Chapter 7

Heat and Phase Transitions

We have put a lot of emphasis on Energy when we talked about motion.

We had

\[ U = mgh \]

kinetic Energy - Energy associated with movement of an object \[ K = \frac{1}{2} mv^2 \]

Some motion is hidden from our sight inside an object.

Thermal Energy - keeps individual atoms & molecules inside "jiggling" back and forth randomly.

We "sense" this random thermal energy as temperature.

The "Hotter" an object is, the higher the temperature.

The more thermal energy it has.
When you touch an object what happen?
- you feel hollness or coldness
results from the transfer of Energy from or to
your hand and the object.

Transfer of thermal Energy = Heat

Heat flows from a hotter object to a colder
object. Energy is conserved. Until Thermal Equilibrium
is reached, - Temp's equal

Question of interest: Why doesn't heat flow
from colder object to hotter, still conserving
energy? (e.g. why doesn't a lake freeze
in the warm air, cooling off the lake and
warming the air?)

Entropy increases. More on this later.

We will examine these concepts in Thermodynamics
in chapters 7, 8 Word stores, clothing, steam & Ice, Air conditions
Temperature: how hot or cold something is quantity - temperature scale

Celsius, Fahrenheit, Kelvin

reflects the average thermal kinetic energy per atom.

Used standard conditions to set the scale

i.e. Freezing Water, boiling Water, Absolute Zero

e.g. for Celsius Scale, Fahrenheit

Freezing Water 0°C 32°F 273.15K
Boiling ° 100°C 212°F 373.15K
Absolute zero 0K, -273.15°C -459.67°F
Woodstoves. - Show picture

Used to heat a room, keep you warm.

Burn wood to produce Thermal energy. That
Then flows into the room.

1) How does the wood produce Thermal Energy?
2) How does the heat "flow" into the room?

**DEMO:** Hydrogen Balloon

A1) **Activation Energy** - initiate the chemical reaction between the fuel and the oxygen.

A2) Stove acts as a "heat exchanger"

transfers heat without transferring the hot molecules themselves.

hot stove > heat flows to cooler room - How?
heat flow by Conduction

heat flows through a stationary material from hot to cold region, but atoms and molecules don't.

The ease with which heat can conduct in a substance is called Thermal Conductivity.

good electrical conductors generally make the best heat conductor.

Demo: Heat Conductivity [2-21]

also show insulator Conduction makes the outside surface of the stove hot. Allowing heat to flow from it to the room.

What carries heat into the room?
Heat Moving with air:

Convection

Moving fluid transports heat from hotter to colder object. The heat and fluid travel together.

The circulation often develops naturally

- Hot air has lower density
- Floats upward
- When fluid cools near colder object, the density increases and sinks downward.

Convection current

Adding ceiling fan will help move the heat at top of room.

**DEMO - 12-43** Convection
3rd mechanism of heat transfer:

Heated Moving as Light: Radiation

Electromagnetic waves. Includes radio waves, microwaves, infrared, visible, ultraviolet, x-rays, & e-rays... (wavelength, frequency)

The type of electromagnetic wave (i.e., radiation) depend on the temperature,

Colder object emits only lower frequency Radiation (Radio, Microwave, Infrared)

Hotter object can also emit visible, or even ultraviolet light.

Think of the red glow in a hot coal or very hot metal in a blacksmith's fire, or a poker getting "red hot" at the tip.
Demo I2-12 Radiation transfer "Light a match"

Think about facing a campfire, or heating by the sun. Radiation can even get a radiation burn. (Sun burn).

Warming the Room.

Relationship between heat energy and temperature change.

Some things get hot (high temp) with not much heat, while others need a lot of heat to get hot. \( \rightarrow \) Heat Capacity

Amount of heat needed to add to an object to raise the temperature limit
**Specific heat**

heat capacity per unit mass

Specific heat is the amount of heat energy (J) needed to raise 1 kg by 1 degree K (or °C).

Unit is: joule-per-kilogram-per K

\[
\frac{J}{kg \cdot K}
\]

Heat Energy = Specific \ x \ Mass \ x \ ΔT

Examples: raise 1 kg by 10°C (or 10K)

- \( C_{\text{copper}} = 386 \ \frac{J}{kg \cdot K} \)
- \( C_{\text{water}} = 4190 \ \frac{J}{kg \cdot K} \)

\[
E_{\text{water}} = 4190 \ \frac{J}{kg \cdot K} \times 1 \ kg \times 10 \ K = 41,900 \ J
\]

\[
E_{\text{copper}} = 386 \ \frac{J}{kg \cdot K} \times 1 \ kg \times 10 \ K = 3860 \ J
\]

Easier to raise temp of copper.
Section 7.2

Water, Steam & Ice

Why does adding ice to a drink make it cold?
How does perspiration cool you off?

Water exists, like most substances, in three distinct forms or Phases: Solid, Liquid, Gaseous.

Reflect different microscopic structure of the water molecules.

Melting ice & Freezing water

Solid $\leftrightarrow$ Liquid Phase Transition or, change of state
Place cold ice from freezer, typically < 0°F (-18°C) on countertop. Heat flows from countertop to colder ice. Warming the ice. The ice remains solid until it reaches the melting point 32°F (0°C).

* At that point the ice stops getting warmer! begins to melt.

* Melting is a Phase Transition from an ordered solid state to the disordered liquid state. (Phase)
  heat needed to break chemical bonds.

Melting point of Water/Ice is 0°C
Melt Remains at 0°C as Heat added Changes solid to Liquid.

"Latent Heat" of Melting or Fusion
333,000 J of heat to melt 1 kg of Ice at 0°C.
lot of heat associated with phase transitions

That 333,000 J of heat would raise 0°C water to 80°C!

\[\text{Temp} \quad \text{specific heat} \quad \text{latent heat of boiling}\]

\[\text{0°C} \quad \text{latent heat} \quad \text{specific heat} \quad \text{heat}\]
Clothing and Insulation

Recall that heat flows from hot to cold.

- How do you stay warm when outside in the cold? And how do you keep heat in your house during the cold winter?

- Why does wrapping food in aluminum foil help keep it hot or cold?

Yes... Insulation

Thermal insulation slows the flow of heat from hot objects to cold objects.

- keep your body warm
- refrigerator cold
- home comfortable temp.

E.g. Clothing, wall insulation, cooler (styrofoam etc...
Why keep your body temperature constant?

- Humans (mammals) and birds

Warm-blooded animals maintain temperature to keep the chemical reactions going - metabolism generating energy - don't "slow down" like cold-blooded animals in cold. Gives an competitive advantage!

Where does the heat come from to keep us warm?

- Convert chemical energy into thermal energy

80 Calories per hour

\[
\text{Calorie} = 1000 \text{ "food Calories"}
\]

\[
\frac{\text{Energy}}{\text{time}} = \text{rate of energy, called power (like J/s)}
\]

\[
\approx 100 \text{ watts (J/s)} \text{ similar to an incandescent light bulb!}
\]

Body limits heat loss the best it can

Heat transfer by?

1. Conduction
2. Convection
3. Radiation
1) Limiting Thermal Conduction

The rate at which heat flows from hot to cold object determined by several factors

a) the overall temperature difference ($\Delta T$)
b) the distance separating the two ($d$)
c) the area through which heat can flow ($A$)
d) the material itself between the two ($k$)

directly proportional to $\Delta T$, $A$

inversely proportional to $d$

depends on material (thermal conductivity $k$)

Heat flow = \frac{\text{Thermal Conductivity} \cdot \text{Temp difference} \cdot \text{Area}}{\text{Separation}}

\[ H = \frac{k \cdot \Delta T \cdot A}{d} \]

Various materials shown in Table 7.3.1 p8 294

Air, 0.025 W/m\(\cdot\)K poor conductor!

Copper, 380 W/m\(\cdot\)K good conductor!
More about Thermal Radiation

- Recall heat transfer by Thermal Radiation
- Sit in front of fire and feel the Radiation warming your skin
- Sun’s Rays of EM Radiation warming you

contrast to sitting in an ice sculpture
- you are absorbing less than you, yourself
point has a cooling effect!

Can you judge the temperature of an object by
the color it emits? Red Hot, White Hot, etc...

Thermal Radiation consists of electromagnetic
waves. Some waves you can see as visible light!
DEMO N1-05 spectra

EM waves are distinguishable by their wavelengths. That is, the distance between their wave crests.

Show spectrum on overhead from computer.

In the visible you perceive different wavelengths as different colors.

Discuss wavelength, frequency, color using projected spectrum.

Longer wavelength \( \Rightarrow \) Lower frequency
Shorter wavelength \( \Rightarrow \) Higher frequency

Everything emits Thermal Radiation:
- Not a single frequency, broad range \( \Rightarrow \) spectrum
- Depends on Temp
  - Higher \( T \) \( \Rightarrow \) More absolute intensity
  - Shifted to shorter wavelengths
This is sometimes called
Blackbody Spectrum or Radiation

Discuss color temperature
Show Fig 7.3.4 in book.

DEMO 52-06 Thermopile and Osc
Show radiation in Infrared from a person

Radiated power

\[ P = e \cdot \varepsilon \cdot \sigma \cdot T^4 \cdot A \]

\( e \) is emissivity (0-1)
\( \sigma \) is Stefan-Boltzmann constant

Power goes like \( T^4 \)
Staying warm by controlling thermal radiation

- Normally surroundings are similar T so net radiation is not much

→ Something with low emissivity (Reflects the radiation)

- Aluminum foil on food
- Space Blanket
- Under a tree at clear cold night
  - Losing radiation to space

DEMO - Radiation from cold object I2-12
I2-10 Dewars.

Finish with Demo on 3 sources to distinguish Blackbody Radiation from single frequency (energy)

N2-02 Spectrum of 3 lights

Quantum Mechanics