Conceptual Physics
Gases, & Plasmas
Heat & Temperature

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Last time

- liquids
- fluid pressure
- buoyancy
- Archimedes' Principle
- Pascal's principle
- gases
- Boyle's law

Overview

- Bernoulli's principle
- plasma
- heat
- temperature

Buoyancy and Archimedes' Principle

Archimedes' Principle

The buoyant force on an object is equal to the weight of the fluid that the object displaces.

$$F_{\text{buoy}} = W_{\text{df}}$$

Logically, if a brick falls to the bottom of a pool it must push an amount water equal to its volume up and out of the way.

Buoyancy in Air

Buoyancy in air works the same way as in liquids:

$$F_{\text{buoy}} = \rho_{\text{f}} V_{\text{obj}}\, g$$

If an object is less dense than air, it will float upwards.

However, in the atmosphere, the density of air varies with height.

Buoyancy in Air

[1]Photo by Derek Jensen, Wikipedia.

Buoyancy in Air

By roughly how much is your weight reduced by the effects of the air you are submerged in?

Suppose you have a mass of 100 kg and volume of 0.1 m^3.

$\rho_{air} = 1.20\ kg/m^3$ (at room temperature and atmospheric pressure)

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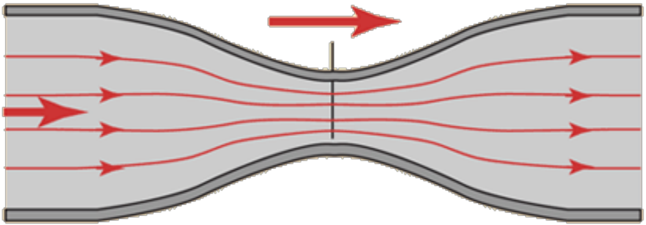
About 1.18 N.

Bernoulli's Principle

What happens to the pressure in a pipe as the pipe contracts?



[1]Figure from hyperphysics.phy-astr.gsu.edu.

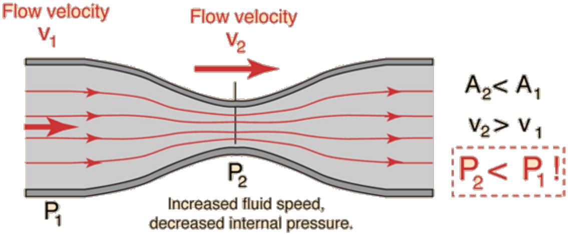
Bernoulli's Principle

A law discovered by the 18th-century Swiss scientist, Daniel Bernoulli.

Bernoulli's Principle

As the speed of a fluid's flow increases, the pressure in the fluid decreases.

This leads to a surprising effect: for liquids flowing in pipes, the pressure *drops* as the pipes get narrower.



Bernoulli's Principle

Why should this principle hold? Where does it come from?

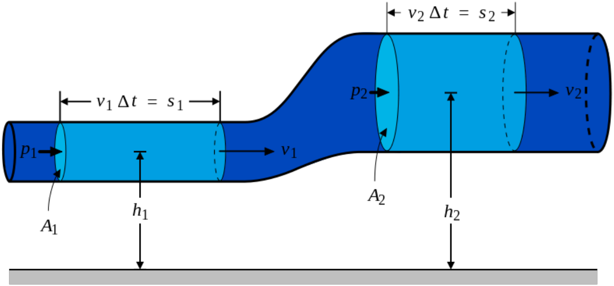
Actually, it just comes from the **conservation of energy**, and an assumption that the fluid is incompressible.[1]

[1] Something similar can be argued for compressible fluids also.

Bernoulli's Principle

Imagine fluid flows in a pipe.

The two volumes shown are the same.



The fluid must flow faster in the narrower part of the pipe.

Bernoulli's Principle

$V = A_1 v_1 \Delta t$

also, $V = A_2 v_2 \Delta t$

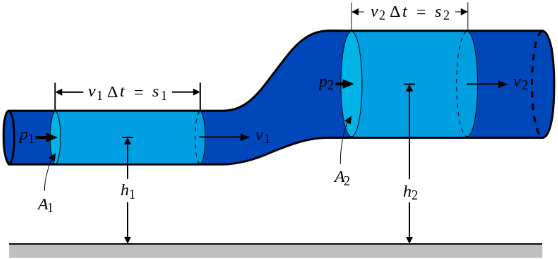
This means

$$A_1 v_1 = A_2 v_2$$

The "Continuity equation".

Bernoulli's Equation

Bernoulli's equation is just the conservation of energy for this fluid. Let the volume of fluid, V, have mass m.



Remember:

- kinetic energy:
- gravitational potential energy:
- work:

Bernoulli's Equation

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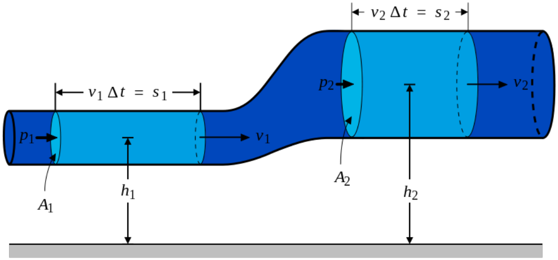
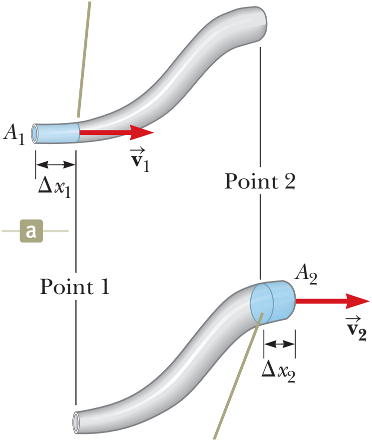


Remember:

- kinetic energy: $\frac{1}{2}mv^2$
- gravitational potential energy: mgh
- work: $W = Fd$

Bernoulli's Equation

As the fluid flows the energy of the fluid might change: the fluid is moved along, and some is lifted up.



How does it change? Depends on the work done:

$$W = \Delta K + \Delta U$$

Bernoulli's Equation

Energy conservation:

$$\begin{aligned} W &= \Delta K + \Delta U \\ (P_1 - P_2)V &= \frac{1}{2}m(v_2^2 - v_1^2) + mg(h_2 - h_1) \end{aligned}$$

Energy per unit volume:

$$P_1 - P_2 = \frac{1}{2}\rho(v_2^2 - v_1^2) + \rho g(h_2 - h_1)$$

Bernoulli's Equation

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

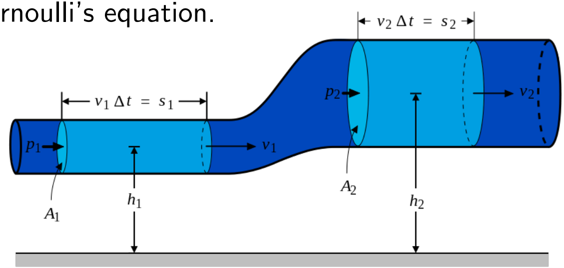
This expression is true for *any* two points along a streamline.

Therefore,

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{const}$$

is constant along a streamline in the fluid.

This is Bernoulli's equation.



Bernoulli's Principle from Bernoulli's Equation

For two different points in the fluid, we have:

$$\frac{1}{2}\rho v_1^2 + \rho g h_1 + P_1 = \frac{1}{2}\rho v_2^2 + \rho g h_2 + P_2$$

Suppose the height of the fluid does not change, so $h_1 = h_2$:

$$\frac{1}{2}\rho v_1^2 + P_1 = \frac{1}{2}\rho v_2^2 + P_2$$

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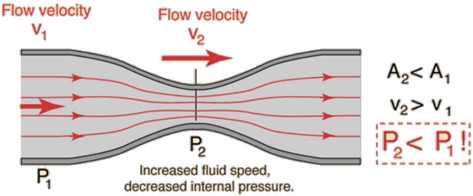
$$\frac{1}{2}\rho v_1^2 + P_1 = \frac{1}{2}\rho v_2^2 + P_2$$

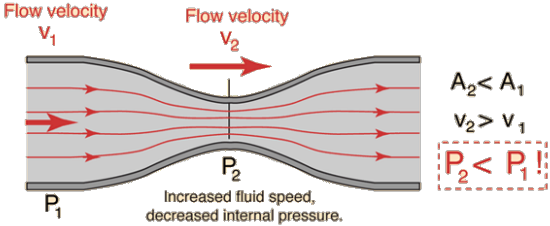
If $v_2 > v_1$ then $P_2 < P_1$.



Faster flow speed means lower pressure.

Bernoulli's Principle

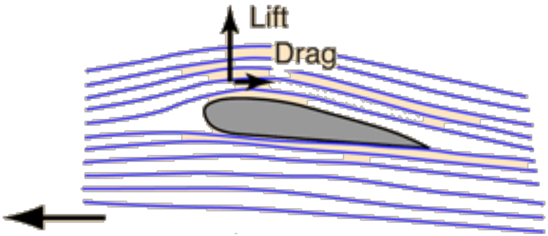
However, from the continuity equation $A_1 v_1 = A_2 v_2$ we can see that if A_2 is smaller than A_1, v_2 is bigger than v_1.



So the pressure really does fall as the pipe contracts!

Implications of Bernoulli's Principle

Bernoulli's principle can help explain why airplanes making use of airfoil-shaped wings can fly.

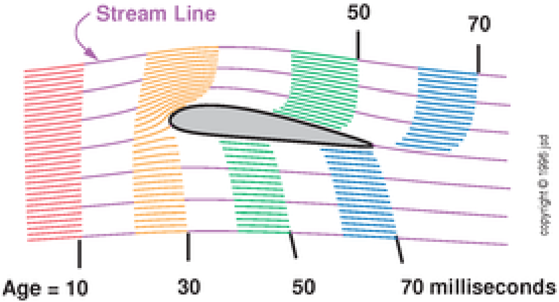


Air must travel further over the top of the wing, reducing pressure there.

That means the air beneath the wing pushes upward on the wing more strongly than the air on the top of the wing pushes down. This is called **lift**.

Air Flow over a Wing

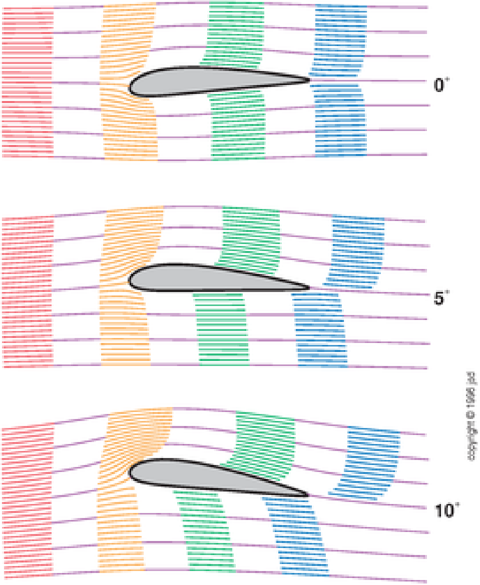
In fact, the air flows over the wing much faster than under it: not just because it travels a longer distance than over the top.



This is the result of circulation of air around the wing.

[1]Diagram by John S. Denker, av8n.com.

Airflow at different Angles of Attack

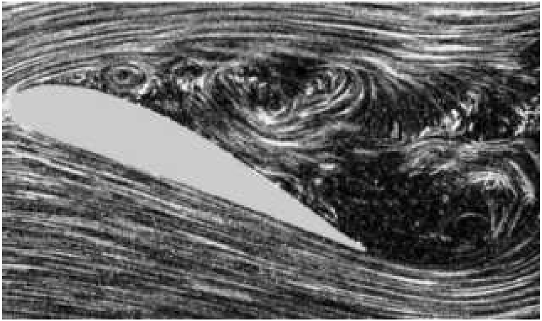


[1] Diagram by John S. Denker, av8n.com.

Implications of Bernoulli's Principle

A **stall** occurs when turbulence behind the wing leads to a sudden loss of lift.

The streamlines over the wing detach from the wing surface.



This happens when the plane climbs too rapidly and can be dangerous.

[1] Photo by user Jaganath, Wikipedia.

Implications of Bernoulli's Principle

Spoilers on cars reduce lift and promote laminar flow.

[1]Photo from http://oppositelock.kinja.com.

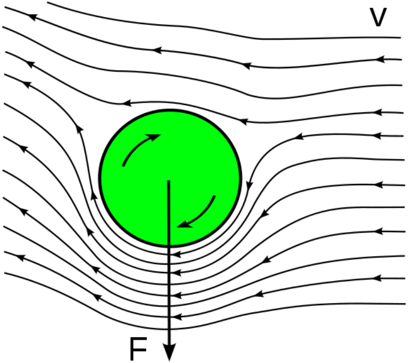
Implications of Bernoulli's Principle

Wings on racing cars are inverted airfoils that produce *downforce* at the expense of increased drag.

This downforce increases the maximum possible static friction force $\Rightarrow$ turns can be taken faster.

[1]Photo from http://oppositelock.kinja.com.

Implications of Bernoulli's Principle



A curveball pitch in baseball also makes use of Bernoulli's principle.

The ball rotates as it moves through the air.

Its rotation pulls the air around the ball, so the air moving over one side of the ball moves faster.

This causes the ball to deviate from a parabolic trajectory.

[1] Diagram by user Gang65, Wikipedia.

Implications of Bernoulli's Principle

Bernoulli's principle also explains why in a tornado, hurricane, or other extreme weather with high speed winds, windows blow *outward* on closed buildings.

Implications of Bernoulli's Principle

Bernoulli's principle also explains why in a tornado, hurricane, or other extreme weather with high speed winds, windows blow *outward* on closed buildings.

The high windspeed outside the building corresponds to low pressure.

The pressure inside remains higher, and the pressure difference can break the windows.

It can also blow off the roof!

It makes sense to allow air a bit of air to flow in or out of a building in extreme weather, so that the pressure equalizes.

Plasmas

plasma

A state of matter which is like a gas in that it is a fluid that can change shape and has variable density, but is composed of charged particles.

A gas that is superheated will form a plasma.

Some electrons are stripped away from atoms in the gas forming a cloud of ions and free electrons.

(Any molecular bonds are also broken.)

It has some different properties compared with a gas:

- it conducts electricity
- it tends to absorb light (and other kinds of radiation)
- it also gives off radiation

Plasmas

Places you see plasmas:

- neon signs
- fluorescent lights
- sodium vapor lamps
- plasma TVs
- arc welding
- lightning
- the Sun

[1]Photo by Wikipedia user Dennisveninga.

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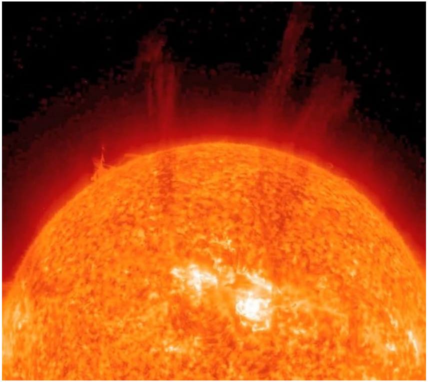


Plasmas are needed for fusion reactions, so all stars are composed of plasma.

[1] Photo credit NASA.

Heat

Temperature, Heat, Heat capacity, and Thermal expansion.

Heat

Heat is a kind of **energy transfer** into our out of a system.

Heat, Q

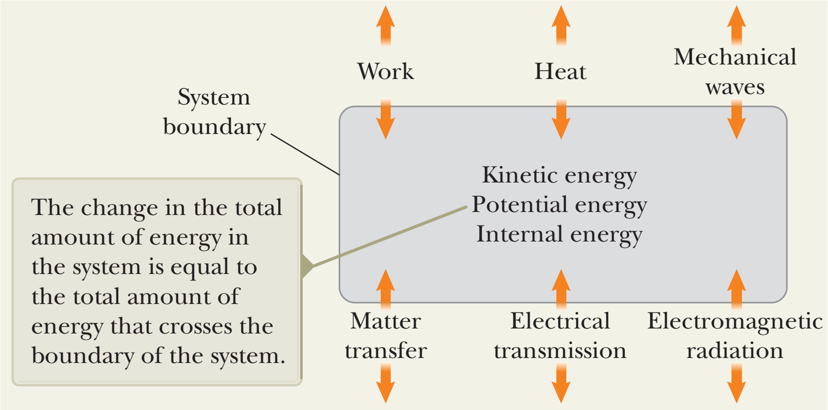
An amount of internal energy that is *transferred* from one object to another.

In the same way we say that something *does work* on an object, we say that *heat flows* from one object to another.

Technically, an object does not “contain heat”, heat is just energy being transferred.

The symbol for heat is Q, and units are Joules, J.

Heat



[1]Figure from Serway & Jewett, 9th ed., page 214.

Thermodynamic Equilibrium

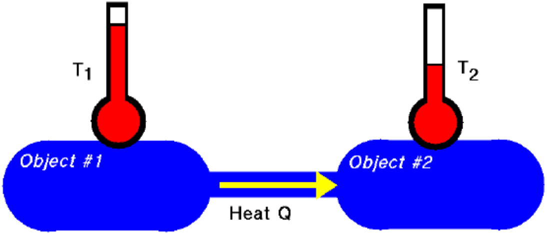
Thermodynamic Equilibrium

Two systems are in thermodynamic equilibrium when they would not exchange energy by heat or EM radiation, even when placed in thermal contact.

Temperature

We can go beyond simply saying that two systems are in equilibrium.

We can also compare two systems that are *not* in equilibrium by analyzing which way heat is transferred when they are brought into contact.



We create a scale for thermodynamic systems to compare them: **temperature**, T.

In the picture (assuming Q is positive): $T1 > T2$

[1]Figure: Tom Benson, Glen Research Center, NASA, www.grc.nasa.gov.

Temperature

Some things in our environment are hotter than others.

temperature

A quantitative measure of how hot or cold an object is.

Temperature sets a scale against which we can compare an object's hotness or coldness.

There are a few different scales in common use:

- Fahrenheit, F
- Celsius, C
- Kelvin, K

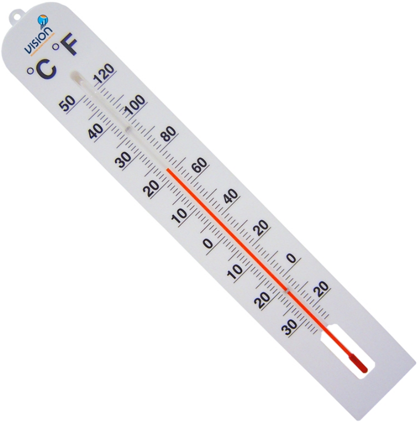
Measuring Temperature

Devices for measuring temperatures are called **thermometers**.

All such devices work by employing a substance that changes its properties as it changes temperature.

Measuring Temperature

The most familiar tool for measuring temperature is the mercury thermometer.



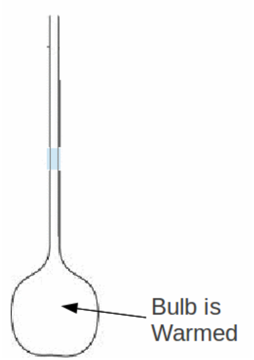
As the bulb warms, the mercury expands into a thin capillary tube.

Temperature and Absolute Zero

Ancient Greek and Egyptian scientists understood that gases expand when heated.

Galileo Galilei used this idea to make a thermoscope – a temperature sensing device without a scale.

Air is the expanding gas, drawing water up or down in a tube.



Temperature and Absolute Zero

Air thermometer in use:

[1]Photos from Washington State LASER org website.

Temperature and Absolute Zero

Robert Boyle (1655) speculated there might be a minimum possible temperature.

Guillaume Amontons (1702) made improvements to the air thermometer.

He noticed that his thermometer would not be able to register temperatures below the value where the air was compressed to (effectively) zero volume.

He proposed this as a zero-point of temperature scales.

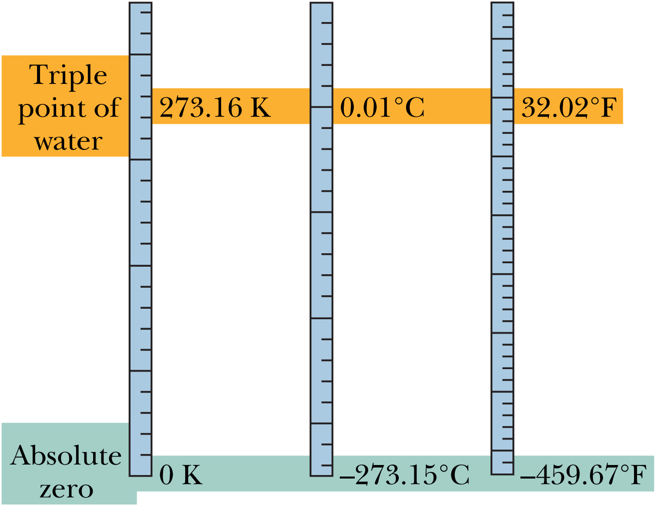
Temperature: Degrees

In all of those temperature scales the unit of temperature is the degree.

Celsius and Kelvin degrees are the same size. (A temperature rise of 1 degree C, is the same as a temperature rise of 1 degree K.)

However, Fahrenheit degrees are smaller. There are 1.8 degrees-F-scale in 1 degree-C-scale.

Temperature: Degrees



[1] Figure from Halliday, Resnick, and Walker, 9th ed.

Fahrenheit

On the Fahrenheit scale, originally,

- 0 degrees corresponds to the coldest salt water can be before freezing
- 100 degrees is human body temperature

This is a very arbitrary choice reference points. Worse yet, different people have different body temperatures and there are many kinds of salt water.

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Now, the Fahrenheit scale is defined so that:

- 32 degrees corresponds to the freezing point of water
- 212 degrees is the boiling point of water at atmospheric pressure

These reference points are easier to reproducibly measure, but now they correspond to degree numbers that are arbirary.

Example: room temperature in Fahrenheit is about 70°F

Celsius

On the Celsius scale,

- 0 degrees corresponds to the freezing point of water
- 100 degrees is boiling point of water

Since there are 100 degrees between water's freezing and boiling points, this is called a *centigrade* scale.

Example: room temperature in Celsius is about 21°C

Kelvin

The SI unit for temperature is the Kelvin K.

The associated Kelvin scale is appealing for scientists because 0 on the Kelvin scale (written 0 K) is the coldest possible temperature.

On the Kelvin scale:

- water freezes at 273 K
- water boils at 373 K.

Room temperature is about 294 K.

Problem

Confirm that there are 1.8 (or 9/5) degrees Fahrenheit for every degree Celsius.

You can use the fact that the freezing point of water is 0°C and 32°F and the boiling point of water is 100°C and 212°F.

Conversions

Celsius to Kelvin:
$[^\circ C] + 273 = [K]$

Kelvin to Celsius:
$[K] - 273 = [^\circ C]$

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$[^\circ C] + 273 = [K]$

Kelvin to Celsius:
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Fahrenheit to Celsius:
$([^\circ F] - 32) \div 1.8 = [^\circ C]$

Celsius to Fahrenheit:
$([^\circ C] \times 1.8) + 32 = [^\circ F]$

Thermal Energy

In the late 1700s, the theory was that heat was a kind of fluid that would pass from one object to another.

Burning an object would release this trapped fluid, which would explain why fire is hot.

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Burning an object would release this trapped fluid, which would explain why fire is hot.

Benjamin Thompson (Count Rumford, or simply "Rumford") was an American Loyalist soldier during the American revolution and moved to Europe after the war.

While studying canon manufacture in Munich, he noticed that the process of boring canons (drilling out the barrel) produced an incredible amount of heat, especially if the drill bit was dull.

Thermal Energy

This fluid model could not explain why *friction* of the drill bit on the canon would produce enough heat to keep water boiling, basically for as long as the drilling continued.

Wearing away the canon metal was not producing the heating (a dull bit wears away the metal more slowly), the friction was.

Thermal Energy

James Prescott Joule realized that this meant there was an equivalence between work and heat: both were kinds of energy transfers.

He did many experiments to quantify this relationship.

About 4,180 Joules of mechanical energy are needed to increase the temperature of 1 kg of water by 1°C. (More on this later.)

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He did many experiments to quantify this relationship.

About 4,180 Joules of mechanical energy are needed to increase the temperature of 1 kg of water by 1°C. (More on this later.)

We conclude that there is another type of energy: a hot object has more energy than a similar cold object.

Thermal Energy and Internal Energy

thermal energy[2]

The energy that an object has as a result of its temperature.

internal energy, E_{int} or U_{int}

The energy that an object has as a result of its temperature and all other molecular motions, effects, and configurations.

Internal energy can be thought of as a combination of kinetic and potential energies of microscopic particles, but it is different from mechanical energy, because it cannot be directly converted into work.

[2] This definition is not universal!

Heat

Again,

Heat, Q

An amount of internal energy that is *transferred* from one object to another.

Heat flows from hotter objects, reducing their internal energies, to colder objects, increasing their internal energies.

This is why ice cubes melt in a drink on a hot day (heat flows into the drink).

This is also why hot coffee cools down (heat flows out into the surrounding air).

Heat

Units of heat: calories.

1 calorie is the heat required to raise the temperature of 1 gram of water by 1 degree Celsius.

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The "calories" listed on food labels are sometimes called "Calories" (capital C) because they are in fact kilocalories.

1 Calorie = 1 kilocalorie = the heat required to raise the temperature of 1 kilogram of water by 1 degree Celsius.

Heat

Another unit: Joules! (This is the SI unit)

Because heat is an energy transfer, and energy is measured in Joules.

Heat can also be measured in Joules.

1 calorie = 4.18 Joules.

Summary

- Bernoulli's Principle
- plasma
- heat
- temperature

Talks! Aug 8-9.

Quiz Tomorrow.

Homework Hewitt,

- Ch 14, onward from page 262. Exercises: 47, 53
- Ch 15, onward from page 281. Exercises: 3, 9, 15, 29, 35, 49; Problems: 1, 3