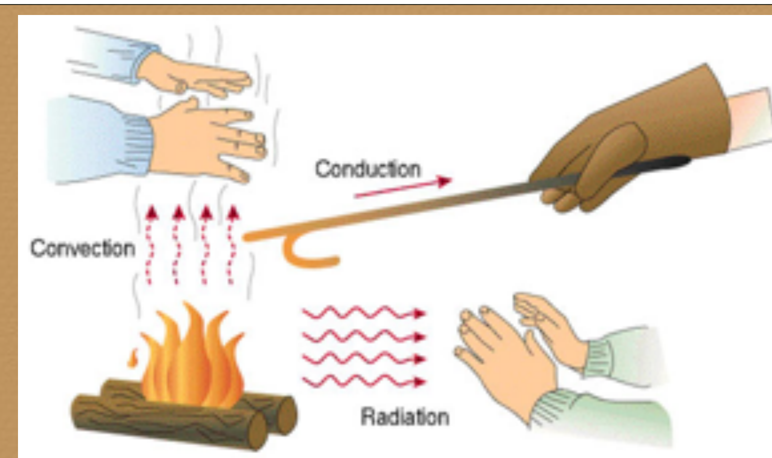


Energy Transfer and Heat!

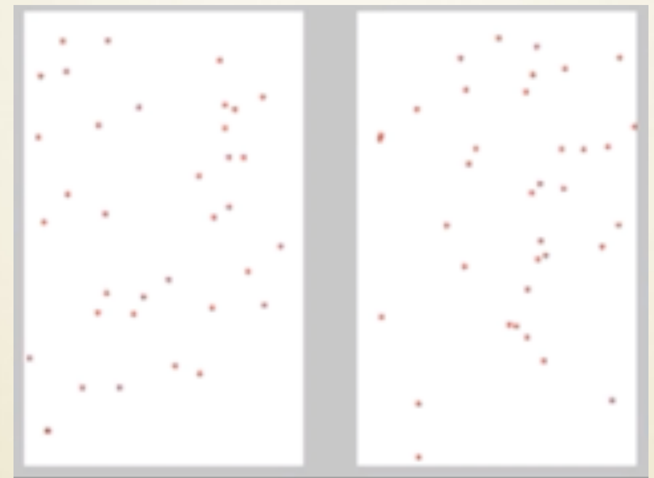
Extra Practice: 11.1, 11.3, 11.5, 11.7, 11.9, 11.15, 11.17, 11.25, 11.27, 11.33

- Specific heat
- Latent heat
- Methods of heat transfer

Applications:
Fire-eating!
Fire extinguishers!
The physics of tin foil!
Weight loss!

Topics for today

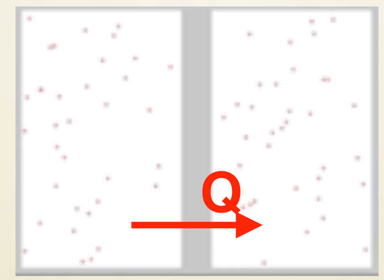
Reminder: Last Lecture



Put two things in thermal contact.
Energy will flow from the hotter to colder object.
(Until they reach thermal equilibrium)

How do we define heat?

Heat (Q)
=
A measure of **energy TRANSFER**.

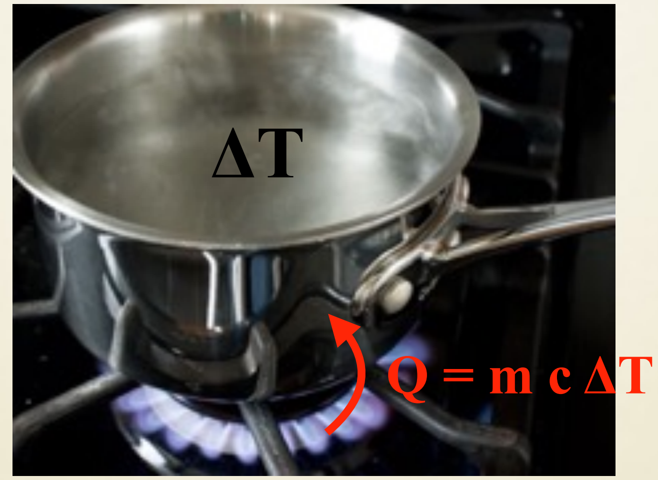


“Heat is the transfer of energy between a system and its environment due to a temperature difference between them”

The term “heat” refers to a movement of energy. Here, heat is being transferred from the thing with more internal vibrations/movement to the thing with fewer; the collisions and vibrations from the hotter thing induce an increase in collisions and vibrations in the colder thing (later we will learn that this particular example shown is doing so via “conduction”.

Some things are hard to make hotter.

(it takes more energy to get them hot)



If two things are adjacent (fire and a pot), it takes an energy transfer of amount Q to change the temperature of an object by delta T degrees
(**depends also on mass and "specific heat", c**).

On Monday I mentioned that the same amount of energy will change the temperature of things differently. The amount of energy it takes to change something by one degree VARIES WITH THE MATERIAL! Each material is quantified by a value we call "specific heat".

Let's back up a little bit. It takes some amount of energy, Q, to elevate the temperature of this water by temperature delta T. You need more energy with MASS, with more TEMPERATURE, and with larger HEAT CAPACITY, defined by "specific heat" of a material.

Converting energy to temperature

$$Q = m\,c\,\Delta T$$

Units of Q:
Joules

[Historically, calories:
4194 Joules
=
1 kilocalorie
=
1 Calorie
(on nutrition labels)]

(**Approximate measure of the energy this food will supply your body**, although there are subtle differences between the physics and the reporting on nutrition labels that I won't discuss in class.)

Since Q is energy, the units are Joules. What's cool is that years ago the human race didn't understand that heat had to do with energy, so we actually had separate units (calories), and these still persist today when talking about food. You can think of the calories on your food label as the approximate amount of energy your body is given by ingesting that food. This is a very first-level explanation of the nutrition label because there are deeper things going on here.

Converting energy to temperature

Units of c:
J / (kg K)
or
J / (kg ^oC)

$$Q = m\, c\, \Delta T$$

Specific heat for several materials:

- c_{water} = 4184 J/(kg K) – very difficult to heat
- c_{ice} = 2090 J/(kg K)
- $c_{mercury}$ = 138 J/(kg K) – very easy to heat (thermometers)
- $c_{ethanol}$ = 2428 J/(kg K) – much easier than water

So applying energy to something can raise its temperature, proportionally to mass, specific heat, and temperature change. Here are some examples of specific heat. Large value = takes lots of energy to heat. Small value: heats up with little energy imparted to it.

Converting Kinetic Energy to Heat

A 2000 kg car traveling at 20 m/s crashes into a tree. If **half** of the kinetic energy of the car is transferred into heat and that energy is absorbed by the car bumper, by how much is the temperature of the bumper temporarily increased?

Let's say a bumper weighs 15kg.
c of bumper plastic is ~1800 J/(kg K)

$$Q = m\ c\ \Delta T$$

Remember we talked about collisions and said that energy loss can happen through heat? Let's apply that now and slam a car into a tree and see how much the bumper will heat up. Usually the conversion of mechanical energy to heat energy is not perfect, so let's say half of the kinetic energy of this car is transferred into in the car bumper when it's distorted. Where do we start on this problem? Well we know the car has some available kinetic energy that is then lost when it hits the tree. So let's see what energy budget we have available by looking at its kinetic energy. So then half is transferred into heat in the bumper. What other information do we need? Can look on google…
[See light board notes]

Converting Kinetic Energy to Heat

A 2000 kg car traveling at 20 m/s crashes into a tree. If **half** of the kinetic energy of the car is transferred into heat and that energy is absorbed by the car bumper, by how much is the temperature of the bumper temporarily increased?

Let's say a bumper weighs 15kg.
c of bumper plastic is ~1800 J/(kg K)

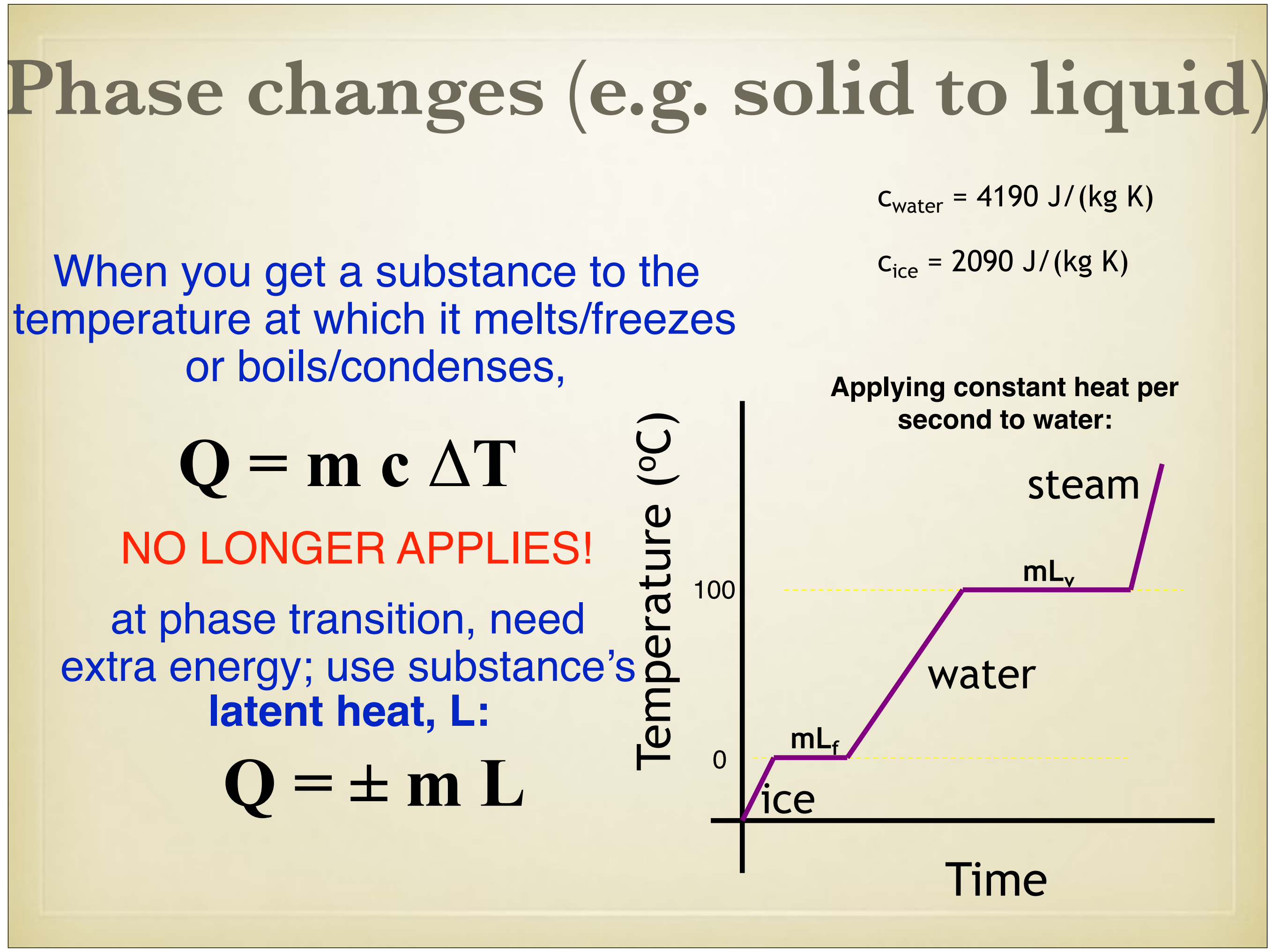
$$Q = m\,c\,\Delta T$$

What is the change in temperature if the $2x10^5$ J went into heating a 15kg chromium car hood, c = 460 J/(kg K)?

A. 0.22 ^{o}C
B. 7.4 ^{o}C
C. 29 ^{o}C
D. 4985 ^{o}C

Q105

ANSWER: C
You'd get A if you used the mass of the car. Remember to use the mass of the thing that the energy is transferred into!
The last one is about the temperature of the surface of the sun. Your car should not get THAT hot :).



Assume add same amount of energy per unit time.
Once you get your substance to a temperature at which a STATE CHANGE happens, if you add more energy the temperature stops rising for a little while! That is because the energy goes into actually changing the state of the substance (solid to liquid-fusion-, or liquid to gas-vaporization-) rather than raising the temperature. There's a specific amount of energy needed to actually change the states.
WATER can exist at both 0 degrees C and 100 degrees C! It just depends how much energy has been put into the water. If it doesn't have quite enough energy in it to make the water into vapor, the water can be 100 degrees Celsius.
https://www.youtube.com/watch?v=lTKl0Gpn5oQ

Energy (Q) required for phase change

Latent heat of fusion (L_f)

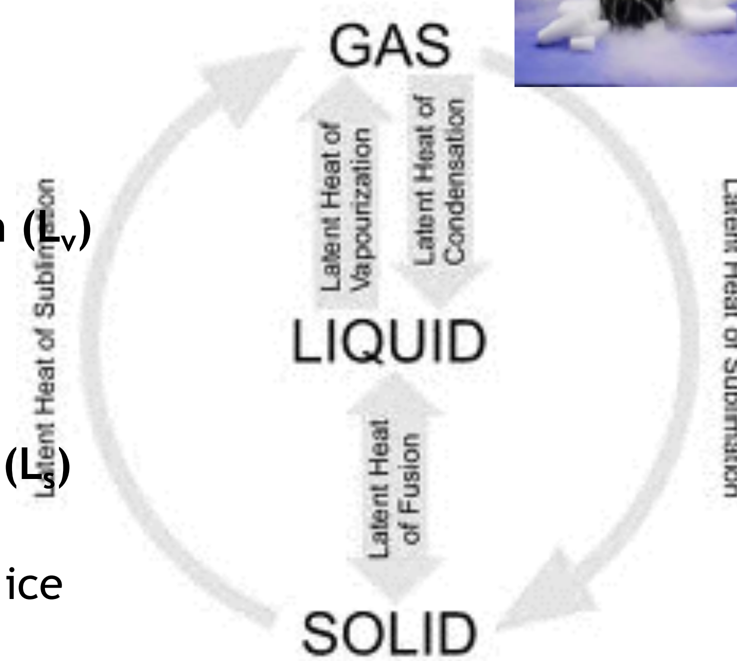
- solid <-> liquid
- melting or freezing
- $Q = \pm mL_f$

Latent heat of vaporization (L_v)

- liquid <-> gas
- boiling or condensing
- $Q = \pm mL_v$

Latent heat of sublimation (L_s)

- solid <-> gas (rare)
- Example: fuming of dry ice
- $Q = mL_s$



Pick sign such that hotter objects have more energy (adding to or taking away energy through the phase change)

How much energy is required to change a 40-g ice cube from ice at -10°C to steam at 120°C?

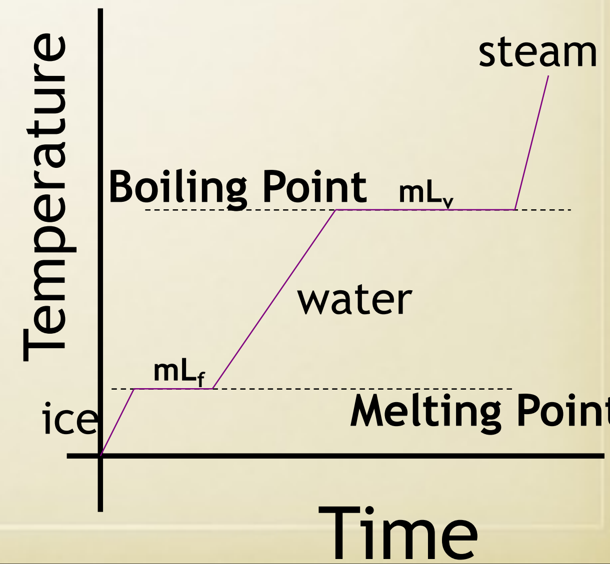
Q106

How many terms of m c ΔT and/or m L will we have?

A. 1 **B. 2** **C. 3** **D. 4** **E. 5**

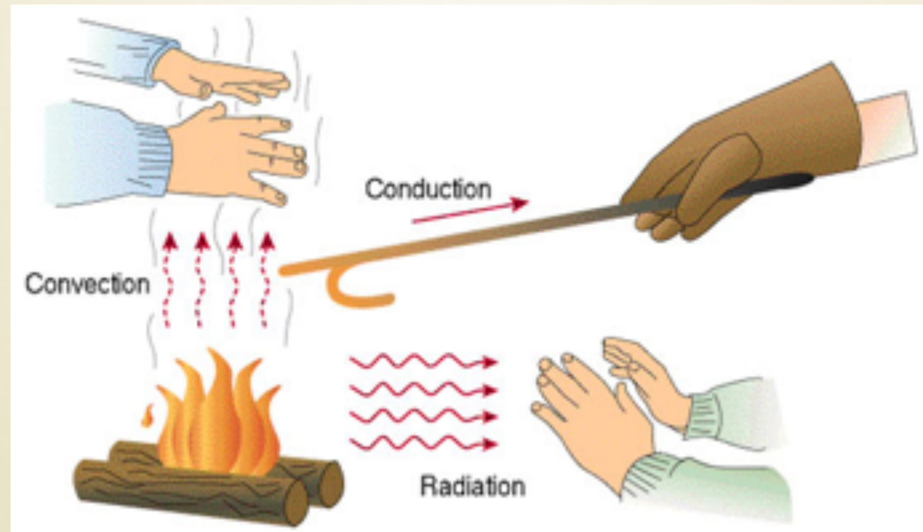
What are the terms?

Q to reach melting point (mc ΔT)
Q to melt (latent heat of fusion)
Q energy to reach boiling point
Q to vaporize (latent heat of vaporization)
Q energy to reach highest temp



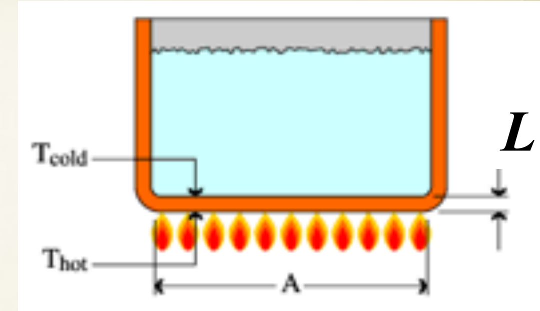
This is meant to set up a question on your homework.
ANSWER: E

Methods of energy transport.



We will cover these conceptually. I want you THINKING! Then we'll talk about some applications.

1) Conduction



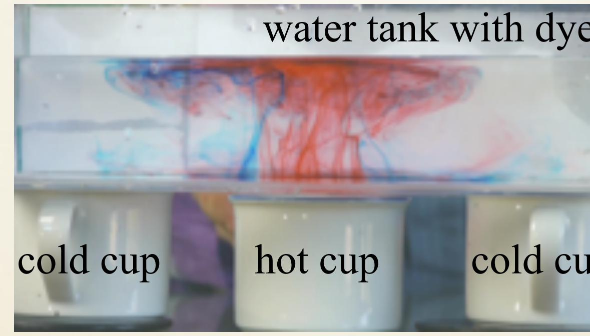
- **DIRECT TOUCH: passing on vibrations directly.**
- Things "FEEL HOTTER" with greater conduction!
- Rate of energy transfer (P=power) depends on
  - Temperature difference (T_H-T_C)
  - Area of contact (A)
  - Thermal conductivity of the material (k)
    - $k_{(copper)}$ = 385 W/(m K) good conductor
    - $k_{(air)}$ =0.02 W/(m K) good insulator
    - Higher k means more heat flow

$$P = \frac{Q}{\Delta t} = kA\frac{T_H - T_C}{L}$$

[not on test, just here to demonstrate]

CONDUCTION is all about direct touch.
Can think of the pot holder as an INSULATOR for conduction!

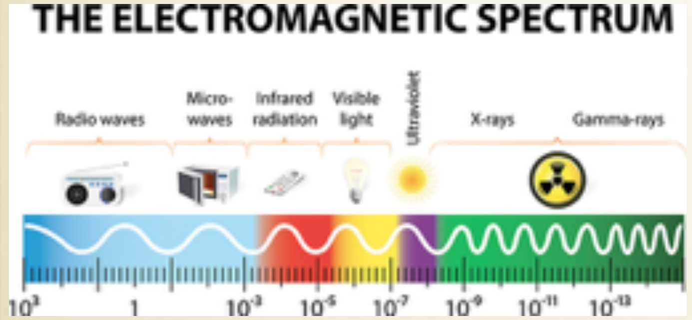
2) Convection



- **Migrating (hot) fluids (air, water).**
- **HOT AIR RISES (why?).**
- Hotter air/fluid: less density ($\rho = m/V$) of the air decreases, and it rises due to a buoyant force

Convection is all about literal movement of a hot fluid. Uses archimedes' principle to function! Less dense air rises.

3) Radiation

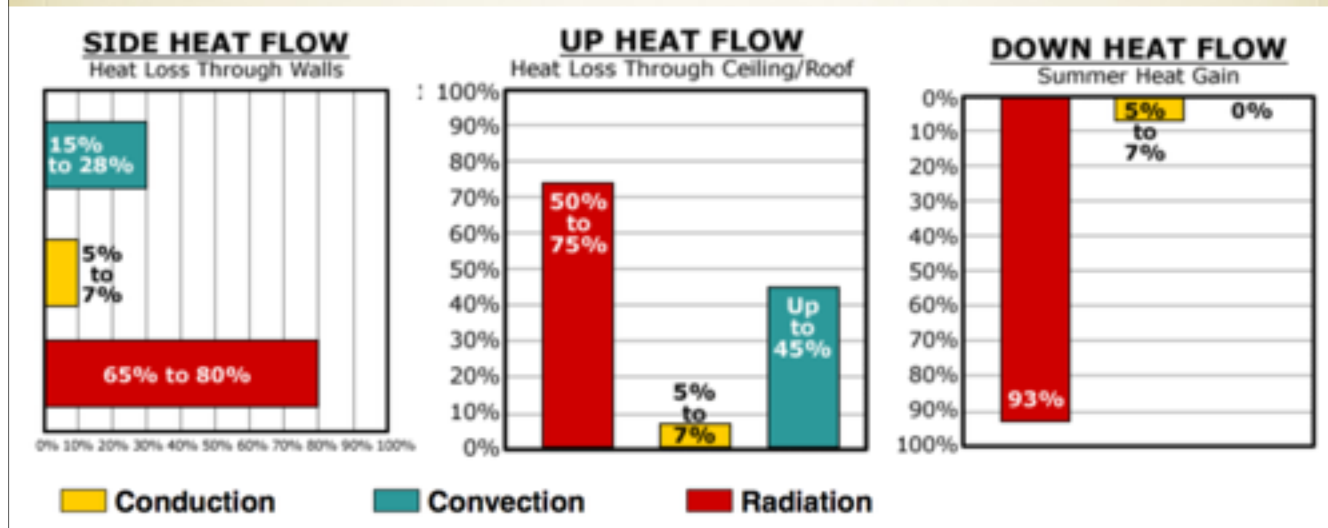


- **ALL OBJECTS RADIATE LIGHT!**
  (at some wavelength! Many things on Earth: infrared.)

- **No touch required.**

ALL objects radiate light due to vibrations of electrons in atoms; they emit at different wavelengths that we can't see. Some bugs like MOSQUITOS can see infrared light because they want to find and eat your warm body, and they are cold-blooded so need to keep themselves warm. This is why some bugs are attracted to lights and your body: they're hot so putting out infrared light.

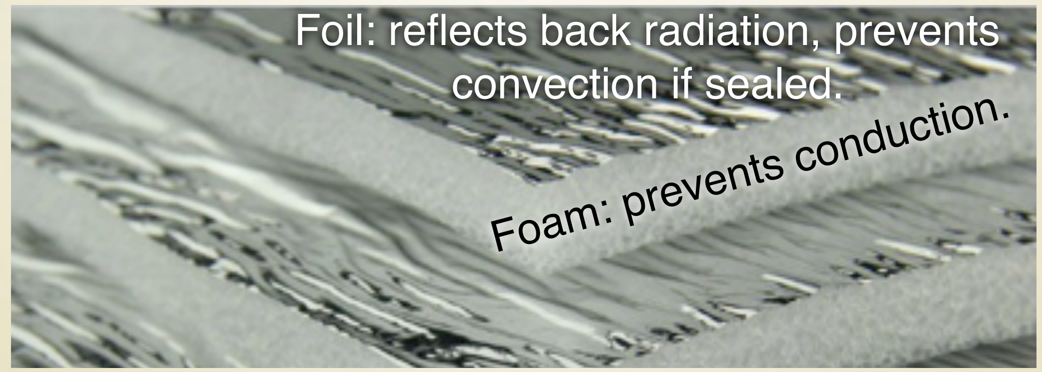
Common examples…



Heat loss/gain from your house is mostly from radiation.

Installing asbestos insulation prevents conduction and to an extent convection, but not radiation! A good insulator will have both a reflective surface and something to block movement of air AND direct conduction, so will pad the reflective surface with something with a LOW k VALUE!

The best insulator!



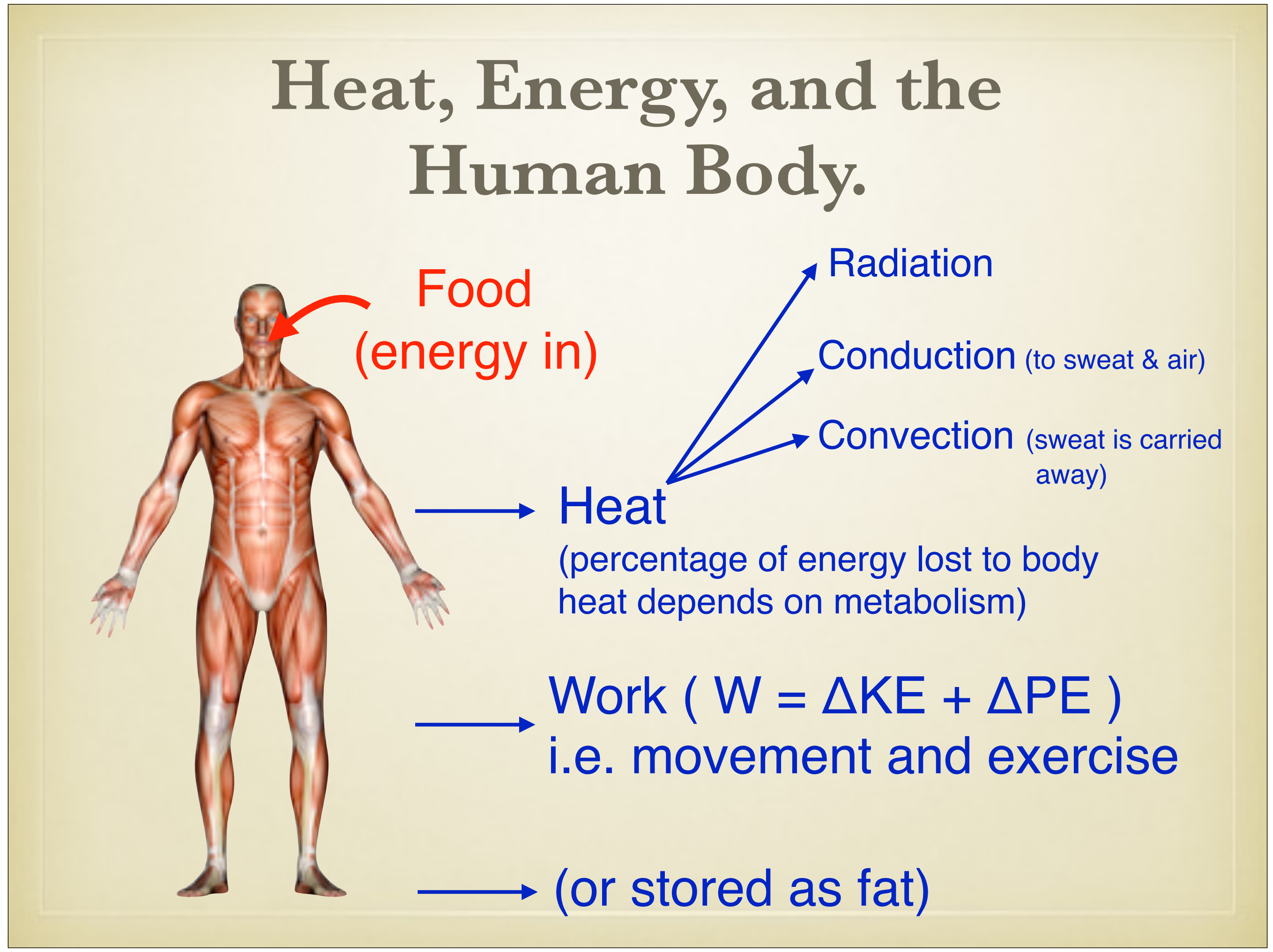
Why is foil good at keeping food warm?

Because food loses heat most through RADIATION AND CONVECTION.

Foil keeps food warm by blocking passage of radiation, and by containing hot air.

Don’t put it by something cold (conduction will take energy away through touch).

If you put your tin-foil wrapped food on a block of ice, that’s NOT A good idea… there will be a lot of conduction and it defeats the purpose of tin foil.



When you eat, your metabolism ensures a lot of the food is converted into heat. Your "basal metabolic rate" is, more or less, how good your body is at converting food to heat. If you have a high metabolism you're probably better at converting food to heat (so you'll have to eat more food to have enough fuel for a particular exercise, or for your body to maintain its weight).

Other energy you get from the food you have to DO MECHANICAL WORK to get rid of it (i.e. exercise!). Otherwise, it gets stored in your body in forms of various things, including fat.

Your body also utilizes all three of the methods of energy transfer to keep itself regulated.

BURGER KING® USA Nutritionals: Core, Regional and Limited Time Offerings
JANUARY 2017

Nutrition Facts	Serving size (g)	Calories	Calories from fat	Total fat (g)	Saturated Fat (g)	Trans Fat (g)	Chol (mg)	Sodium (mg)	Total Carb (g)	Dietary Fiber (g)	Total Sugar (g)	Protein (g)
WHOPPER® Sandwiches												
WHOPPER® Sandwich	260	630	340	38	11	1.5	85	810	49	2	11	26
w/o Mayo	239	470	180	20	8	1	75	670	49	2	11	26
WHOPPER® Sandwich with Cheese	283	710	400	45	15	1.5	105	1160	50	2	11	30
w/o Mayo	262	560	240	27	12	1.5	95	1030	50	2	11	30
Bacon & Cheese WHOPPER® Sandwich	279	750	440	49	16	2	115	1260	46	2	8	33
DOUBLE WHOPPER® Sandwich	341	850	480	54	18	2.5	155	870	49	2	11	48

4194 Joules
=
1 kilocalorie
=
1 Calorie
(on nutrition labels)

About how many Joules do I have available?

Standard metabolism: ~70% to heat.
(~30% residual in body)

Higher metabolism: food mostly goes to heat!
So you'll need to expend less mechanical energy (less exercise) to work it off!

Let's say I go to burger king and get a whopper, no fries or anything. What do I have to do to work it off (how high of a mountain should I climb)?
[See light board notes]
This is a silly example but you can see why checking calorie counts of your food is a wise idea if you want to lose or gain weight!

Challenge to you.

Think of your winter coat.
What principles does it use
keep you warm?