

Chapter 9: Finish Electromagnetic Waves

Electromagnetic Spectrum

X-Rays

Solar radiation

Review for Exam 2: Chapters 6 – 9

Chapter 10: Special Relativity

Classical (Galilean) Relativity

Two Postulates of S. R.

Their Consequences

**Typical Sources
That Send out Waves
at This Frequency:**

Frequency, Hz

E & M Spectrum, λ , m

**Typical Object
Whose Size Is the
Same as This
Wavelength:**

Processes by protons and
neutrons in atomic nuclei

10^{22}

Gamma ray

10^{-14}

Nucleus

10^{20}

10^{-12}

Electrons in atoms,
high-energy processes

10^{18}

X-ray

10^{-10}

Atom

Electrons in atoms,
low-energy processes

10^{16}

Ultraviolet

10^{-8}

DNA molecule
Amoeba

Thermal vibrations of
molecules

10^{14}

Visible

10^{-6}

Fine dust particle

Microwave oven
Radar antenna

10^{12}

Infrared

10^{-4}

Millimeter

**↑
Energy**

10^{10}

Microwave

10^{-2}

Centimeter

Cell phone

10^8

Radar

10^0

Meter

FM radio, TV antenna

10^6

TV, FM radio

10^2

Soccer field

AM radio antenna

10^4

AM radio

10^4

Kilometer

60 Hz power-line
radiation

10^2

Radio

10^6

Earth

10^0

10^8

10^{-2}

10^{-6}

10^{-4}

10^{-8}

10^{-6}

10^{-10}

10^{-8}

10^{-12}

10^{-10}

10^{-14}

10^{-12}

10^{-16}

10^{-14}

10^{-18}

10^{-16}

10^{-20}

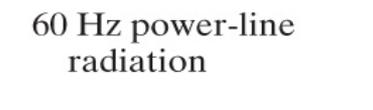
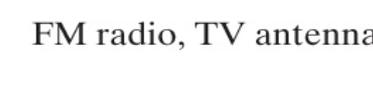
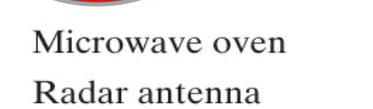
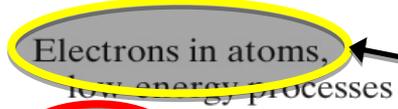
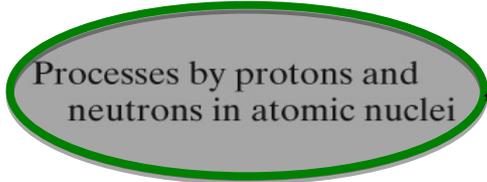
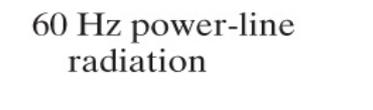
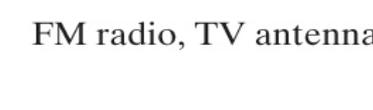
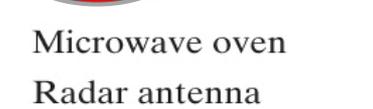
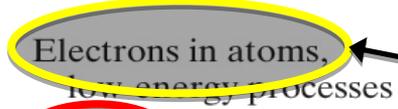
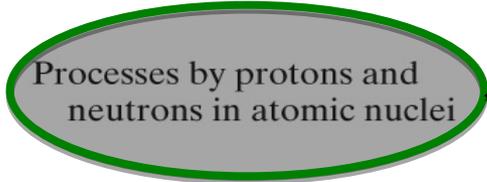
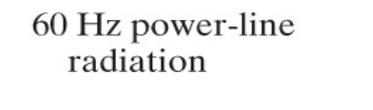
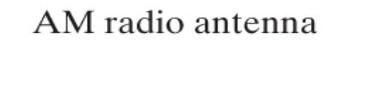
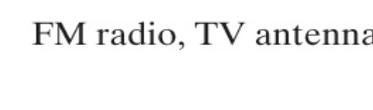
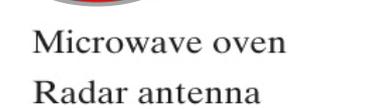
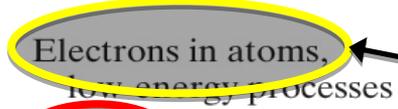
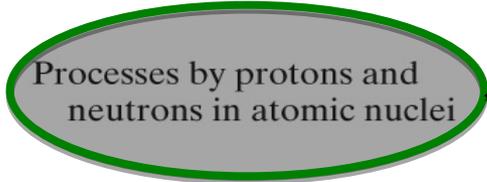
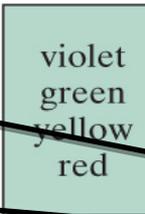
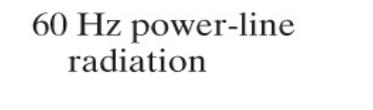
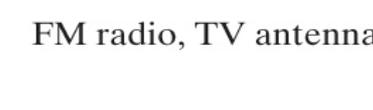
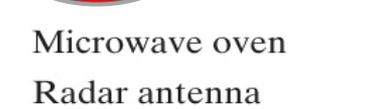
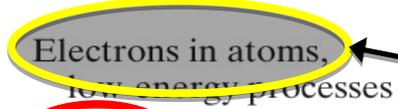
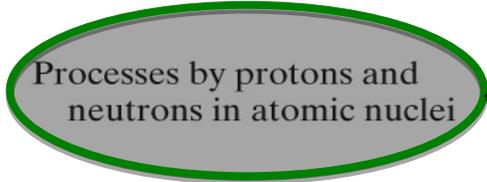
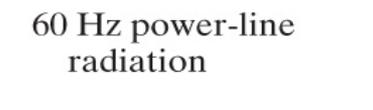
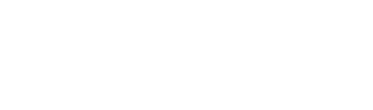
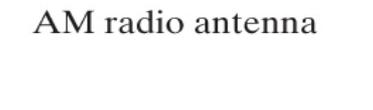
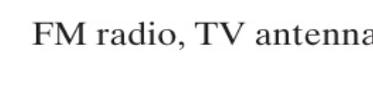
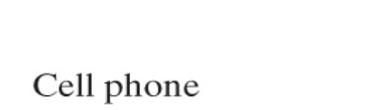
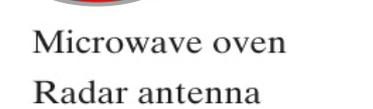
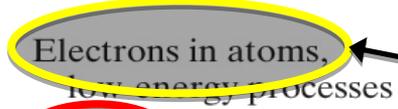
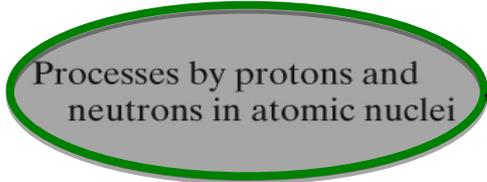
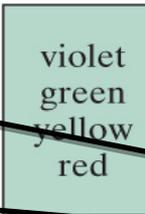
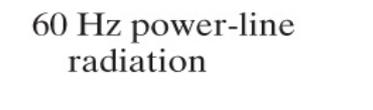
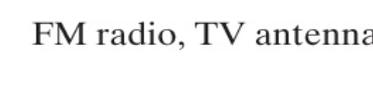
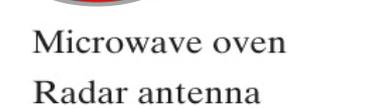
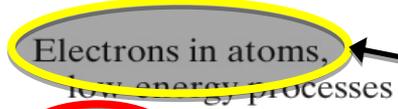
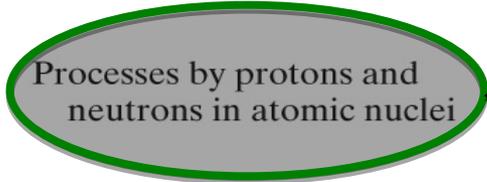
10^{-18}

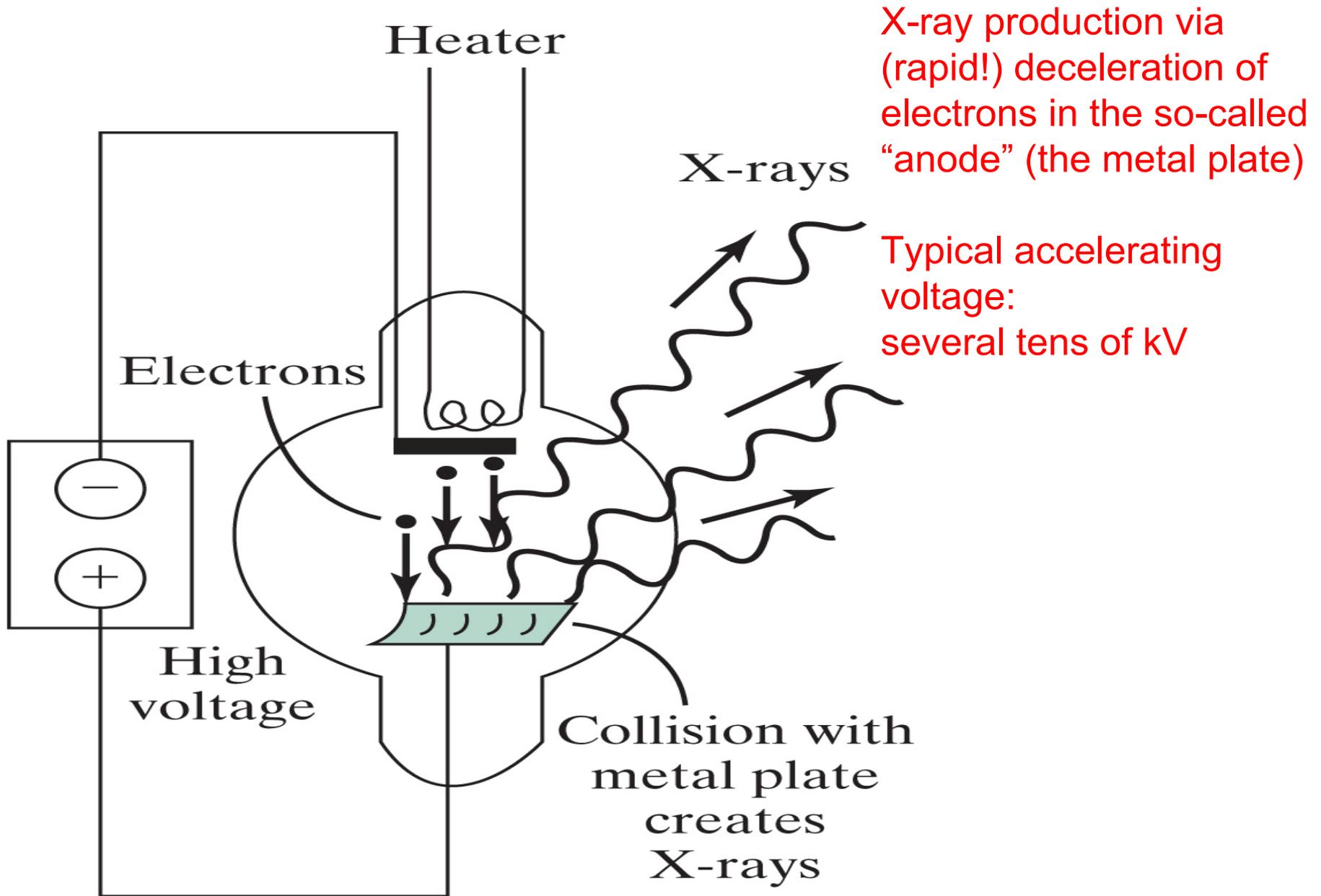
10^{-22}

10^{-20}

10^{-24}

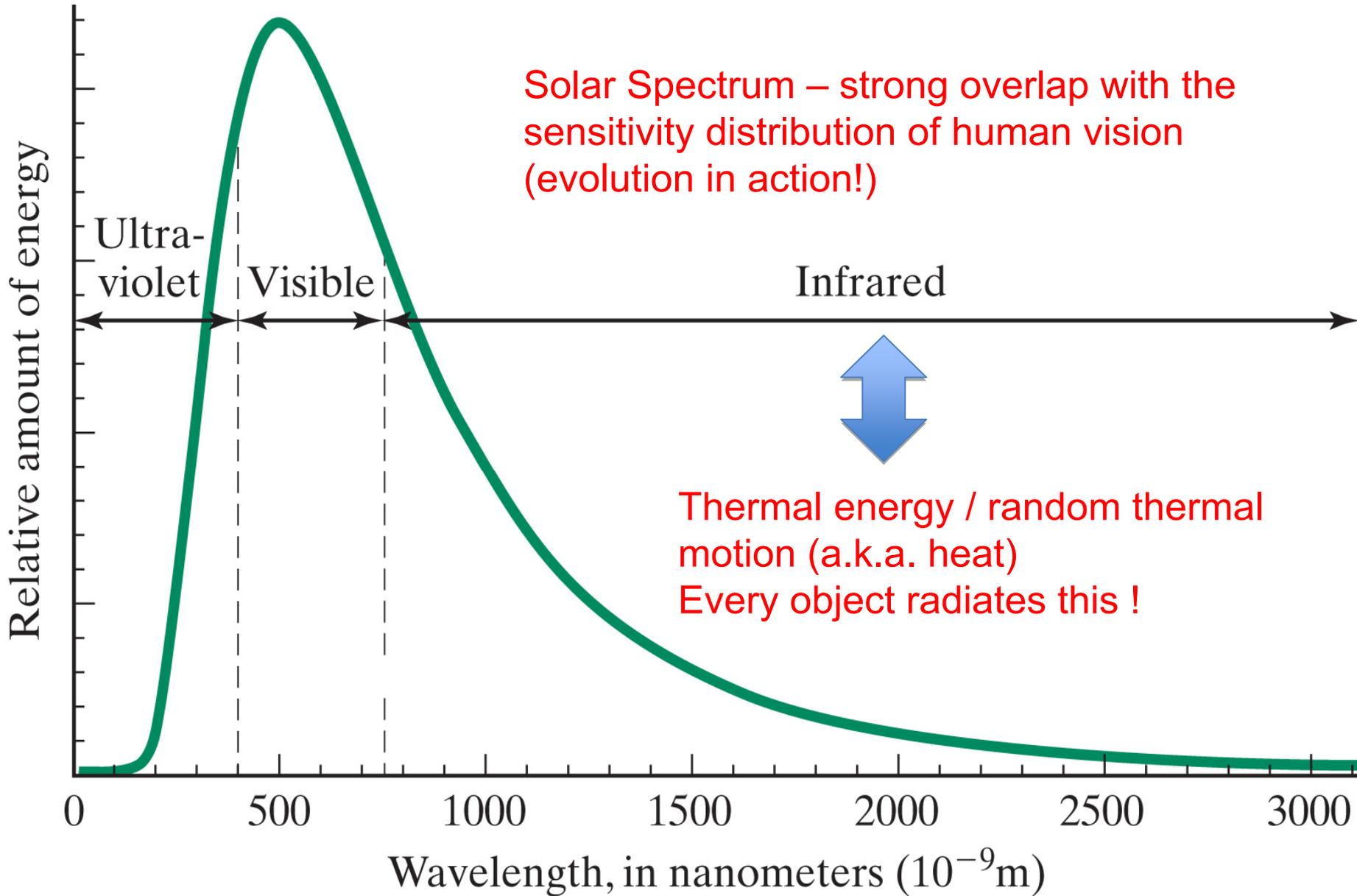
violet
green
yellow
red





X-ray production via (rapid!) deceleration of electrons in the so-called "anode" (the metal plate)

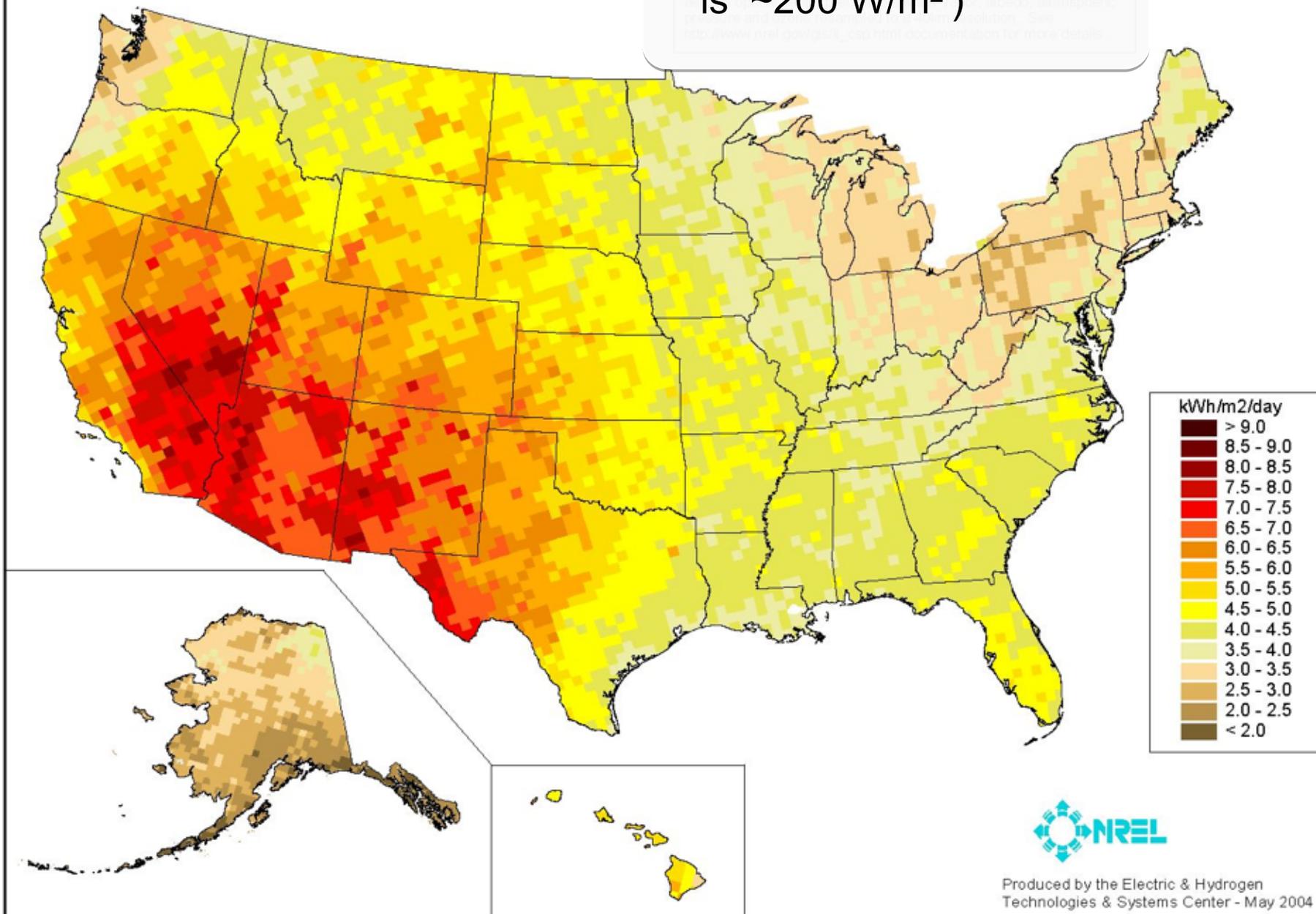
Typical accelerating voltage: several tens of kV



Direct Normal Solar Radiation (Two-Axis Tracking Concentrator)

(from our book: US average
is $\sim 200 \text{ W/m}^2$)

Annual



Quiz # 75: As solar radiant energy is absorbed by your skin, it

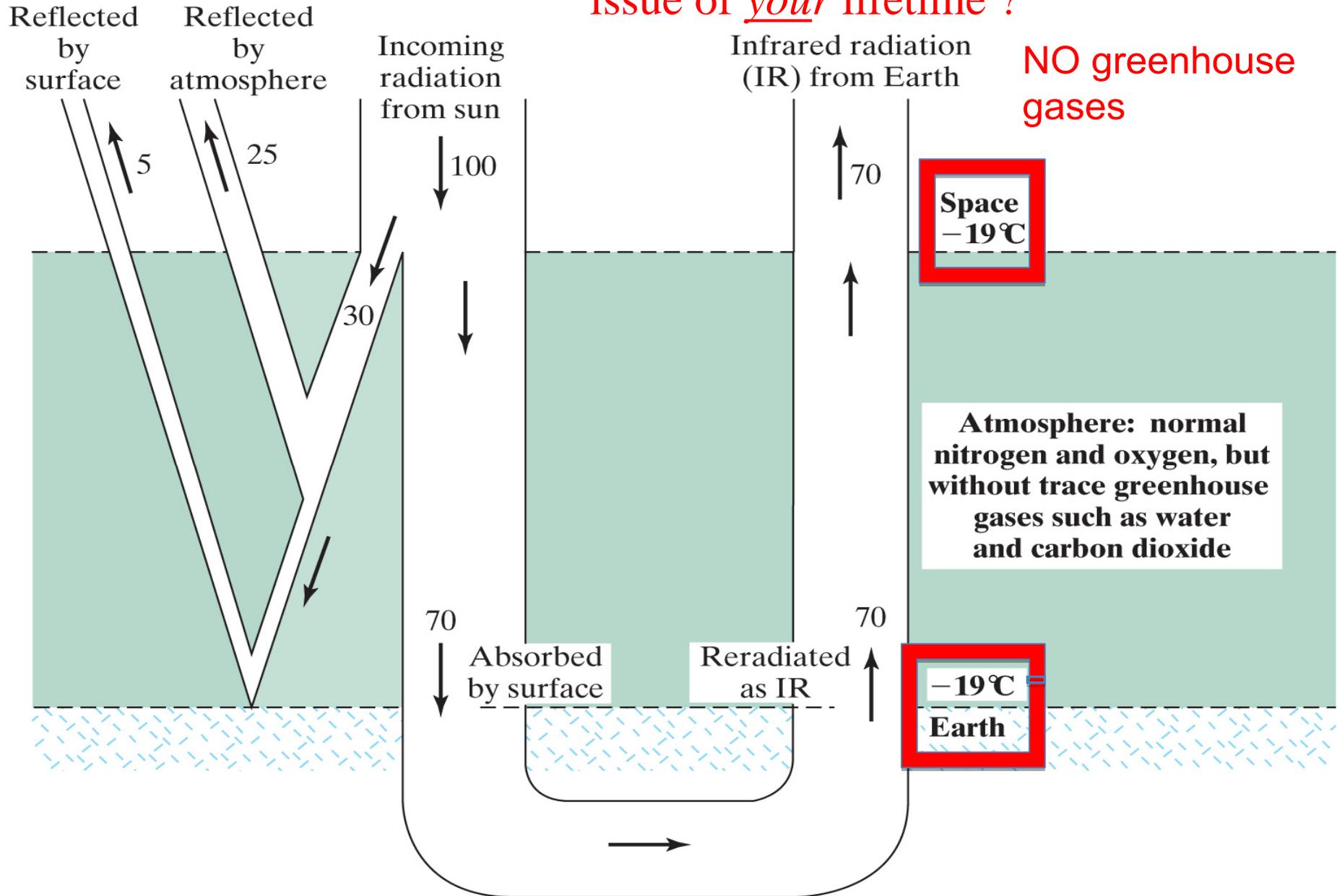
- (a) remains there as radiant E.
- (b) transforms into gravitational potential E.
- (c) transforms into thermal E.
- (d) is totally reflected again.
- (e) transforms into nuclear E.

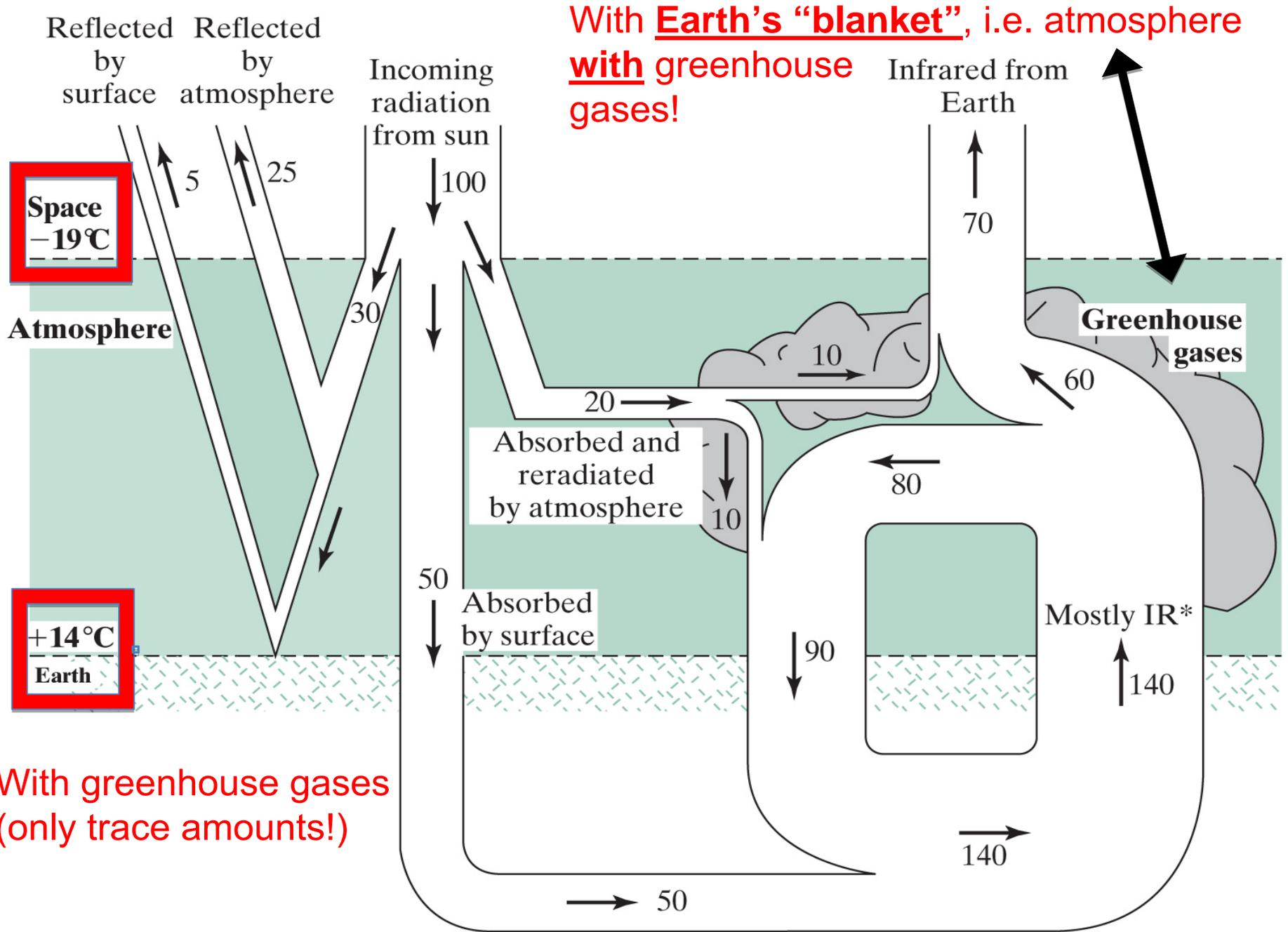
Quiz # 76: Across the US on average 200 W of solar radiation power strike every m^2 . Photovoltaic (PV) cells transform solar energy directly

into electric current. Let's assume they have 10% efficiency (good modern ones are more like 15-20%), and you have a 10 m^2 array of PV cells. How long will it take you to generate 1 kW-hour of electric energy?

- (a) 5 hours
- (b) 2 hours
- (c) 2.5 hours
- (d) 1 hour
- (e) 10 hours

Physics of Global Warming – most important “global-societal-physics” issue of *your* lifetime ?





Exam 2: Chapters 6 – 9

Themes:

Energy/work, Energy Conservation, Power

2nd Law of Thermo, Heat Engines incl. Cars & Power Plants

Electric Charges & their Conservation, F_{Coulomb} , Ohm's Law & Electrical Resistance

Waves, incl. Electromagnetic Waves such as Light

New units: J(oules) = N(ewton)-m(eters); W(att) = J/sec

C(oulomb); V(olt) = J/C, A(mp) = C/sec, O(hm) = V/A

“100 W” lightbulb – meaning?

Two types of mechanical energy:

$E_{\text{kinetic}} = \frac{1}{2} m v^2$ $E_{\text{gravitational}} = mgh$ (h relative to somewhere!) $\rightarrow E_{\text{total}}$ is conserved, leading to E transformations.

Examples: falling, sliding down an incline, but also roller coaster approaching a hill, etc.

Distinguish: $F_{\text{gravitational}}$ & $E_{\text{gravitational}}$

Example: two satellites at different altitudes

2nd Law of Thermo \rightarrow always limited efficiency of heat engines

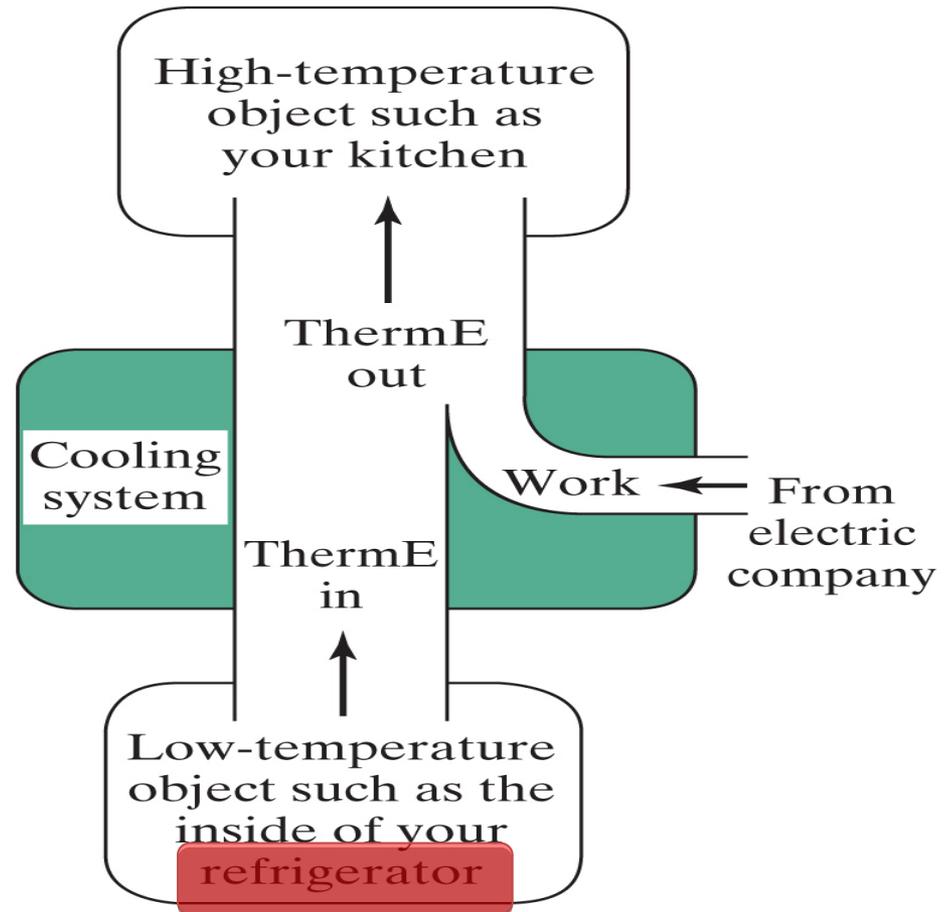
$E_{\text{thermal in}} = \text{Work}_{\text{out}} + E_{\text{thermal out}}$ (exhaust/waste)

(But: not everything is a heat engine!)

How is a **refrigerator** related to a heat engine?

Is E_{thermal} exhausted by your fridge *necessarily* larger than the E_{thermal} extracted from the fridge's content?

- (a) Depends on the fridge's efficiency.
- (b) No.
- (c) Yes.
- (d) Depends on the temperature of the fridge's contents.



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Remember: both $F_{\text{gravitational}}$ and F_{Coulomb} scale with $1/\text{distance}^2$

Compare electrostatic force p(roton) – p(roton) at distance d with He – He nuclei at $\frac{1}{2}d$. And what about He – He at $2d$?

Can p(roton) + n(eutron) $\rightarrow e^- + e^+$ happen?

Ohm's Law: 100 Ohm resistor with 100 V(olt) across. Current $I = ?$
Now voltage cut in half, i.e. 50 V. What happens to $I = ?$

By the way, electrical power $P_{\text{electrical}} = V \times I = I^2 \times R$

Chapter 10: Special Relativity

Einstein's revolutionary demolition of the classical notions of absolute space and time and motion, as well as a radically new insight into mass & energy.

“Common sense consists of those layers of prejudice laid down in the mind before the age of eighteen.”

Albert Einstein

Does it matter in your life? Name some examples.....

Key to understanding: keep an open mind (mental flexibility), drop preconceptions about time/space/motion/mass & energy

1st part of the “modern” physics revolution of the early 20th century.
Difficulty: far removed from our normal experiences, NOT the math

Fascinating history & legends/folklore related to Einstein...makes great reading.

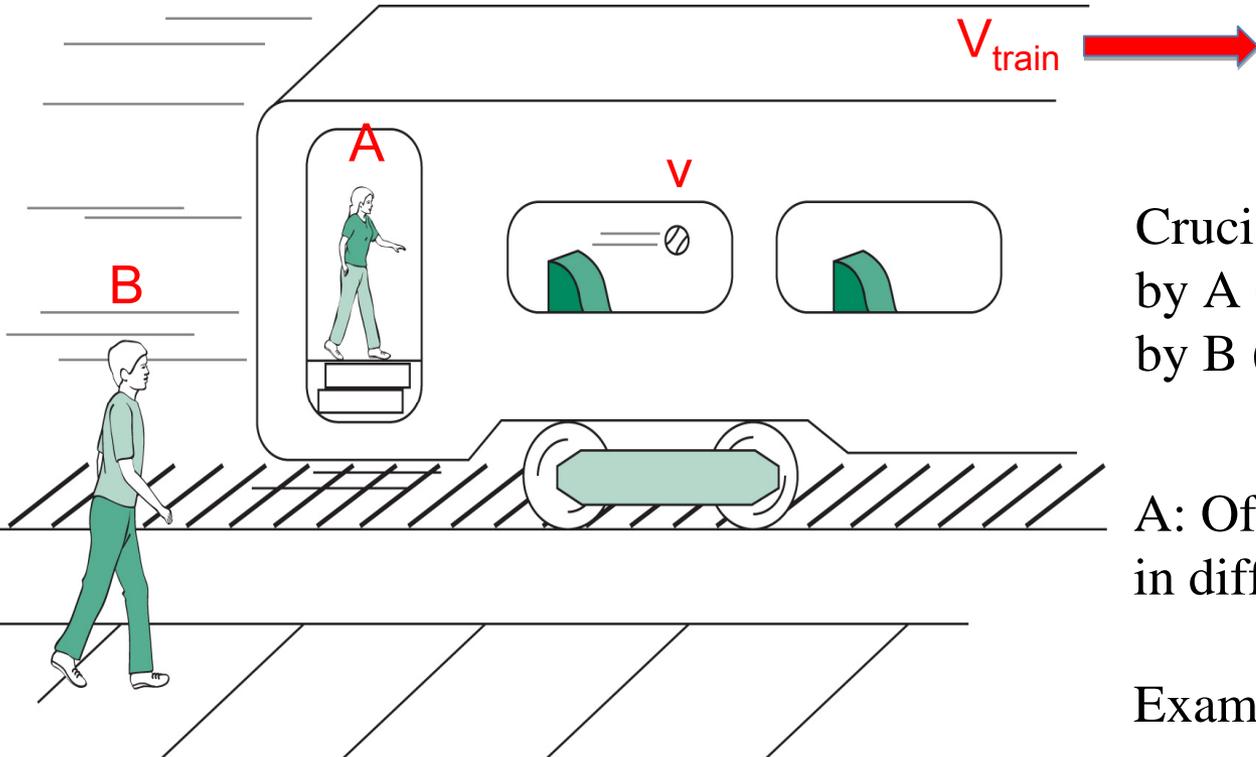
Foundations of S. R. are 2 postulates or principles:

1) Principle of Relativity: Laws of Physics are the same for every non-accelerated observer. (not that surprising, makes sense)

2) Constancy of c – i.e. independent of motion of source and/or observer. (quite surprising!)

Start with the non-strange: relativity principle in the context of **relative motion**. Need the important concept of **reference frame**.

Think back: what does $v = 20 \text{ km/hr}$ mean?



Crucial question: is v measured by A (v_A) same as v measured by B (v_B)?

A: Of course not – they measure in different “reference frames”!

Examples.....