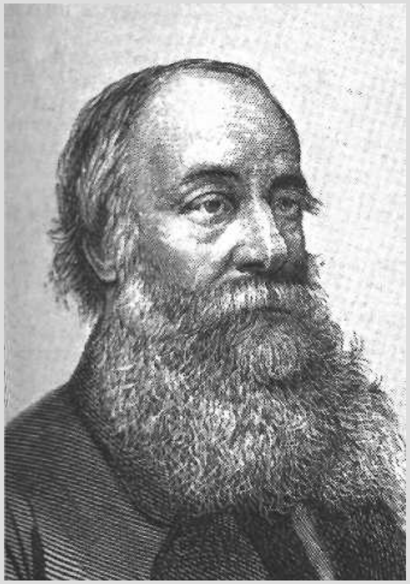
NATS 101
Section 13: Lecture 4

Temperature and Heat Transfer

What is Energy?



JP Joule

<u>Energy (E)</u>: The product of a force over the distance (*d*) which it is applied.

$$E = F \times d \quad \text{or} \quad E = \int F dx$$

SI Units of energy = Joule = kg m^2 s^{-2}
1 Joule = 0.24 Calories

$$E = \int F dx = \int (ma) dx = \frac{1}{2} m v^2 \longrightarrow \text{Kinetic Energy}$$

v = Velocity (m s^{-1})

What is Power?

James Watt

<u>Power (P)</u>: The rate of change energy per unit time, or time rate of doing work.

$$P = \frac{\Delta E}{\Delta t} \quad \text{or} \quad P = \frac{dE}{dt}$$

SI Units of power = Watt = kg m^2 s^{-3}

What we'll use to describe Earth's energy budget…

Kinetic Energy

Kinetic Energy: Energy due to the movement of an object with mass (*m*). Proportional to the __________ of the of the speed.

$$E = \frac{1}{2}mv^2$$

***v* = Velocity or speed (m s^{-1})**

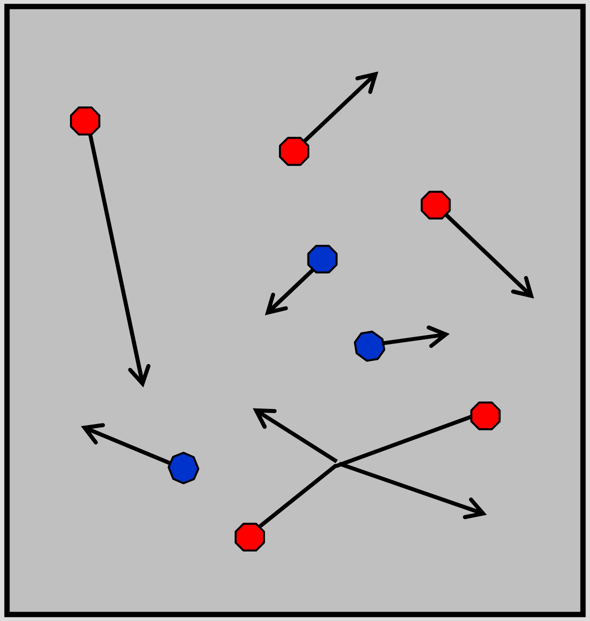
A doubling of the wind speed would increase the energy of the wind by a factor of_____.

What is Temperature?

Temperature: **A measure of the average kinetic energy of atoms and molecules for the given substance, or internal energy.**

"Hotter" temperature: Atoms and molecules move faster
→ more internal energy

"Colder" temperature: Atoms and molecules move slower
→ less internal energy

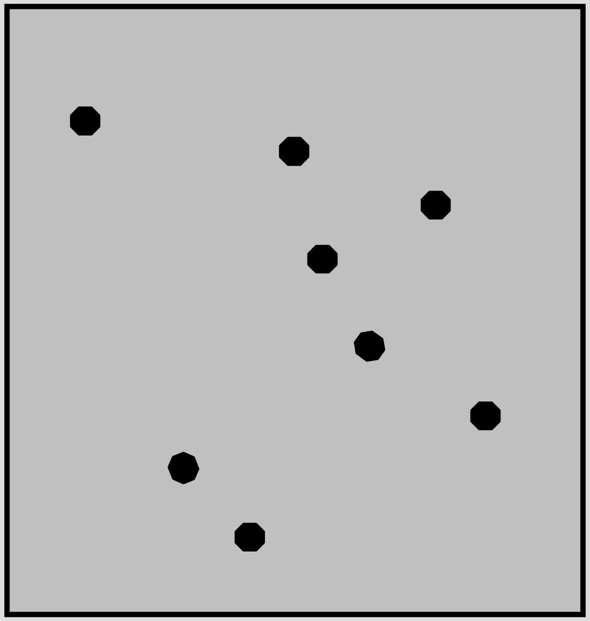


$$E = \frac{1}{2}mv^2$$

Absolute Zero: Temperature at which all molecular motion stops

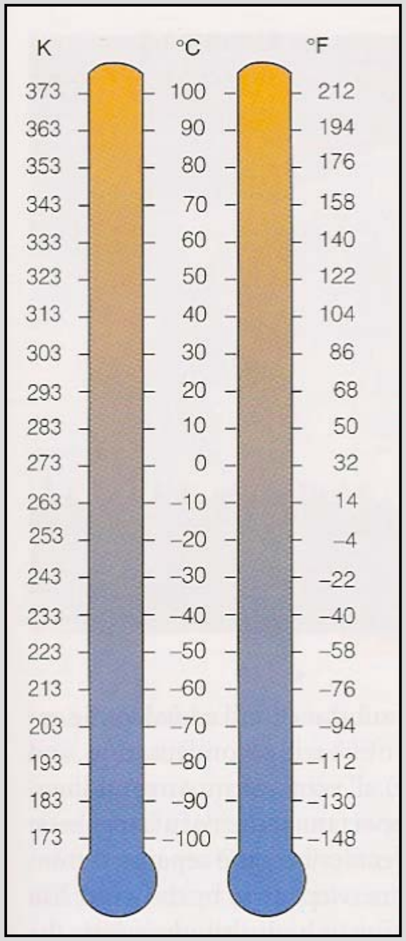
Absolute zero: **Temperature at which there is no internal energy.**

Defined as:



$$E = \frac{1}{2} m v^2$$

Temperature Scales



The ***Celsius*** scale (°C) is based on the reference points of the freezing and boiling points of water.

Freezing = ______

Boiling = _______

The ***Kelvin*** scale (K) is referenced to absolute zero.

The ***Fahrenheit*** scale: Referenced to the lowest temperature obtained with a ice, water, and salt mixture. Only commonly used now in the U.S.

Temperature Conversions

°C = 5/9(°F - 32)

K = °C + 273

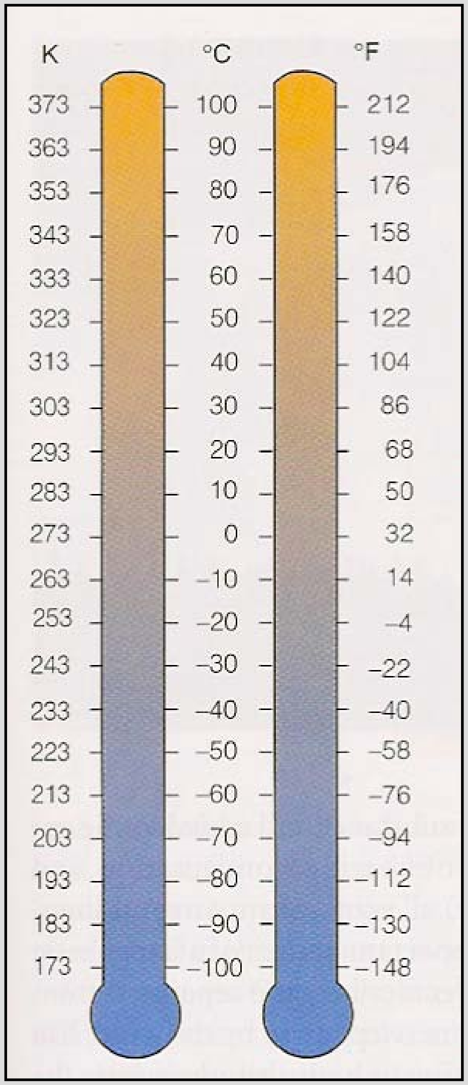
Using these equations, for example:

Freezing point of water = _______ = 273 K = 32° F

Boiling point of water = ________ = 373 K = 212° F

***You should familiarize yourself with these equations and know how to convert from the three scales*.**

Range of Terrestrial Surface Temperatures



Hottest recorded temperature: Sahara Desert, Libya: 136° F

Typical Summer highs in Tucson: 90-115 °F

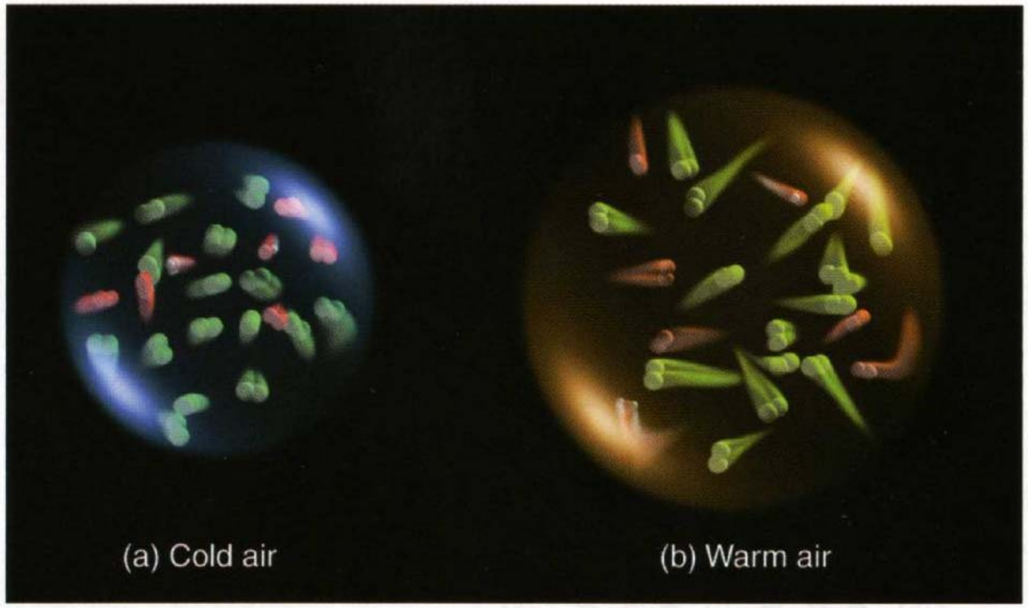
Spring break in Cancun: 85-90 °F

Indoor room temperature: 68 -74 °F

Typical winter highs in Seattle: Mid 40s

Lows during server artic outbreak in northern Plains or interior New England: -10 to -20 °F

Lowest recorded temperature: Vostok, Antarctica: -129 °F



• FIGURE 2.1
Air temperature is a measure of the average speed of the molecules. In the cold volume of air the molecules move more slowly and crowd closer together. In the warm volume, they move faster and farther apart.

(Ahrens p. 29)

Assuming pressure remains constant, an ***increase in air temperature means:***

1.

2..

What is Heat?

Heat: **Energy in the process of being of being transferred from one object to another due to a difference in temperature.**

Consider a boiling pot of water:

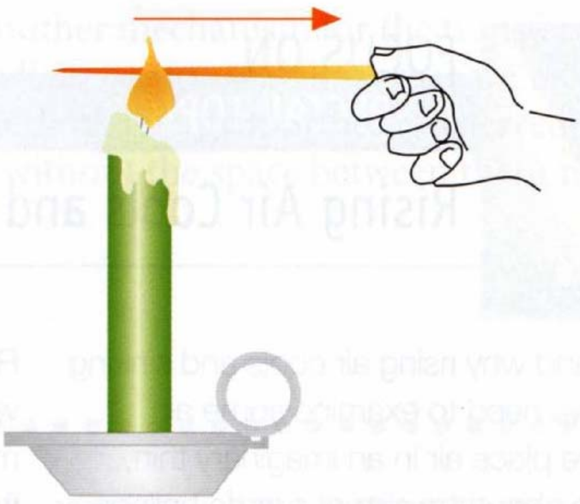
There are several different types of energy transfer processes going on here. ***What are they?***

Answer:

What are these modes of heat transfer and how do they work in the boiling pot example?

Heat Transfer Type 1: Conduction

***<u>Conduction</u>*: Transfer of heat from molecule to molecule within a substance**



• FIGURE 2.5

The transfer of heat from the hot end of the metal pin to the cool end by molecular contact is called *conduction*.

Concept of Heat Conductivity

***<u>Conductivity</u>*: How efficiently substances transfer heat between molecules.**

Conductivity depends on how molecules are structurally bonded together, which relates to the state of matter.

<u>Solids</u> → Molecules strongly bonded → High conductivity

<u>Liquids</u> → Molecules weakly bonded → Some conductivity

<u>Gases</u> → Molecules not bonded → Low conductivity

POOR CONDUCTORS

GOOD CONDUCTORS

•TABLE 2.2

Heat Conductivity* of Various Substances

SUBSTANCE	HEAT CONDUCTIVITY (Watts† per meter per °C)
Still air	0.023 (at 20°C)
Wood	0.08
Dry soil	0.25
Water	0.60 (at 20°C)
Snow	0.63
Wet soil	2.1
Ice	2.1
Sandstone	2.6
Granite	2.7
Iron	80
Silver	427

*Heat (thermal) conductivity describes a substance's ability to conduct heat as a consequence of molecular motion.

†A watt (W) is a unit of power where one watt equals one joule (J) per second (J/s). One joule equals 0.24 calories.

Heat Capacity
(*different* from conductivity)

<u>Heat capacity</u>: **ratio of the amount of heat energy of absorbed by that substance to its temperature rise.**

<u>Specific heat capacity</u>: **Amount of heat needed to raise the temperature of one gram of a substance by 1 °C.**

Low specific heat → Heat or cool quickly

High specific heat → Heat or cool slowly

• TABLE 2.1

Specific Heat of Various Substances

SUBSTANCE	SPECIFIC HEAT (Cal/g × °C)	J/kg × °C
Water (pure)	1.00	4186
Wet mud	0.60	2512
Ice (0°C)	0.50	2093
Sandy clay	0.33	1381
Dry air (sea level)	0.24	1005
Quartz sand	0.19	795
Granite	0.19	794

Water has a relatively high specific heat, so:

1.

2.

CONDUCTION

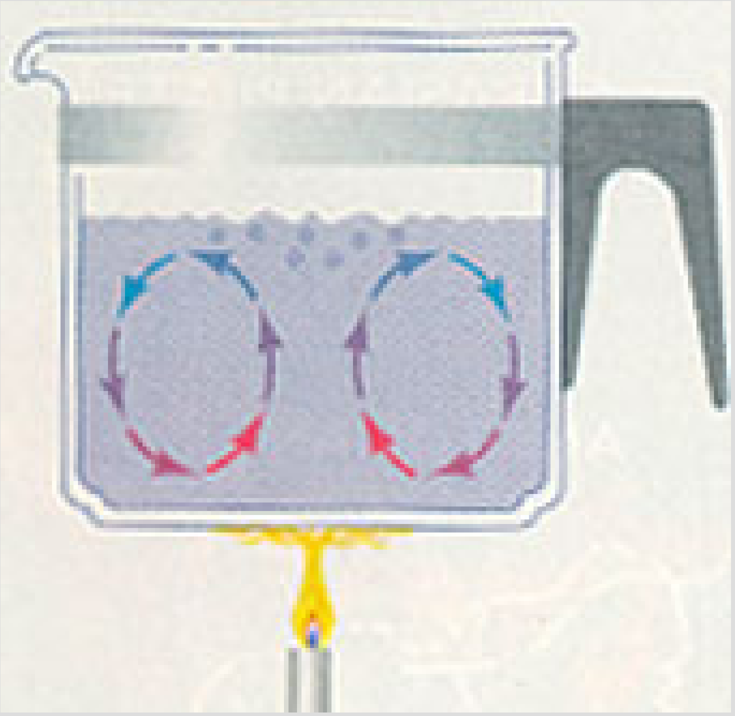
HEAT TRANSPORT BY MOLECULE TO MOLECULE

Conduction accounts for transfer of heat from stove to glass of the post

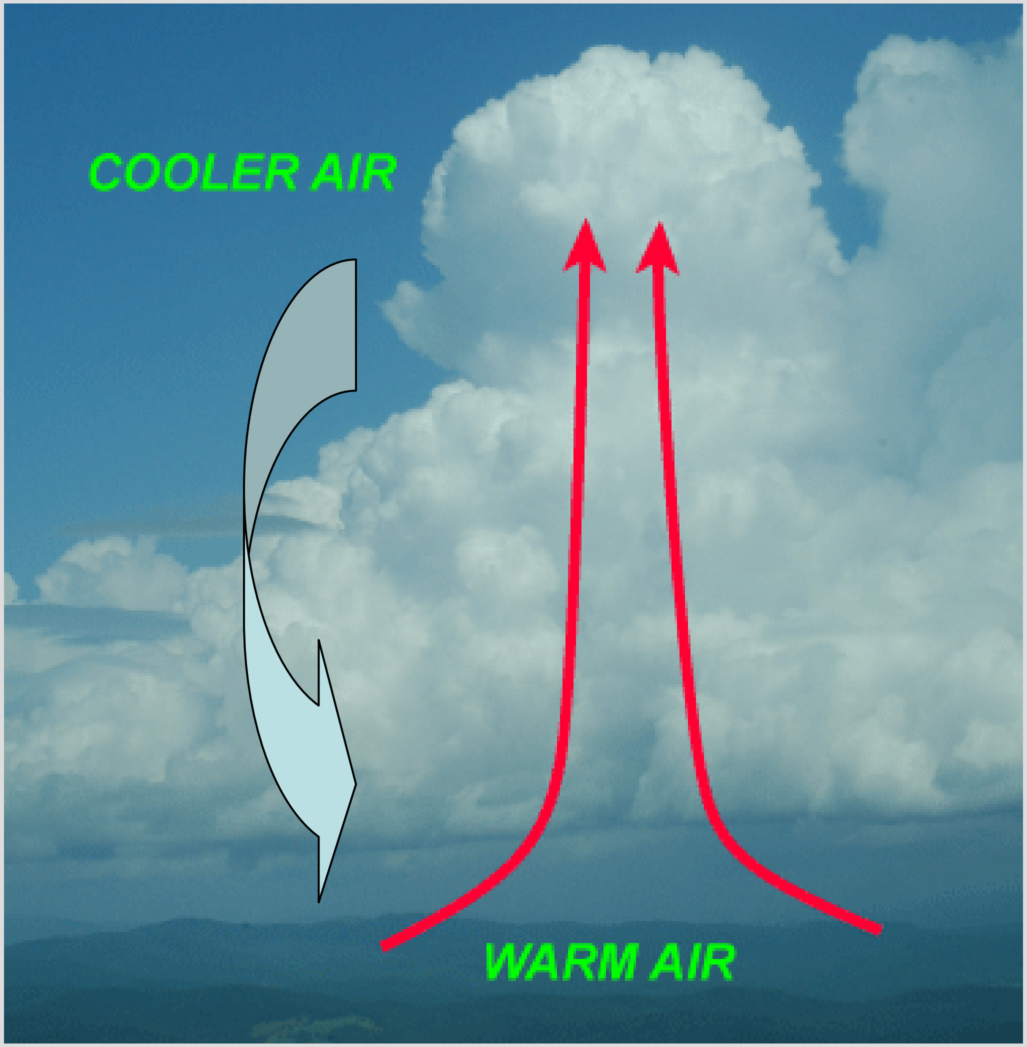
Within the liquid, something else is going on, though…

Heat Transfer Type 2: Convection

Convection: Transfer of heat by the mass movement of a fluid or gas, like water and air. Warm part of the fluid rises, cold part sinks.



Convection in the atmosphere



The SAME process happens in the atmosphere, *except air is the medium instead of liquid water*.

As the course proceeds, we'll see numerous examples on a wide range of scales…

CONVECTION

MASS MOVEMENT OF FLUID OR GAS

So far, we've established that:

***Conduction* is the mode of heat transfer within the walls of the pot.**

***Convection* is the mode of heat transfer within the water**

The rate at which the temperature of the water and the walls of the pot change is determined by the heat capacity of water and glass, respectively.

Remaining questions in the boiling pot example:

What causes the bubbles to form in the water?

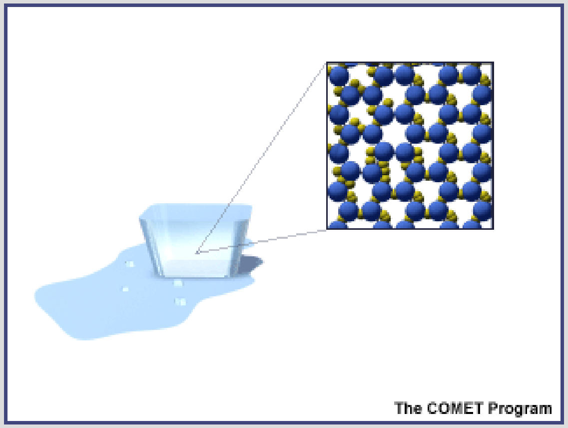
Why does it feel hot when your hand is near the pot, *but not touching it?*

Latent Heat: Energy of Phase Change

***Latent heat*: Energy required to change matter from one state to other**.

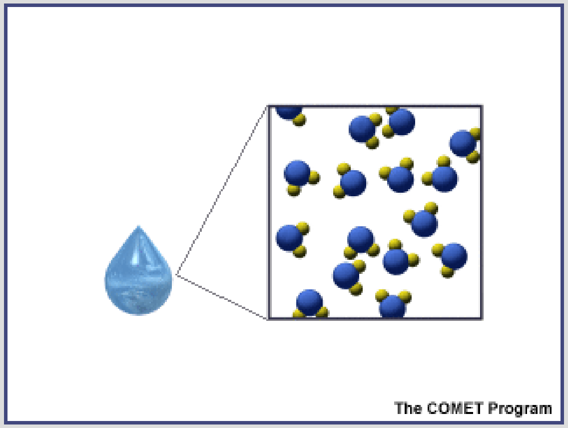
Our main concern in this course is water, since the range of terrestrial temperature permits it to exists in all three matter states on Earth.

Ice (Below 0 °C)



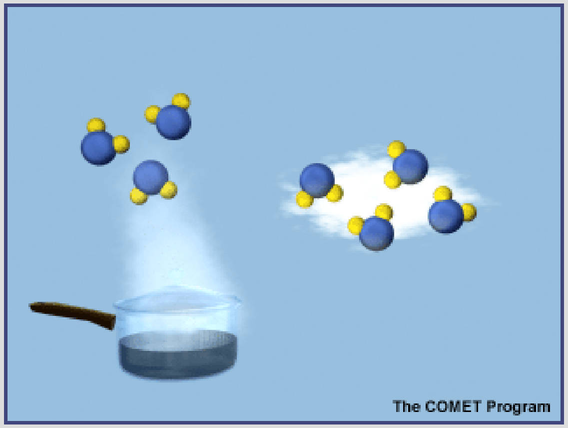
SOLID: molecules tightly bound in a lattice structure.

Liquid water (0 – 100 °C)

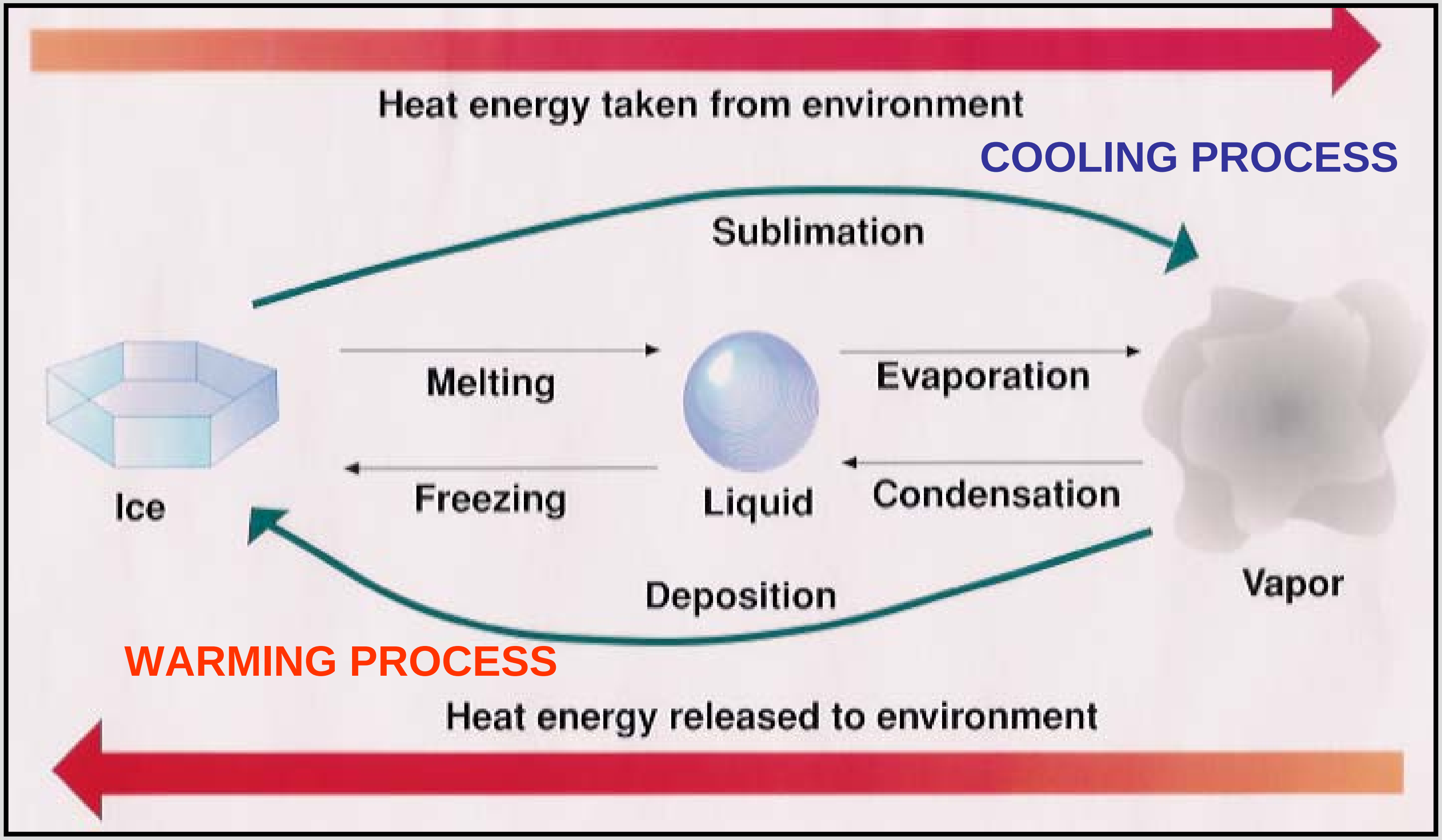


LIQUID: Molecules more loosely bound by attractive forces and no organized structure

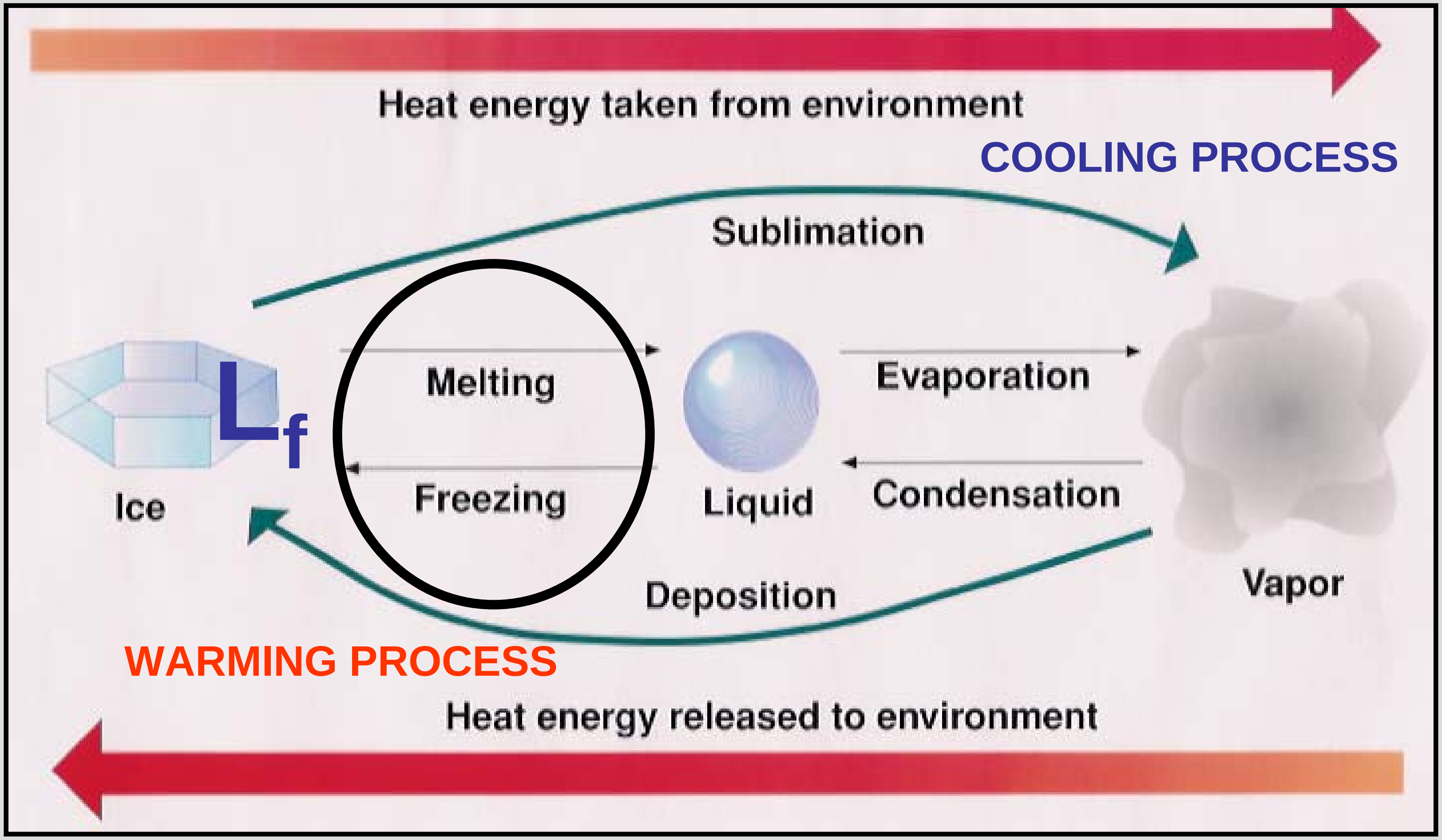
Water vapor: (Above 100 °C)



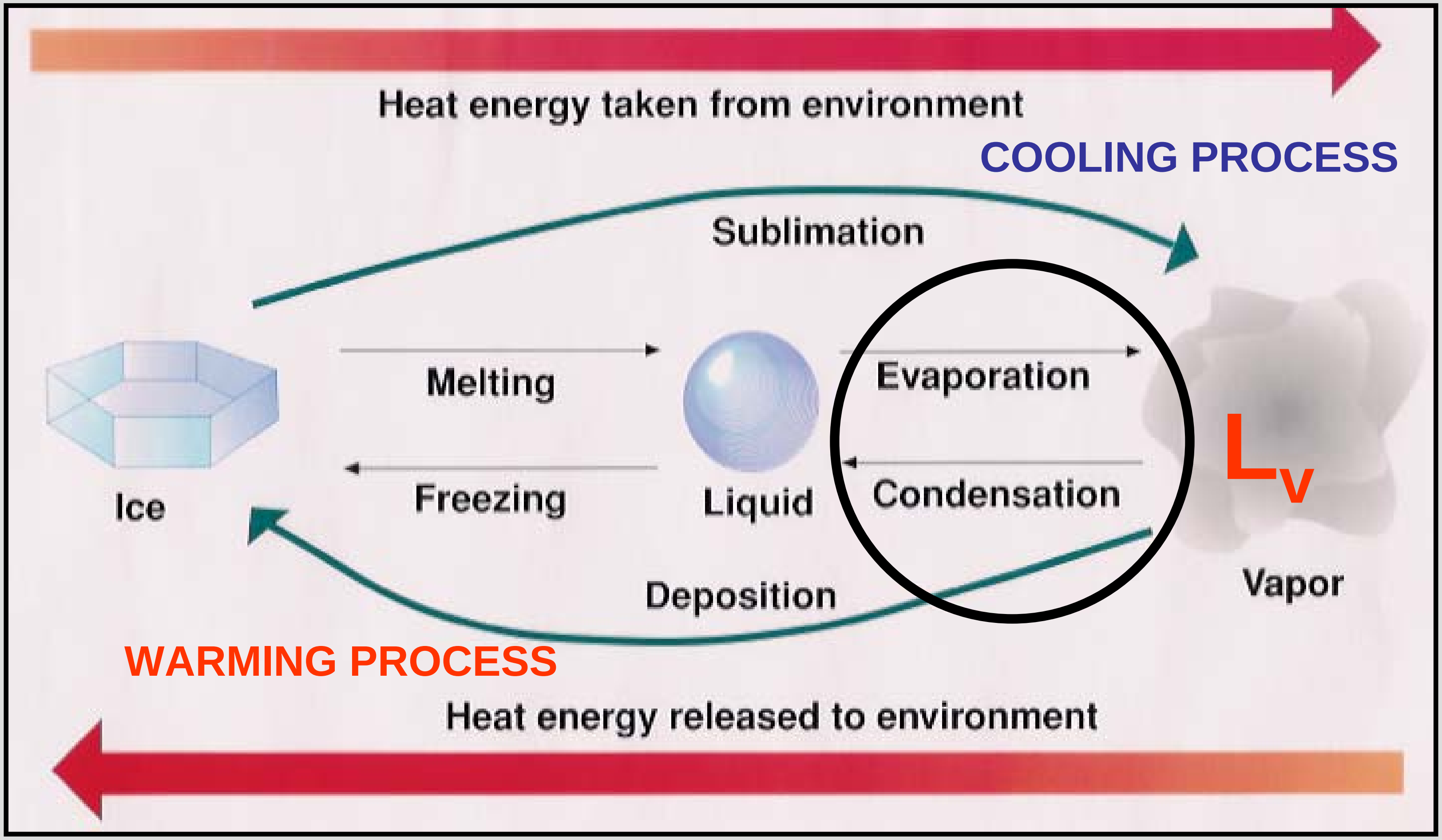
GAS: Molecules move rapidly and are not bound together



Heat energy taken from environment
COOLING PROCESS
Sublimation
Melting
Evaporation
Ice
Freezing
Liquid
Condensation
Vapor
Deposition
WARMING PROCESS
Heat energy released to environment

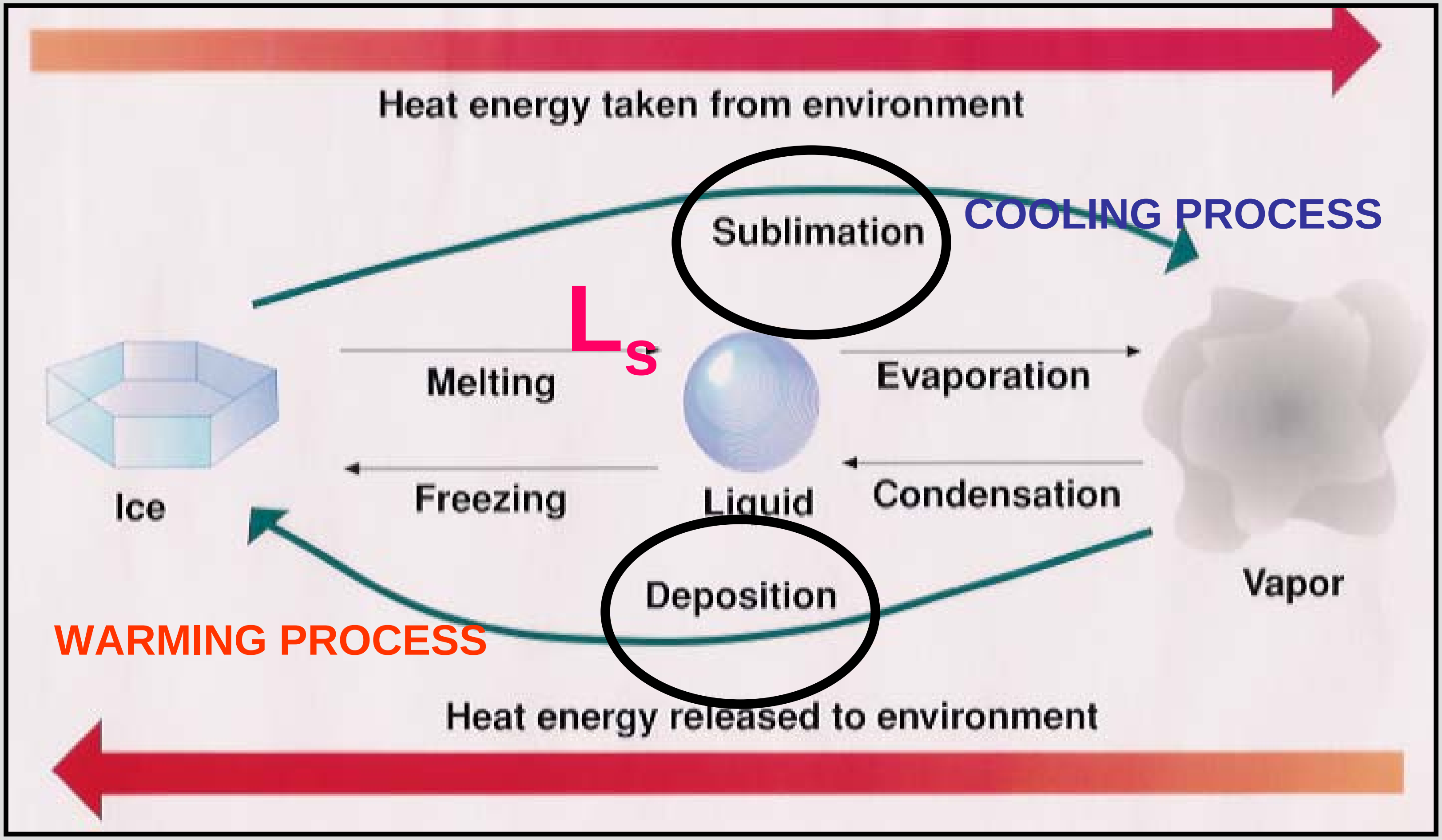


Latent heat of fusion (L_f) = 335 J g^{-1} → solid-liquid transition



Latent heat of fusion (L_f) = 335 J g^{-1} → solid-liquid transition

Latent heat of vaporization (L_v) = 2500 J g^{-1} → liquid-gas transition



Latent heat of fusion (L_f) = 335 J g^{-1} → solid-liquid transition

Latent heat of vaporization (L_v) = 2500 J g^{-1} → liquid-gas transition

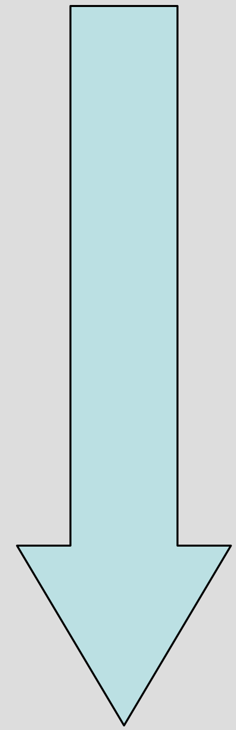
Latent heat of sublimation (L_s) = 2850 J g^{-1} → solid-gas transition

LESS ENERGY WITH PHASE TRANSITION

Latent heat of fusion (L_f) = 335 J g^{-1}
solid-liquid transition

Latent heat of vaporization (L_v) = 2500 J g^{-1}
liquid-gas transition

Latent heat of sublimation (L_s) = 2850 J g^{-1}
solid-gas transition



MORE ENERGY WITH PHASE TRANSITION

LATENT HEAT

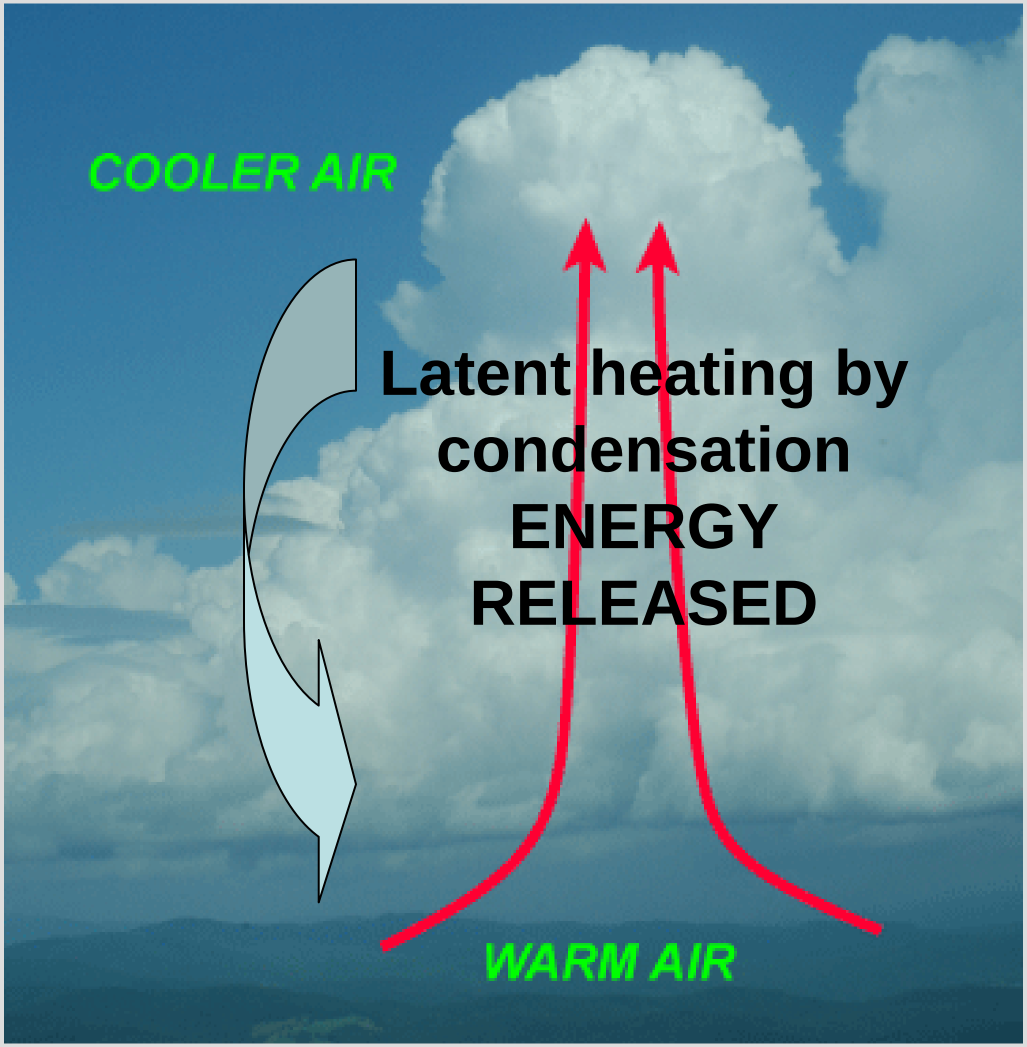
ENERGY OF PHASE CHANGE

Water reaches its vaporization, or boiling, point and escapes into the air surrounding the pot as a vapor.

This process __________ heat energy from the environment.

The *latent energy* stored within the water vapor can be realized if the water vapor ___________, and then heat is released.

Latent heating in the atmosphere



Latent heating takes place within the cloud as water vapor condenses (drops) or deposits (ice).

This process *releases* energy to the environment.

Why is this important for weather??

Condensation of water releases LOTS of energy!

How much energy is released when one kilogram of water is condensed?

Latent heat released = mass of water X latent heat of vaporization

$= 1000 \text{ g} \times 2500 \text{ J g}^{-1} = 1.0 \times 10^{3} \text{ g} \times 2.5 \times 10^{3} \text{ J g}^{-1}$

$= 2.5 \times 10^{6} \text{ J}$

How fast would a typical car (1500 kg) move with the equivalent amount of energy?

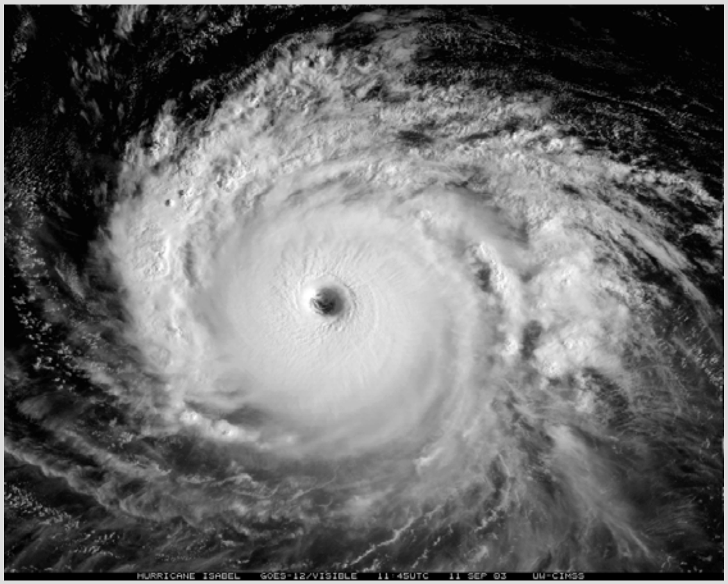
Latent heat released = Kinetic energy of car = (1/2) x mass of car x velocity^2

$2.5 \times 10^{6} \text{ J} = (1/2) \times (1500 \text{ kg}) \times v^2$

$2.5 \times 10^{6} \text{ kg m}^2 \text{ s}^{-2} = (1/2) \times (1500 \text{ kg}) \times v^2$

$V = 57 \text{ m s}^{-1}$ or about 127 mph!

ENERGY RELEASED BY WATER CONDENSING IN A HURRICANE



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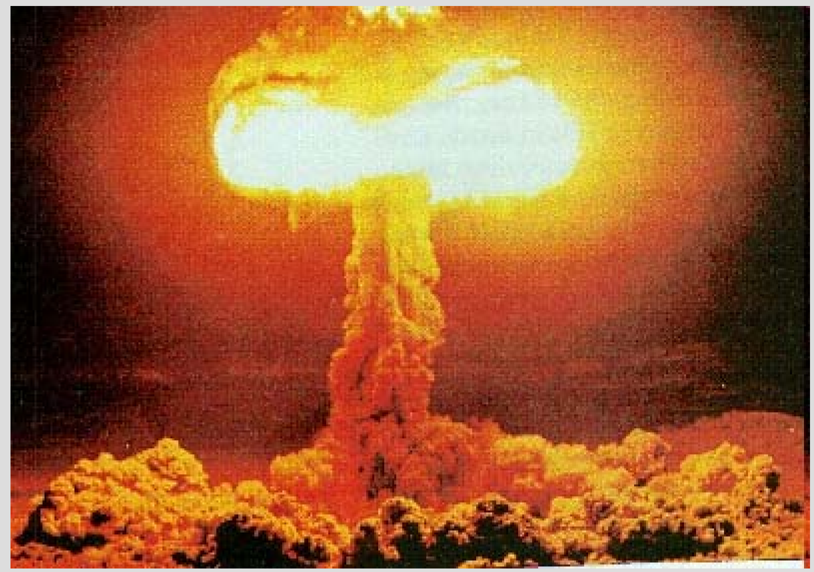
10 MEGATON NUCLEAR BOMB EXPLODING EVERY 20 MINUTES



Source: Chris Landsea, National Hurricane Center

We still haven’t answered why it feels hot when your hand gets near the pot.

This is due to *radiation*, the third mode of energy transfer.

We’ll discuss that next time…

Summary of Lecture 4

Defined a new quantity, *energy*: product of a force over a distance which it is applied.

***Temperature* is the measure of the average kinetic energy of a given substance, or internal energy. Defined °F, °C, and K scales and their conversions.**

Assuming pressure remains constant, an increase in temperature means the volume of air expands and its density decreases

***Heat* is energy in the process of being transferred.**

- ***Conduction*: heat transfer molecule by molecule**
- ***Convection*: mass movement of a fluid or gas**

***Latent heat* is energy associated with phase changes from one state of matter to another.**

Reading Assignment and Review Questions

Ahrens, Chapter 2, pp. 35-40 (8th ed.), 37-42 (9th ed.)