Final, 8pm, December 19, Room TBA Friday's problem solving day recorded New Stuff Since Test 2 (~50% of final) Chapter 13: Springs, Pendula, Waves Chapter 9 (more questions): Density, Pressure, Continuity and Bernoulli Equations, Stress/Strain Today: Chapter 10.0-10.3 only Wednesday: Chapter 11.0-2 & 11.4-6

<u>Old Stuff</u> (only Chapters 2-5, the foundations) Chapter 2: Basic problem solving with kinematics Chapter 3: Vectors and projectile motion Chapter 4: Newton's Laws, Forces, Inclines, Friction Chapter 5: Work, Conservation of Energy

## Main Ideas in Class Today

We will discuss:

- Thermal equilibrium and heat flow
- Different temperature scales
- The cause of thermal expansion

After today's class, you should be able to:

- Convert between temperatures
- Calculate the amount of thermal expansion

If you want more practice: C10.3, C10.11, 10.1, 10.3, 10.5, 10.7, 10.11, 10.13, 10.17, 10.19 (harder), 10.21

A video on today's material: temperature and thermal expansion

#### Thermal Equilibrium

#### Two objects of different temperature when placed in contact will eventually reach the same temperature



### In Thermal Equilibrium?

- This is why when you crowd a bunch of people into a room, it gets hotter.
- But not up to 98.6°F. Why don't we come into equilibrium with the air in the room?



- Air conditioning, thankfully
- Our body, the furnace
- What else is the room in contact with?

Body A has a higher temperature than body B (not necessarily the same size, maybe drastically different). Which of the following statements must be true?

- A. Body A will feel hotter than B.
- B. Body A contains more energy than B.
- C. If placed in contact with each other, energy will flow from body A to body B.
- D. More than one statement is true.

Body A has a higher temperature than body B. Which of the following is true?

- Body A will feel hotter. (How "hot" an object feels depends on the object's temperature <u>AND</u> how quickly heat can flow through the object to your hand or vice versa. A metal ice tray feels colder than a package of frozen vegetables even if it's the same temperature)
- 2. Body A contains more energy. (Thermal energy depends on the material and volume. For example, 1 cm<sup>3</sup> of lead holds much more thermal energy than 1 cm<sup>3</sup> of plastic at the same temperature, and 1 m<sup>3</sup> of lead holds much more heat than 1 cm<sup>3</sup> of lead.)
- If placed in contact with each other, energy will flow from body A to body B. (Heat always flows from a higher-temperature object to a lower-temperature one. This is the zeroth law of thermodynamics.)

#### Heat flows from hot to cold but it might feel otherwise



Recap: thermal equilibrium is the state where no heat flows between two systems in contact because they have the same temperature. Temperature indicates.

How do we measure temperature in a standard way?





Other standards we've used



- Temperature is measured using scales, and different scales are designed to suit various purposes and historical contexts.
- Temperature scales (like Celsius, Fahrenheit, and Kelvin) are all anchored in observable physical phenomena, such as the freezing and boiling points of water or absolute zero.



#### Temperature and scales

# Temperature scales (melting point MP & boiling point BP of water)

–Degrees Celsius (MP 0°C, BP 100°C)
–Degree Fahrenheit (MP 32° F, BP 212°F)
–Degrees Kelvin (MP 273.15 K, BP 373.15 K)

18th-century physicist Daniel Fahrenheit originally took as the zero of his scale the temperature of an equal ice-salt mixture and selected the values of 30° and 90° for the freezing point of water and normal body temperature; these later were revised slightly.



#### WARNING:

Unlike the other standards we have used, these temperature standards can not be converted between each other with our fraction approach.

90 m<sup>2</sup> X 
$$\frac{3.28 \text{ ft}}{1 \text{ m}}$$
 X  $\frac{3.28 \text{ ft}}{1 \text{ m}}$  = 968 ft<sup>2</sup>

It's because zero isn't the same on all scales.

#### Converting between scales

$$T_{\rm C} = \frac{5}{9}(T_{\rm F} - 32^{\circ})$$
$$T_{\rm F} = \frac{9}{5}T_{\rm C} + 32^{\circ}$$
$$T_{\rm K} = T_{\rm C} + 273.15$$

Not a simple factor conversion

Let's do an example!



#### The first thermometer

# Any guesses why this works?



The bulb floating in the gap tells the temperature. If no bulb in the gap then the average of the values of the bulb above and below gives the temperature.

# Galileo realized density changed with temperature

- A **Galilean thermometer** (after Galileo Galilei), is a thermometer containing a series of objects of different densities.
- But why would it float sometimes and not others?



## The bulb floating in the gap tells the temperature.

### **Changes between states of matter**

- We discussed that density (p) changes with temperature.
- A significant change is often observed at a phase transition
- There is an important exception!



#### Water: A Rare and Important Exception

- Density of ice is less than water!!!
   Why Icebergs float
- Density of water maximum at 4°C
  - Nearly frozen water floats to the top of the lake and hence freezes

If ice were more dense than water (meaning it would not float), life on Earth may not have been possible!

Ice would sink to the bottom and then more ice would form and sink.

Over time, this would have turned the Earth to ice similar to Hoth in Star Wars.



#### **Changes with temperature**

Properties of materials change with temperature

–Length –Volume

-Resistance



–Ability to store heat (next time)

Joints such as this one are used in bridges to accommodate thermal expansion.

#### Hotter things become longer

- Most solids get bigger when they get hot
  - A 1 meter long bar heated
     by 1 degree gets bigger by
    - Steel ≈0.01 mm
    - Glass ≈ 0.001 mm
    - Zerodur ≈ 0.0001mm



Rails expand and may buckle on a hot summer day

e.g. fire alarms and thermometers



## Thermal expansion, why?

- Every microscopic object moves due to thermal energy
- Atoms vibrate with respect to each other as if attached by springs
- Hotter atoms vibrate more (more energy)







#### Three ways things expand



 $\gamma = 2 \alpha$  and  $\beta = 3 \alpha$ 

Fahrenheit to Celsius  $T_F = T_C \times (9/5) + 32$   $T_C = (T_F - 32) \times (5/9)$ Kelvin to Celsius  $T_K = T_C + 273.15$  $T_C = T_K - 273.15$ 

 $\Delta L = \alpha L_0 \Delta T$   $\Delta A = \gamma A_0 \Delta T$   $\Delta V = \beta V_0 \Delta T$ 

The New River Gorge is a 518-m-long steel arch. How much will its length change between temperatures 15°F and 95°F? (The coefficient of linear expansion for steel is 1.1\*10<sup>-5</sup> °C<sup>-1</sup>.



## **Global Warming: Ocean Expansion**



Let's consider a modest temperature change of 1°C.

Use the fact that the average depth of the ocean is 4000 m to estimate the change in depth due to this global warming.

Note that  $\alpha_{water}$  = 6.9 x 10<sup>-5</sup> (°C)<sup>-1</sup>.

Neglects melting of ice caps with may be more significant



#### Hurricanes



#### May not seem like much, but consider the effect of flooding.





## Regardless of the cause of Global Warming

- Warmer air can make and hold more water vapor, which means more frequent and longer droughts, as well as more severe floods.
- Leads to less reliable food supply and higher food prices
- Hotter temperatures means increased intensity of storms (hurricanes, tornadoes, snow)



 Also hurts our ability to produce energy. Coal, hydroelectric and nuclear power plants all require water (e.g. cooling).

#### **Overview of Geological Storage Options**

- 1 Depleted oil and gas reservoirs
- 2 Use of CO2 in enhanced oil and gas recovery
- 3 Deep saline formations --- (a) offshore (b) onshore
- 4 Use of CO, in enhanced coal bed methane recovery
- 5 Deep unmineable coal seams

1km

2km

3a

6 Other suggested options (basalts, oil shales, cavities)





Produced oil or gas Injected CO<sub>2</sub> Stored CO<sub>3</sub>

#### Carbon sequestration (thought to be our best idea)

#### How do we stop it?

#### **Measurement Error due to Temperature**

Metersticks are calibrated at 20°C.

What is the error in a measurement of 500mm if made at 45°C?

 $\alpha_{steel}$ = 1.2x10<sup>-5</sup> K<sup>-1</sup>

$$\Delta L = L_o \alpha \Delta T$$

 $\Delta L = 0.5 \text{ m x } 1.2 \text{ x } 10^{-5} \text{ x } 25$ 

 $\Delta L$  = 0.00015m = 0.15 mm

#### Venus is a runaway greenhouse



Venus' atmosphere is 96.5% CO<sub>2</sub> Any water originally on Venus is now gone. (boiled into space) Water is key in controlling the greenhouse effect on Earth:

(1) the oceans absorb a lot of  $CO_2$ (2) water and  $CO_2$  react with silicate rock to lock the  $CO_2$  up in carbonaceous rock; and (3) water nourishes plants, which remove  $CO_2$  from the atmosphere.



#### We could do the same thing on Mars to make it ideal for life!



## No atmosphere on Mars now, but we could build one by polluting it some.





### **Common misconception**

# Holes in objects undergoing thermal expansion get bigger!

Like if the hole weren't there.



A solid object has a hole in it. Which of these illustrations more correctly shows how the size of the object and the hole change as the temperature increases?



- A. illustration #1 (hole radius increases)
- B. illustration #2 (hole radius decreases)
- C. Hole radius stays the same
- C. The answer depends on the material of which the object is made.
- D. The answer depends on how much the temperature increases.



The illustration shows a thermometer that uses a column of liquid (usually mercury or ethanol) to measure air temperature. In thermal equilibrium, this thermometer measures the temperature of

- A. the column of liquid.
- B. the glass that encloses the liquid.
- C. the air outside the thermometer.
- D. both A. and B.
- E. all of A., B., and C.





## **Converting Temperature**

The **temperature difference** between the inside and outside of a home on a cold winter day is 57.0°F. Express this difference on the Celsius scale. What if I asked the question for the Kelvin scale?

- A. 13.9°C
- B. 31.7°C
- C. 45.0°C
- D. 57°C
- E. 134.6°C

Fahrenheit to Celsius  $T_F = T_C \times (9/5) + 32$   $T_C = (T_F - 32) \times (5/9)$ Kelvin to Celsius  $T_K = T_C + 273.15$  $T_C = T_K - 273.15$ 

If you would like, you can pick outside and inside temperatures to compare.

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