PHYSICS 102N
Spring 2009

Week 4

Heat Transfer and Phases

Heat transfer revisited

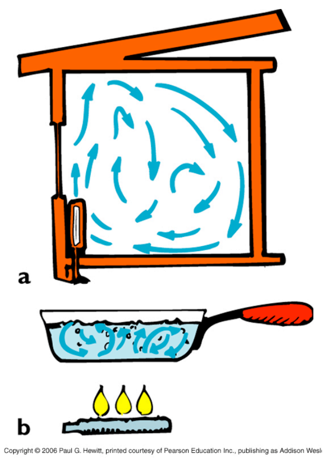
- 3 mechanisms to transfer heat:
  - Conduction: adjacent molecules bump into each other, transfer energy
  - Convection: molecules move from one place to another, taking energy with them
  - Radiation: hot material emits it, colder material absorbs it
- First two: heat transfer proportional to temperature difference ("Newton's law of cooling" {and warming!})
  - The warmer your home in winter, the more heating energy you use
  - The cooler your home in summer, the more power consumed by the AC (actually for more reasons than just this one - see later)

Conduction

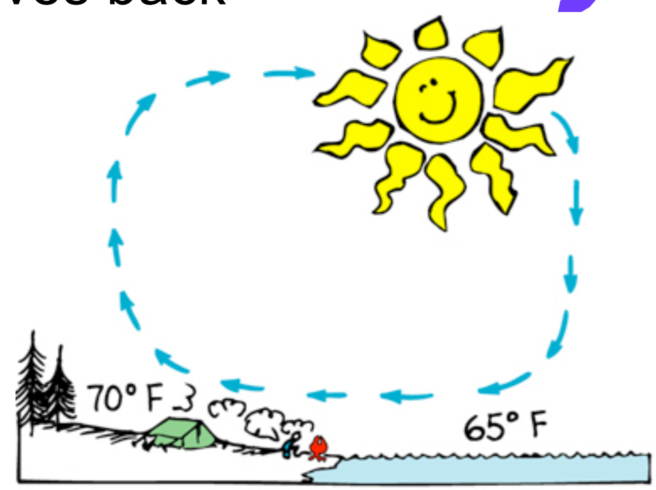
- Heat transported from neighbor to neighbor or, within a metal, via electrons
- Greater temperature difference and larger cross sectional area increase conduction, larger distance decreases it
- Materials can be strong or weak conductors:
  - Strong: metals, solid stone
  - Weak (=insulators): Wood, fur, wool, straw, other organic materials; plastic; anything having lots of trapped air (feathers, styrofoam, snow,…); water is pretty weak, too
- Heat can also be “conducted” from one object to another if they touch

Convection

- Dominant method of heat transfer in gases and other fluids
- Flow of hot material carrying energy with it
- Aided by temperature dependence of density - convection circle:
  - Hot fluid is less dense => rises up (buoyancy)
  - To make space, fluid at top moves sideways and cools; (expanding gas cools down)
  - Denser, colder fluid drops down and moves back



Large scale convection -> weather
Forced convection -> Oven



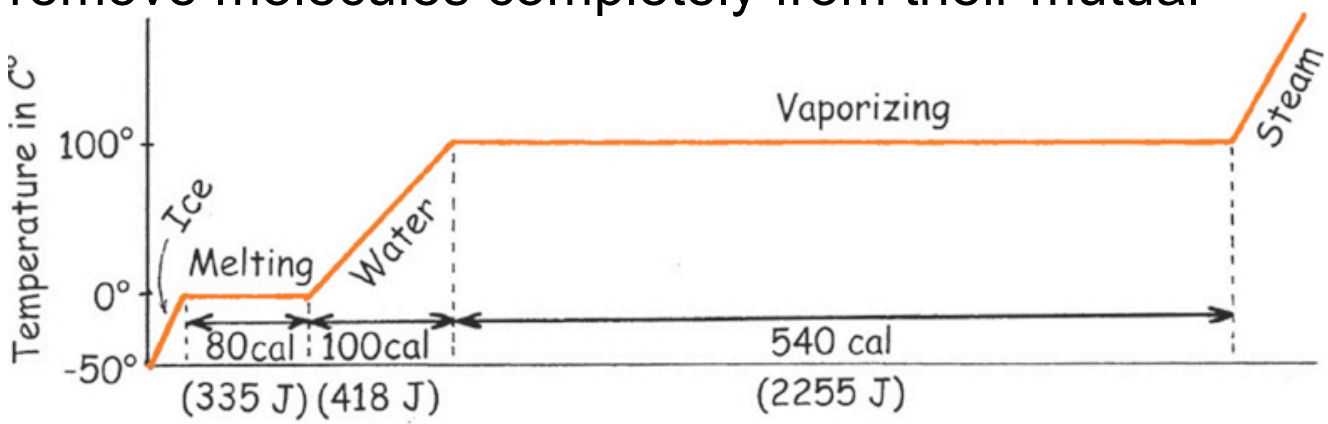
Radiation

- **Electromagnetic radiation:** oscillating electromagnetic fields traveling through space as waves -> see later in semester
- Characterized by **frequency** and **wave length**
- Given off by any wiggling charge
- A form of **energy** that can be transmitted through empty (or transparent) space
- => **Any** object with temperature T > 0K gives off some electromagnetic radiation, any object receiving it will warm up until equilibrium is reached (example: Earth; day and night difference)
- Black objects emit and absorb more radiation than reflecting ones

- **The hotter an object:** More and more radiation emitted, at shorter and shorter wave lengths (infrared - visible [red-yellow-blue] - ultraviolet) -> stars, fires
- **Cold objects** (everyday temperatures): mostly far infrared, radio waves…
- Greenhouse effect: Absorption high at short wavelengths, emission suppressed at long wavelengths

Phase Changes

- A phase change is typically a modification of the properties of a substance that requires energy **without** changing temperature *)
  - Melting ice: it takes 80 cal (335 J) to melt 1 g -> energy needed to break up some bonds so molecules can move around more freely
  - Evaporating water: it takes 540 cal (2255 J) to evaporate 1 g !!! (needed to remove molecules completely from their mutual attraction)



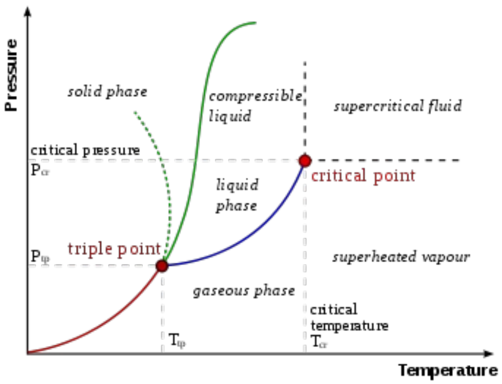
*) All numbers are given for the usual freezing (0°C) and boiling (100°C) points of water; but melting or evaporation can occur over a wide range of temperatures

Evaporation - Condensation

- Water at any temperature gives off vapor
  - evaporation takes energy -> either have to add heat or water (and surrounding air) will cool (hot coffee)
- If there is vapor around, some fraction of it will condensate into water
  - condensation releases energy -> warms surroundings
- For given temperature T, there is a corresponding vapor density ρ (or P_{vap} = partial pressure) such that
  - if surrounding vapor density (pressure) is lower, more water evaporates then condenses (very dry air, higher T)
  - if surrounding vapor density (pressure) is higher, more water condenses than evaporates (“steamy air”, lower T)
  - if surrounding vapor density (pressure) is equal, equilibrium is reached - no net condensation or evaporation
  - the higher T, the higher ρ (or P_{vap})

Boiling

- What if T is high enough so that P_{vap} = 1 atm?
  - evaporation happens not only on surface but also throughout liquid since vapor bubbles don't collapse
  - => very rapid evaporation as long as pressure remains the same (counter example: pressure cooker)
  - => very rapid removal of heat from liquid - have to keep supplying to keep boiling; self-regulating
- What happens if external *P* is as low as P_{vap}?
  - the very same thing: boiling!!!
  - => Boiling temperature depends on pressure (Denver: 95^{o}C)
  - again: liquid cools!
    - reason there is no liquid water on Mars (and no water on moon)



Melting - Freezing

- For a given pressure, there is a temperature T_{melt} (melting point) at which water and ice are in equilibrium
  - To go below, water has to freeze (giving off energy)
  - To go above, water has to melt (absorbing energy)
- Increasing pressure **lowers** T_{melt} (ice is less dense than water!)
  - Regelation (snow balls)
- For one specific pressure and temperature, ice, water and vapor are in equilibrium -> triple point
  - used for 2nd fixed point on Kelvin temperature scale

273.16 K (0.01 °C) and a partial vapor pressure of 611.73 Pa (ca. 0.006 atm)

Examples

- Weather - Clouds, Fog, Rain, Snow, Humidity
- Taking a shower - “steam heating”
- Evaporative cooling - sweating (VA vs. NM)
- Geysers
- Refrigeration and Heat Pumps
- Ice skating
- Regelation (snow balls)

Q1

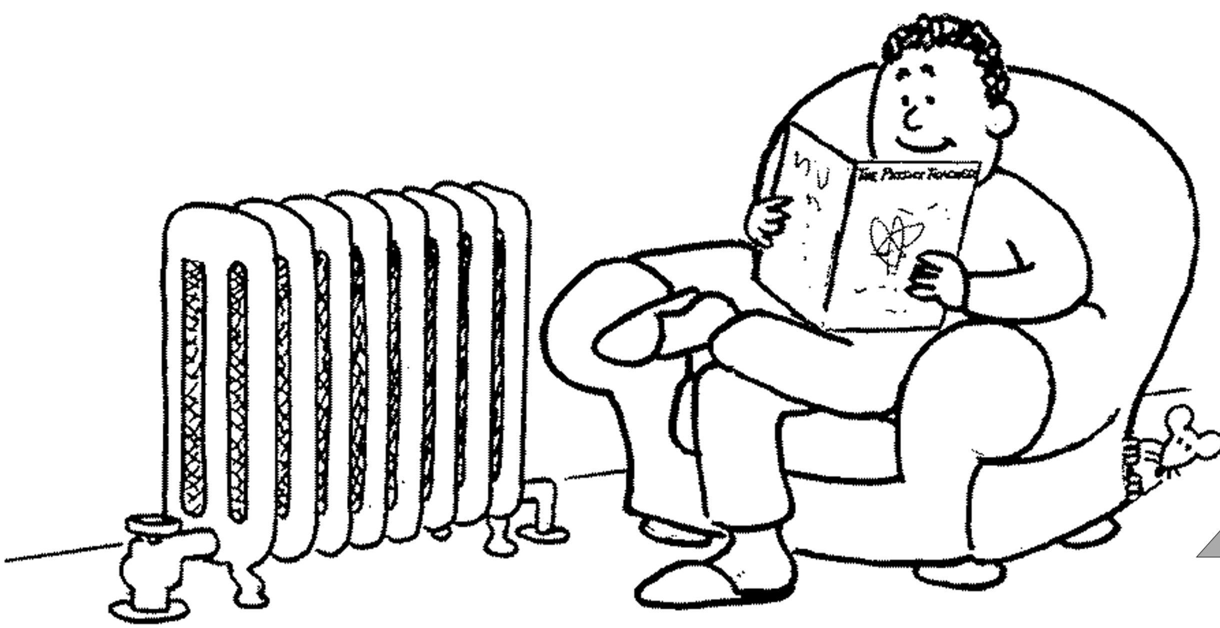
Hot water/steam radiators are common fixtures that nicely warm the interiors of buildings. These radiators warm a room primarily via

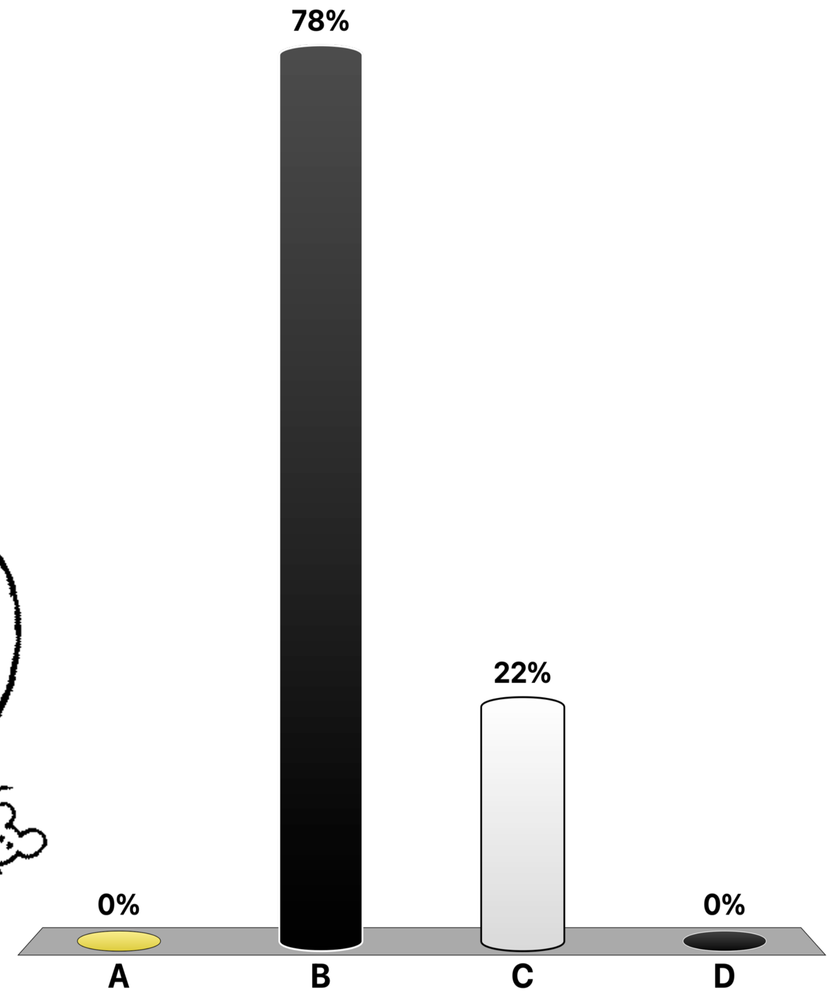
A. Conduction

B. Convection

C. Radiation

D. …all about equally





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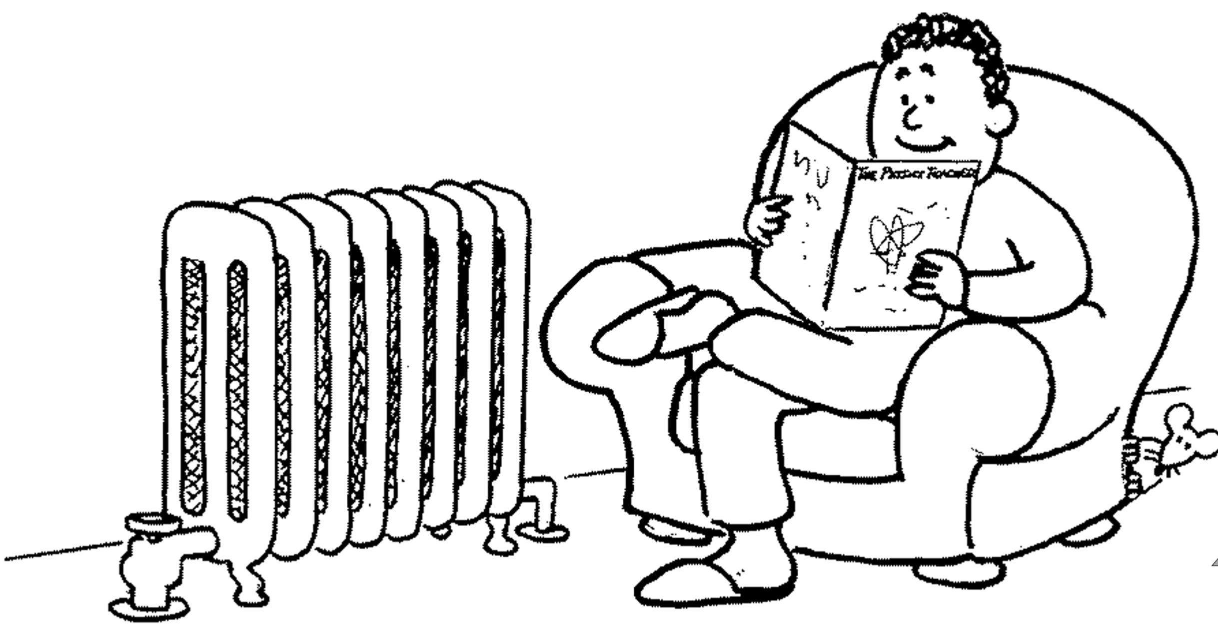

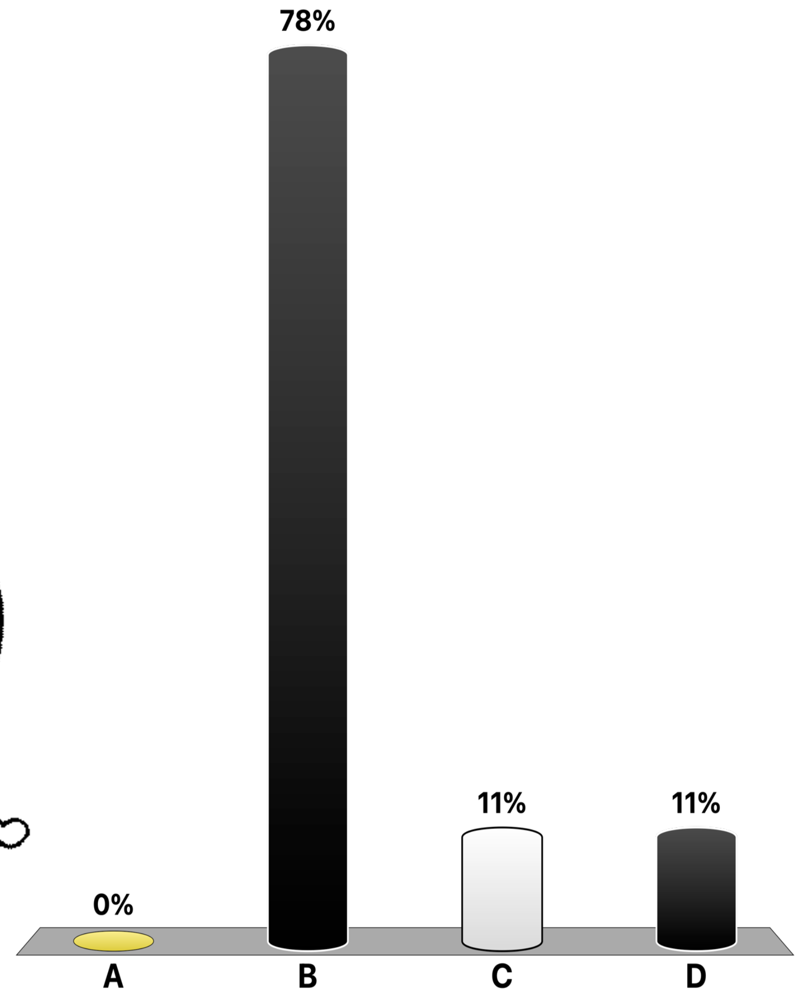

Q2 You're a consultant for a cookware manufacturer who wishes to make a pan that will have two features: (1) absorb thermal energy from a flame as quickly as possible, and (2) have an inner surface that remains as hot as possible when cooking. You should recommend a pan with the

A. Outer and inner surfaces black.

B. Outer and inner surfaces shiny

C. Outer surface shiny and inner surface black

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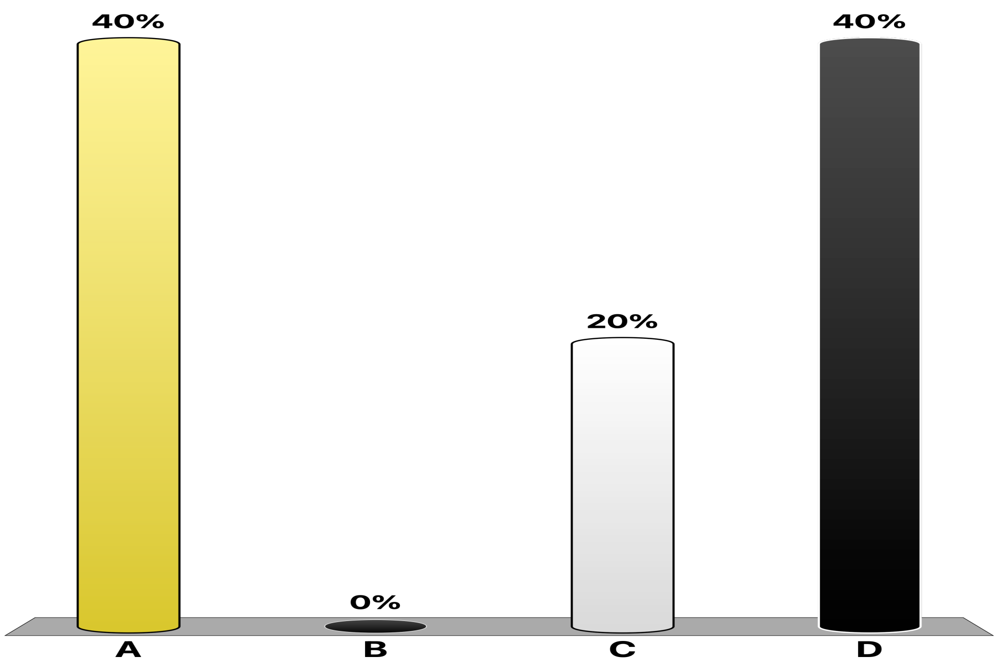

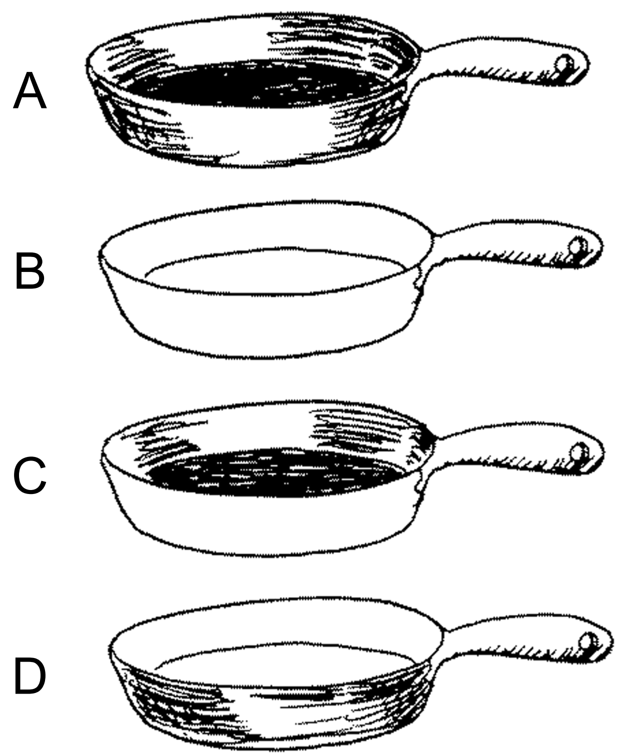

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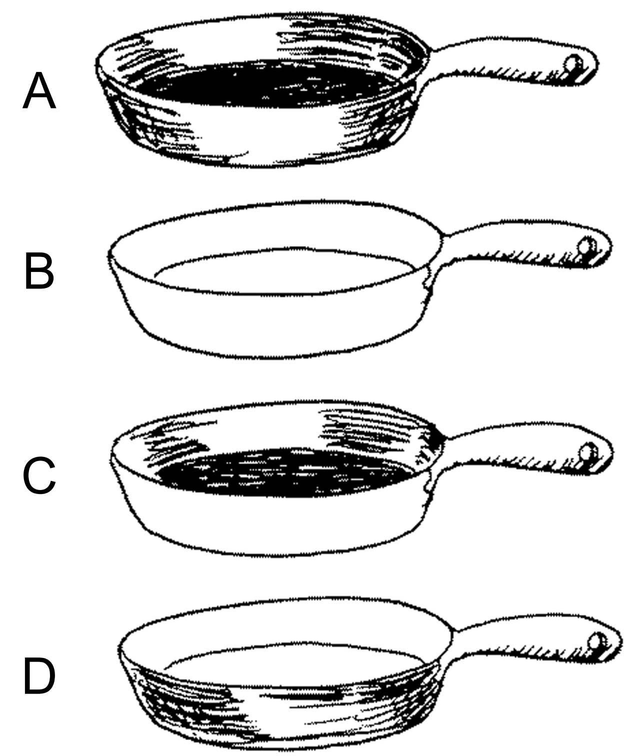

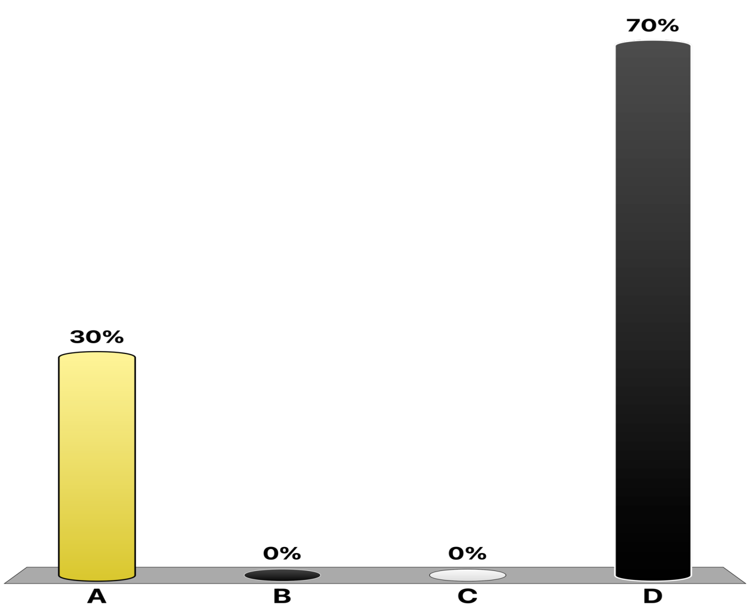

Q3 Suppose in a restaurant your coffee is served about 5 or 10 minutes before you are ready for it. In order that it be as hot as possible when you drink it, should you pour in the room-temperature cream right away or when you are ready to drink the coffee?

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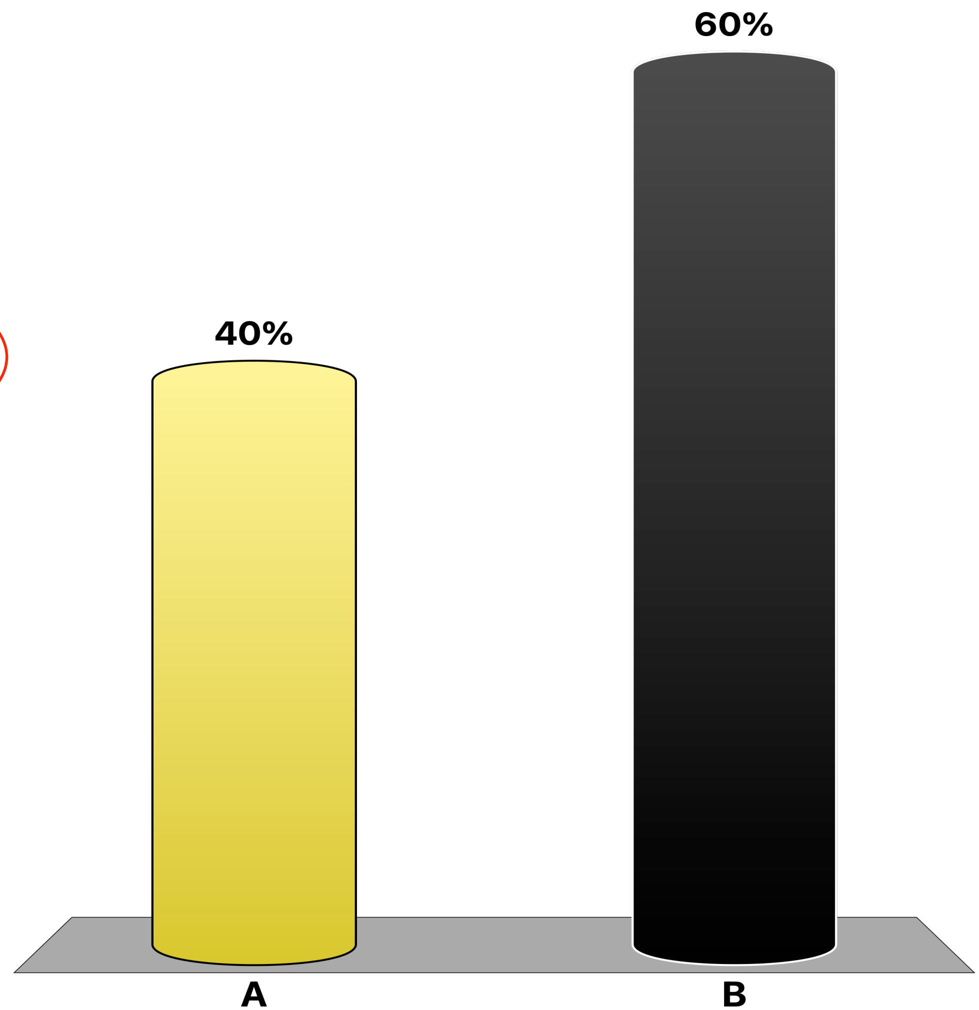

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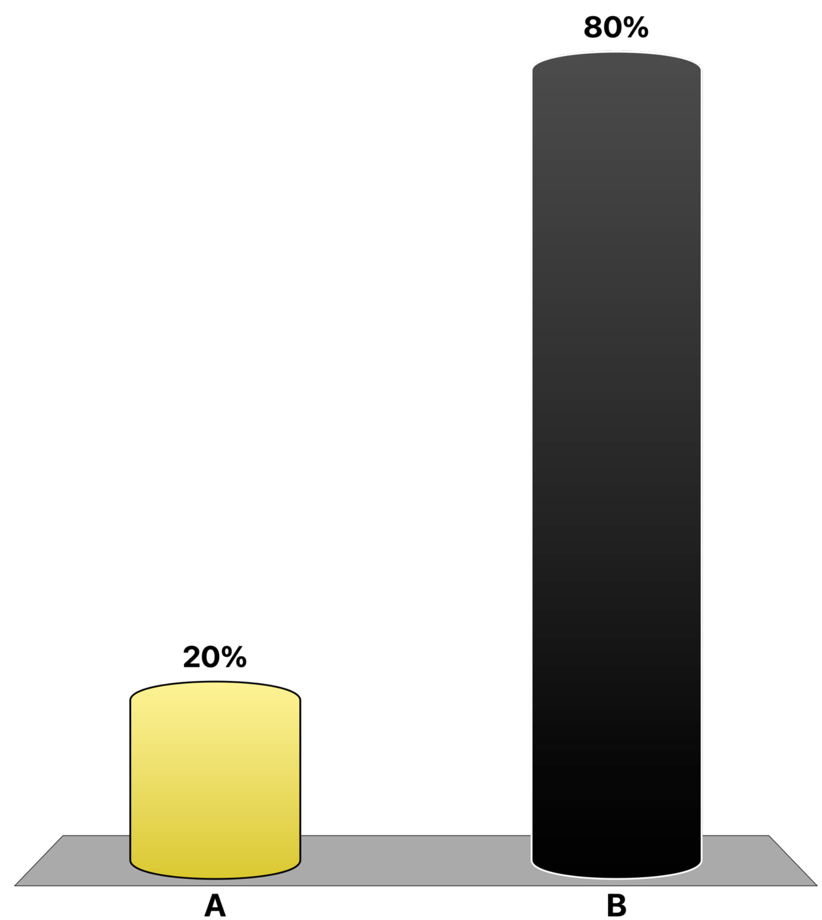
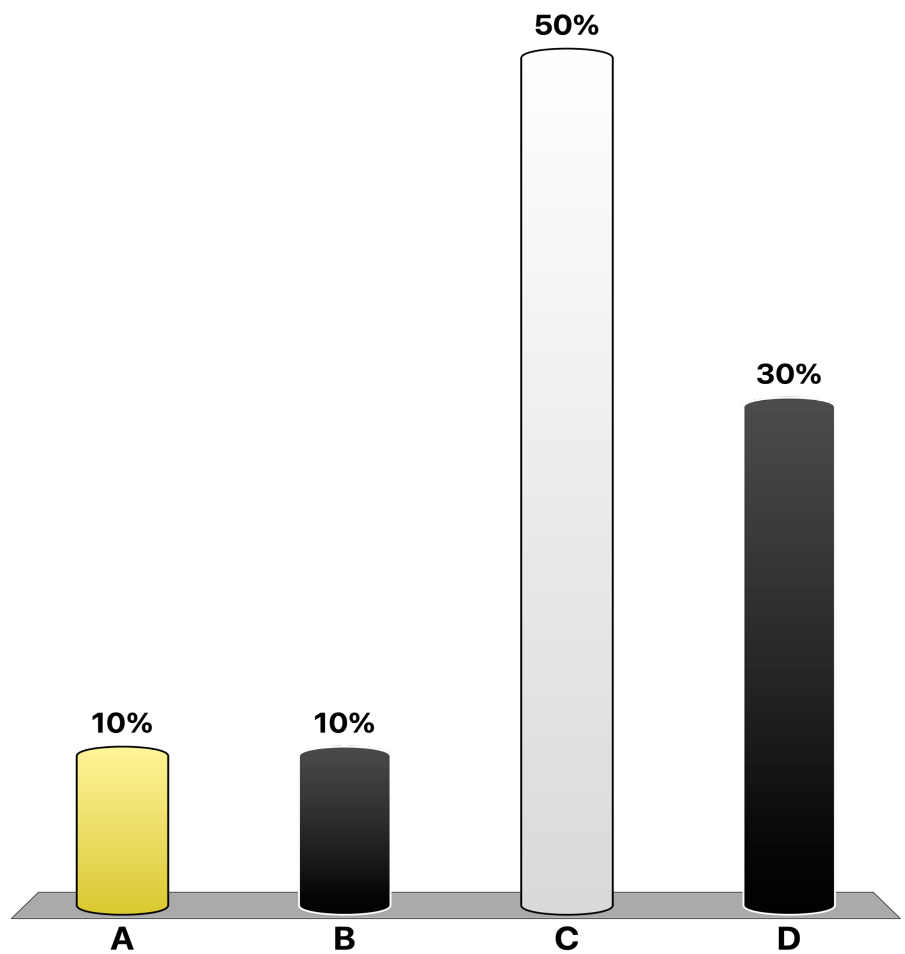


Q4

A beaker of water is placed inside a vacuum and the water begins to boil. If you could somehow put your finger into the water (without breaking the vacuum), would the water

A. Burn your finger?
B. feel hot?
C. have room temperature?
D. feel cold?

You can argue for both



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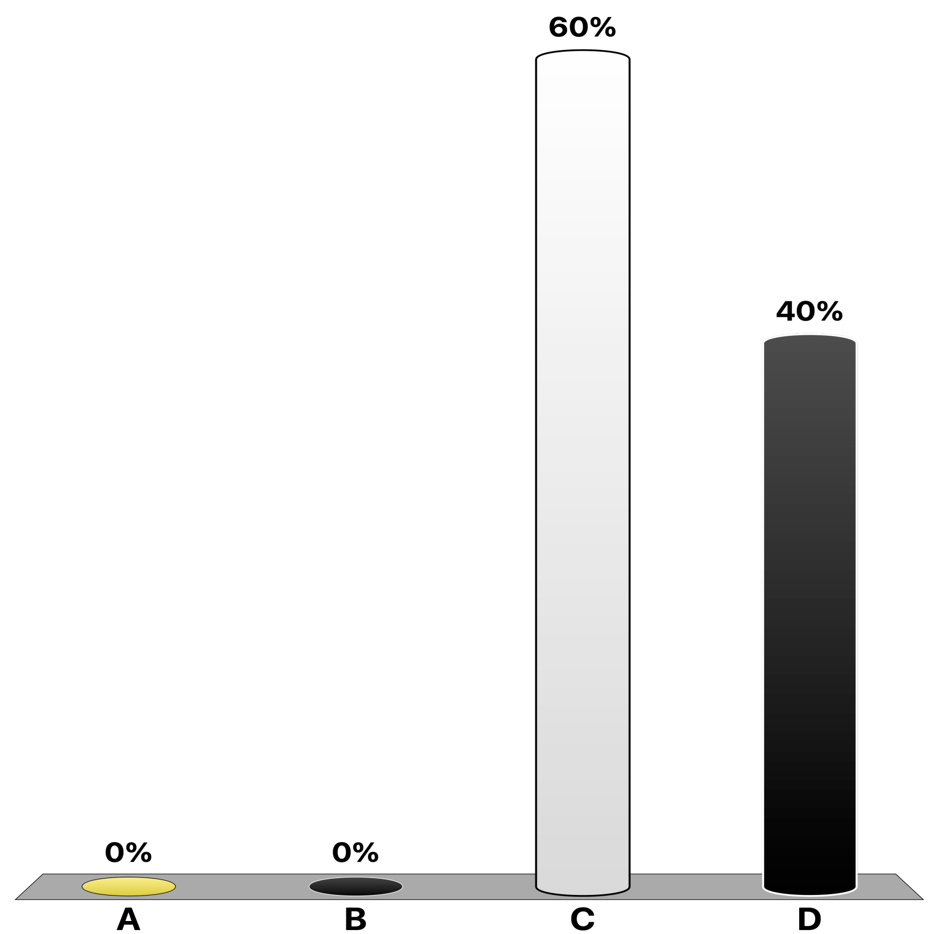

Q5 Why do we cook some foods (like eggs) by submerging them in boiling liquids like water?

A. To get them super-hot
B. To control their cooking temperature without a thermostat
C. No good reason – it's just a tradition