelength, from 380nm (violet) to 700nm (deep red).

Same stuff, different Energy:

Electromagnetic Radiation

- Radio
- microwave
- infrared
- visible light
- ultraviolet
- X-ray
- gamma ray

Energy per photon increasing



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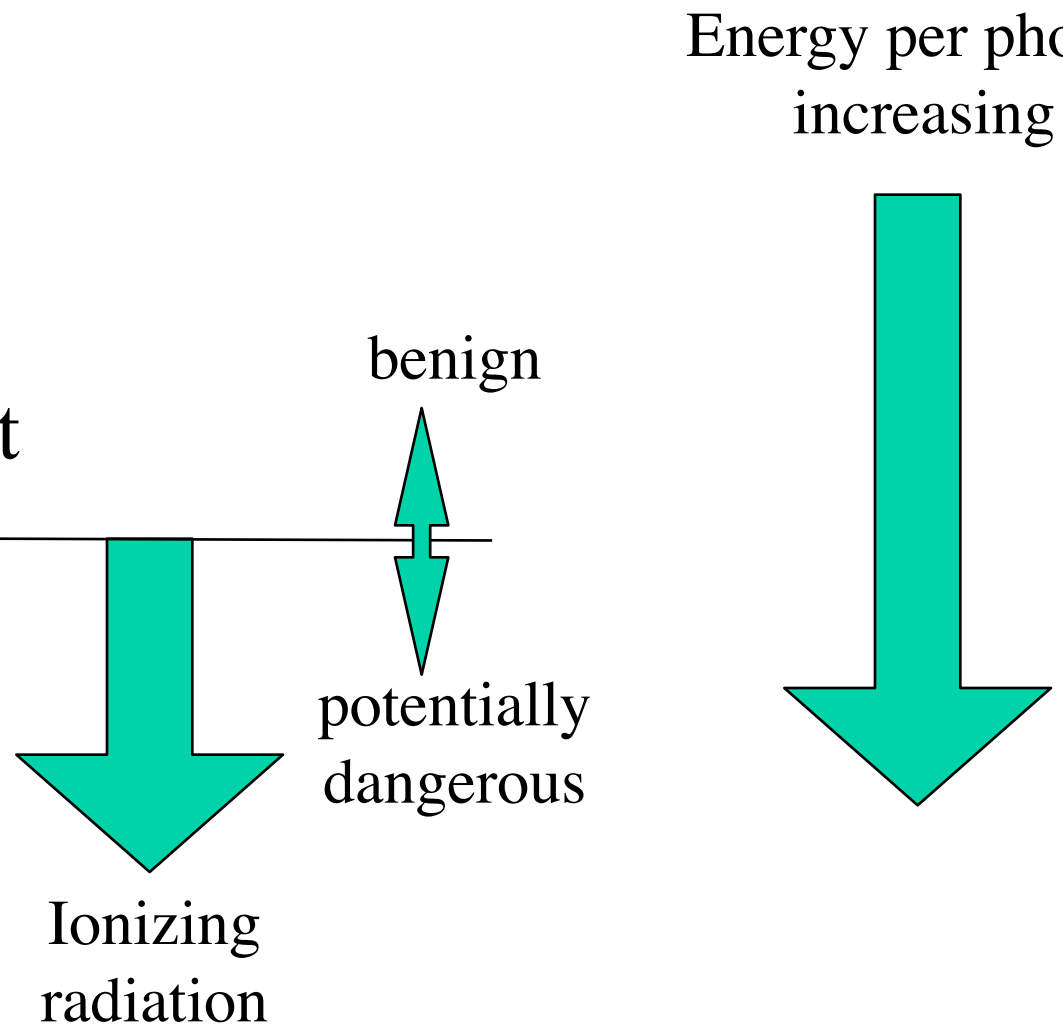

How do light and matter interact?

- Emission
- Absorption
- Transmission:
  - — Transparent objects transmit light.
  - — Opaque objects block (absorb) light.
- Reflection or scattering
  - – we see by scattered light

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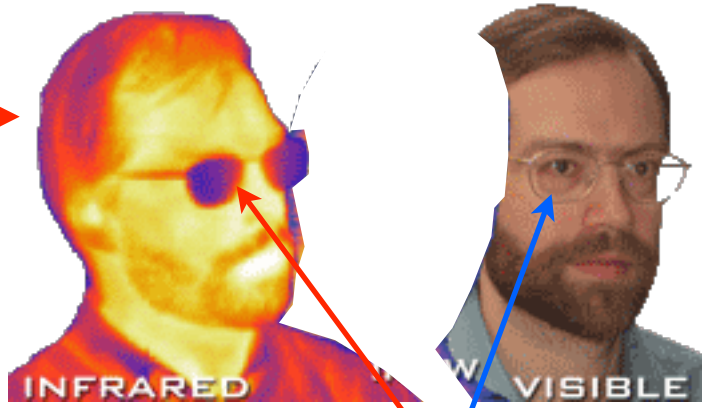
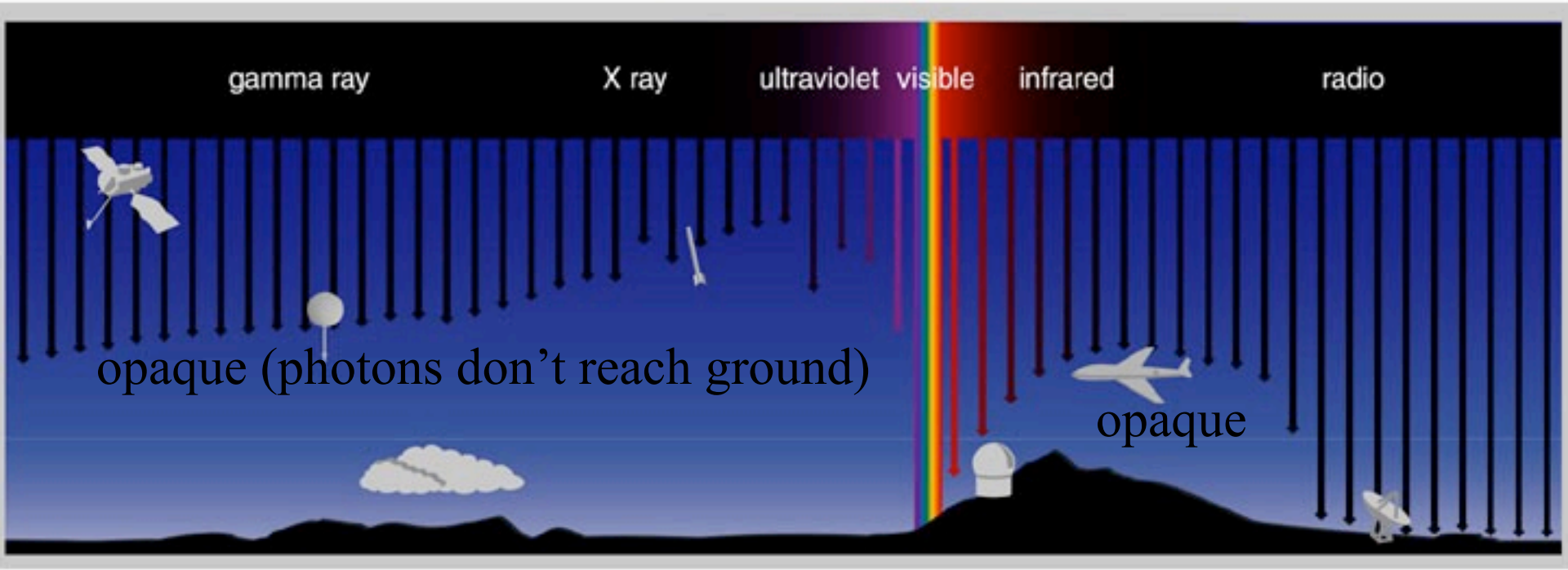
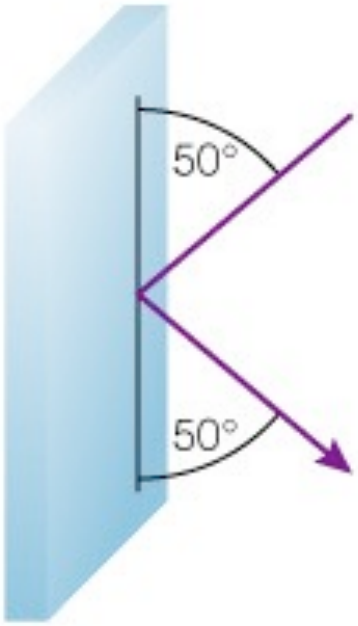


transmission & absorption

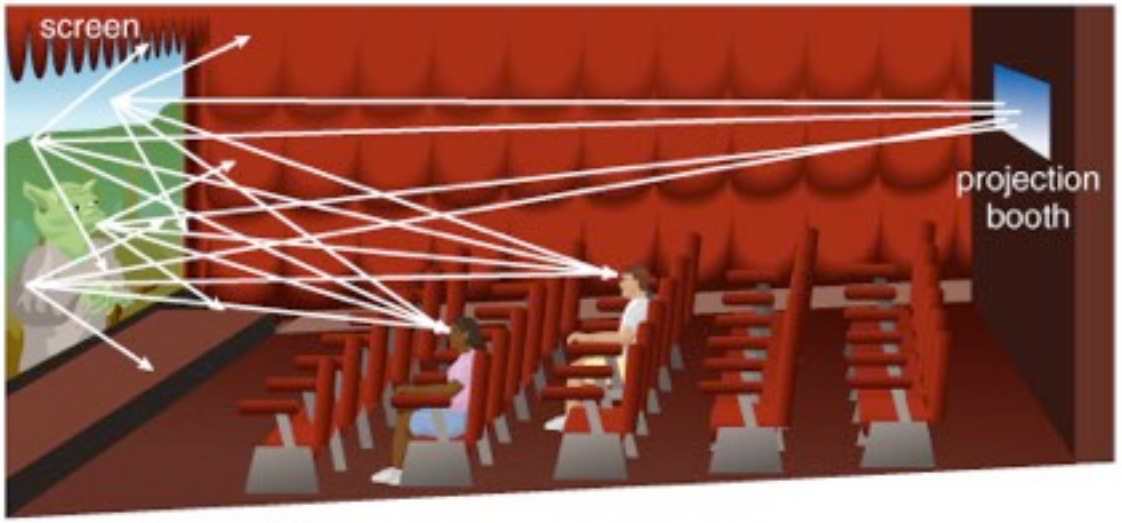


Earth's atmosphere is opaque to light at most wavelengths.
It is transparent only to visible light and radio waves.

Reflection and Scattering

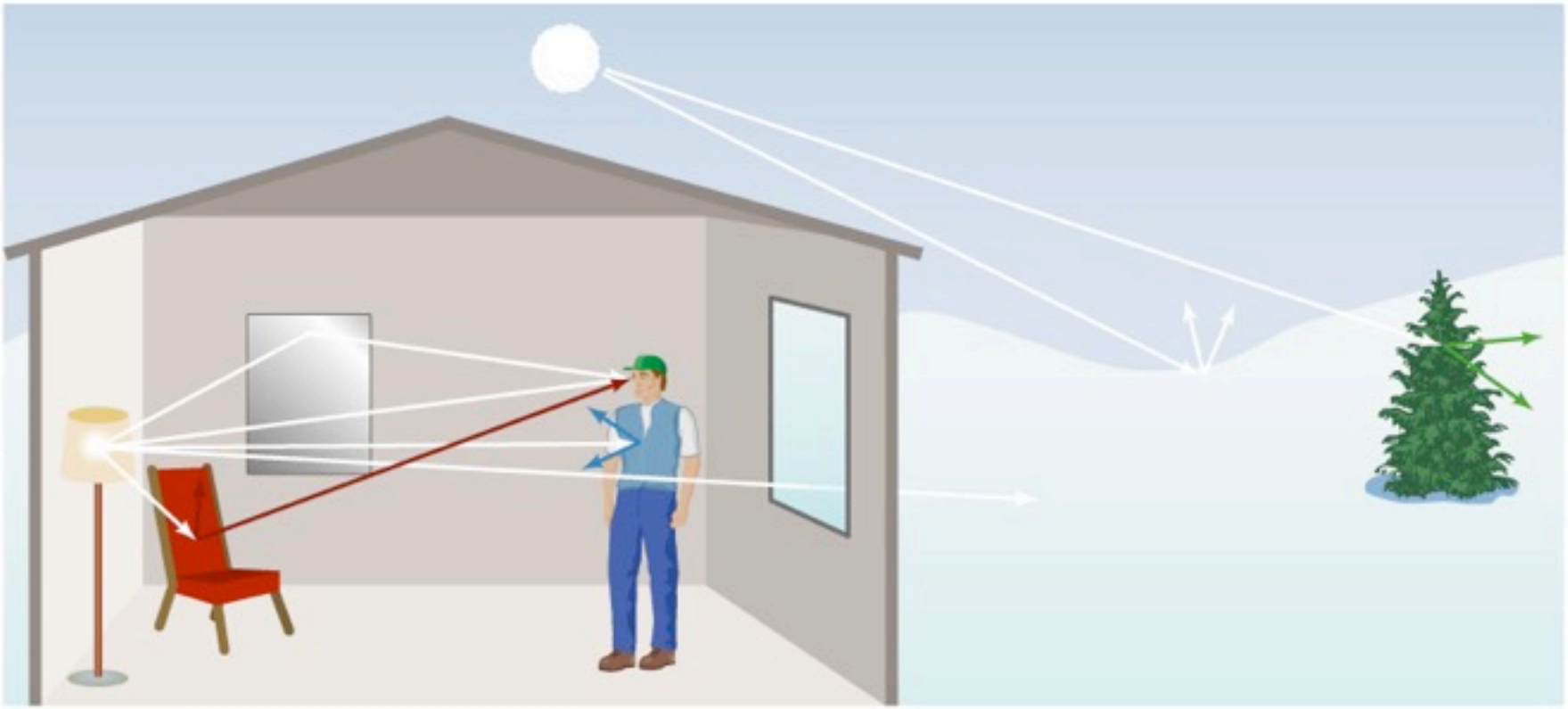


Mirror reflects light in a particular direction.



Movie screen scatters light in all directions.

We see by scattered light



Interactions between light and matter determine the appearance of everything around us.