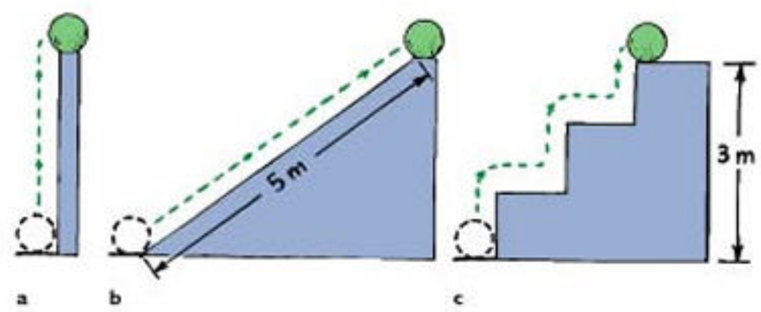
Announcements

- CAPA homework 4 due on Thursday Sept 27 at 10 AM
- Please register your iclicker through LON-CAPA
  - if you want to receive credit
  - only a few of you have not
- Help room hours (1248 BPS)
  - Ian La Valley(TA)
  - Mon 4-6 PM (except not Monday Sept 17)
  - Tues 12-3 PM
  - Wed 6-9 PM
  - Fri 10 AM-noon
- First exam Tuesday Oct. 2 10:20 AM this room
  - you may bring 1 sheet of hand-written notes; no xeroxing; bring picture ID
- Final Exam Tuesday Dec 11 7:45-9:45 AM

Gravitational potential energy

- Work is required to elevate objects against Earth's gravity
- The potential energy due to elevated positions is called gravitational potential energy
- The amount of gravitational potential energy possessed by an elevated object is equal to the work done in moving it to its position
- Suppose I have a ball 3 m above the ground
- The work I have to do to lift the ball 3 m above the ground is
  - $W=Fd=(mg)h=mgh$
- This is the gravitational potential energy of the ball
  - $W=(1kg)(9.8N/kg)(3m)=29.4$ J

1 kg



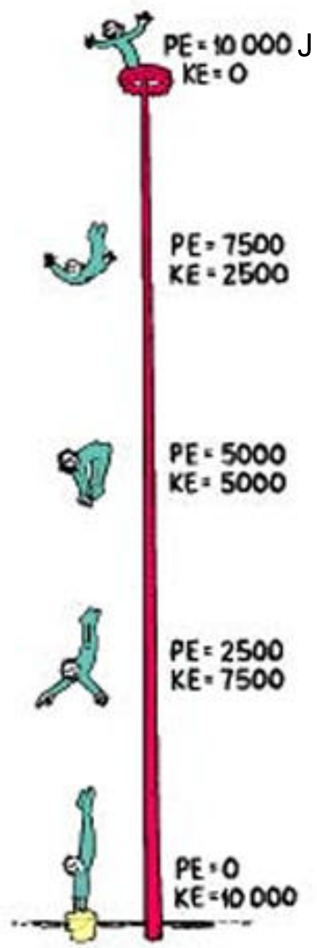
Why mg as a force?
Because gravity is pulling down on the ball with a force mg, and if I want to move it upwards at a constant velocity (no acceleration), then I must exert a force of mg in the opposite direction.

Note that the potential energy is always defined with respect to some reference level, for example the ground or the floor of a building

Conservation of energy

- Whenever energy is transformed or transferred, none is lost and none is gained
- In the absence of work input or output, the total energy of a system remains constant
- Consider the circus diver to the right
- As he jumps off the platform, he loses PE but gains an equal amount of KE
- Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes

maximum potential E
mininum kinetic E



minimum potential E
maximum kinetic E

Conservation of energy

- So the circus performer has a PE of 10,000 J (and a mass of 50kg)
- How high up is he?

$$PE = mgh$$

$$h = \frac{PE}{mg} = \frac{10{,}000J}{(50kg)(9.8m/s^2)}$$

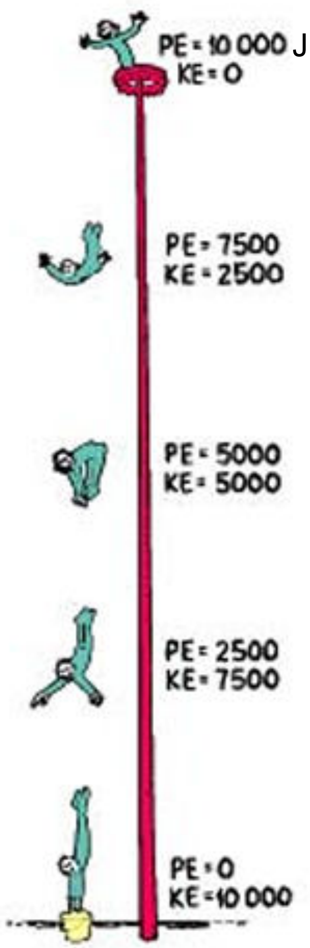
$$h = 20.4$$

- What units?
  - J is a unit of energy
  - So 1 J= 1 kg·m^2/s^2
  - so h=20.4 m
- How fast is he going when he hits the bucket?

$$KE = \frac{1}{2}mv^2 = \Delta PE = 10000J$$

$$v^2 = \frac{(2)(10000J)}{50kg} = 400J/kg$$

$$v = 20m/s$$



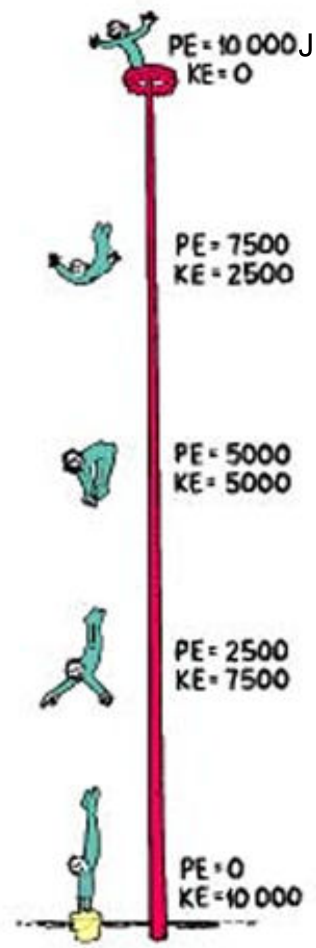
Conservation of energy

- How fast is he going when he’s halfway down?
- Half of the potential energy has been converted to kinetic energy

$$KE = \frac{1}{2}mv^2 = \Delta PE = 5000J$$

$$v^2 = \frac{(2)(5000J)}{50kg} = 200J/kg$$

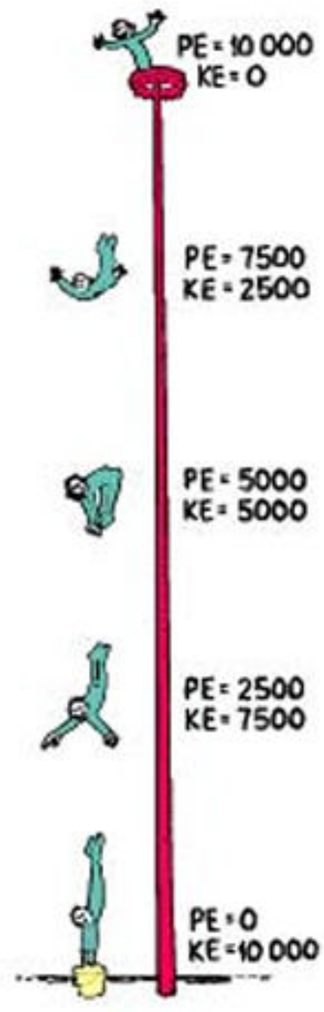
$$v = 14.1m/s$$



KE + PE = constant everywhere

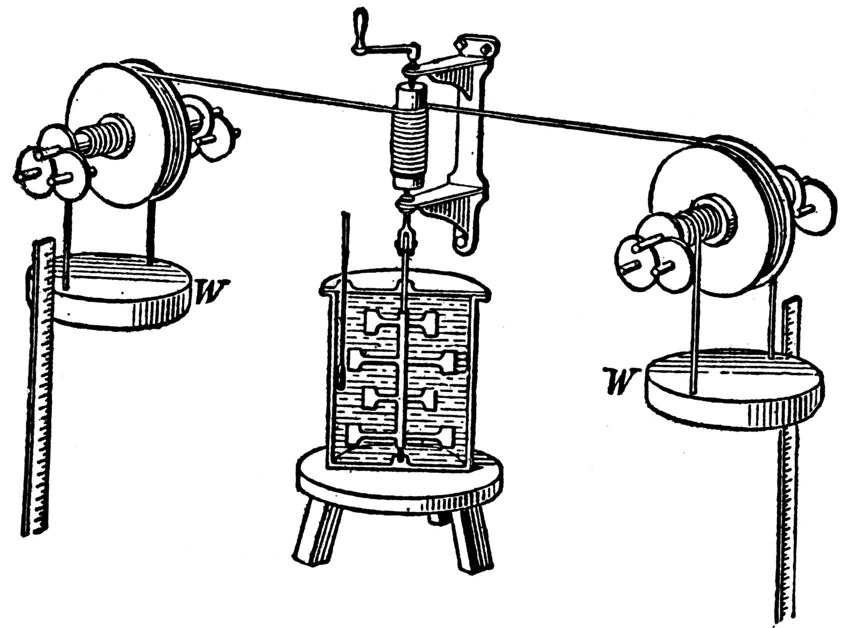
Joule's experiment

- Where does the kinetic energy go when the guy hits the water?
- This was a question that physicists had trouble with up to the 19th century
- They thought the energy disappeared
- But it's transformed into heat



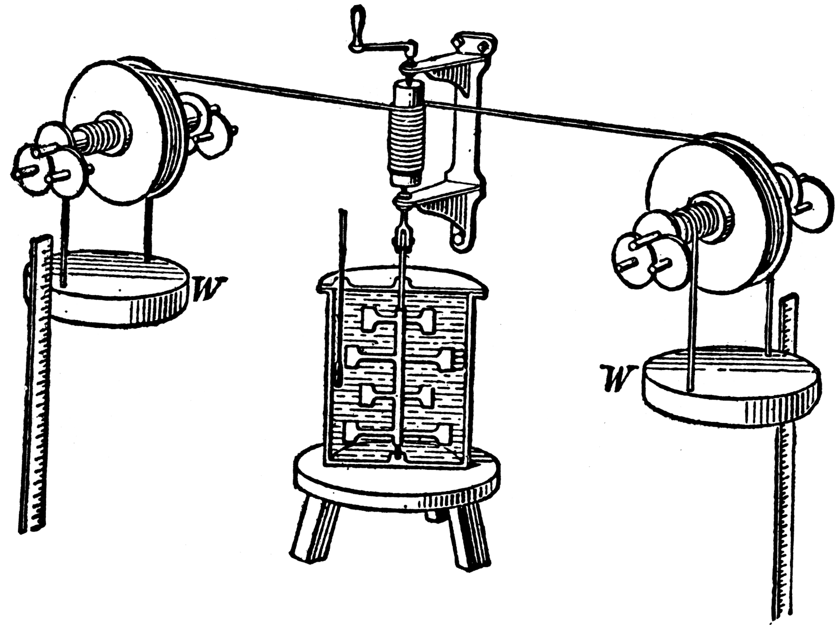
Joule’s experiment

- Joule proved this when he performed a very clever experiment
- A falling weight causes paddles to turn inside a cylinder filled with water
- The weight loses potential energy
- Which is transformed into an increase in temperature of the water by the mechanical motion of the paddles
- The heat energy gained by the water equaled the potential energy lost
- And Joule gets a unit of energy named after him



Joule's experiment

- Joule showed that 4200 J of work would always produce a 1 degree Centigrade temperature rise in 1 kg of water
- This amount of energy is known as 1 Calorie (dietician)
  - not to be confused with 1 calorie (physicist) which is the amount of energy needed to raise 1 g of water by 1 degree C
- A 70 Calorie slice of bread has 70 Calories of stored chemical energy that can potentially provide 70 Calories of work and/or thermal energy



but your body is not so efficient at converting input energy to output energy ~10%

$$\text{Efficiency} = \frac{\text{output energy}}{\text{input energy}}$$

Power

- The definition of work says nothing about how long it takes to do the work
- A measure of how fast the work is done is the power
- Power is equal to the amount of work done per unit time

$$\text{Power} = \frac{\text{work done}}{\text{time interval}}$$

- Power is also the rate at which energy is changed from one form to another

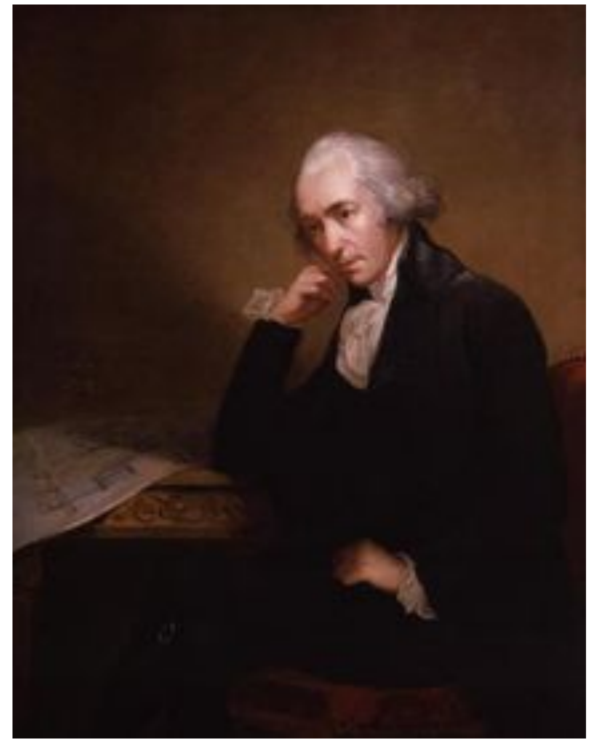
- An engine with twice the power does not necessarily move a car twice as fast or twice as far, but it can do twice the work in the same amount of time
  - it can produce a more powerful acceleration

Power

- We defined power as

$$\text{Power} = \frac{\text{work done}}{\text{time interval}}$$

- So it must have units of energy over units of time (J/s)
- We name the units of power (J/s) after James Watt, the developer of the steam engine
  - in English units, horsepower
- Often will talk about kilowatts or megawatts
- Note that your electric bill tells you not how many watts you used, but how many kilowatt-hours
  - power X time = unit of energy



another illustrious Scotsman

1 kw-hr=1000 J/s * 3600 s = 3.6×10^6 J

A little calculation

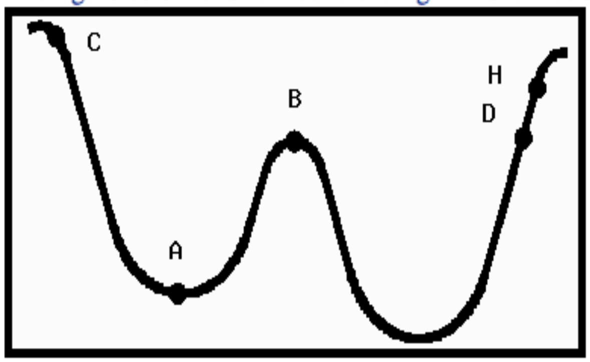
- BMR (basal metabolic rate) for an 18 year old (male) with a mass of 60 kg is ~1600 C(alories)/day
- This corresponds to 1600 C X 4200 J/C = 6.72E6 J
- This is the energy consumed by your body just by sitting around (like in lecture)
- There are 24X60X60=86,400 seconds in each day
- Power = Energy/time
- Power = 6.72E6 J/8.64 E4 s = 78 W
- So just by sitting there, you're giving off as much heat as a 75 W light bulb

100 of you give off 7500 W

LON-CAPA problem

Sum of the potential energy and kinetic energy is a constant.

The figure below shows a bead sliding without friction along a curved wire in a vertical plane.

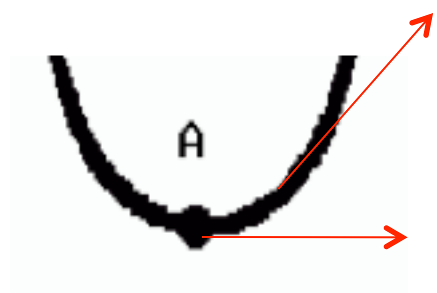


The bead slides starting from rest at position C on the frictionless wire. The direction of the gravitational field is in the -y direction (toward the bottom of the page).

False: The velocity at B equals the velocity at D.
Equal to: The acceleration in the x-direction at A is ... zero.
Greater than: The speed at A is ... the speed at B.
Equal to: The speed at B is ... the speed at D.
Greater than: The acceleration in the y-direction at A is ... zero.
False: The acceleration at B is zero.

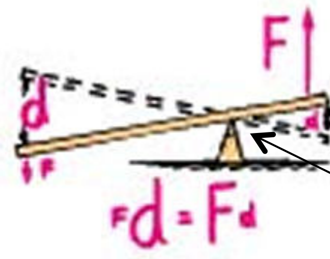
You are correct. Computer's answer now shown above.
Your receipt is 149-1639

Previous Tries



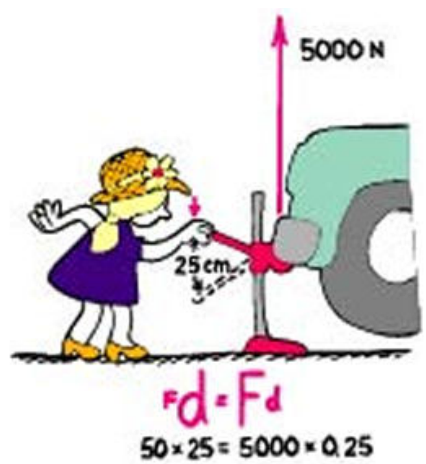
Simple machines

- A machine is a device for multiplying forces or simply changing the direction of forces
- The principle underlying every machine is the conservation of energy
- One simple machine is the lever
- A force downwards on one side creates and upward force on the other side
- But that's not the big deal
- The big deal is that
  - work input = work output
- $(\text{ForceXdistance})_{input} = (\text{ForceXdistance})_{output}$



It's a way of multiplying force, although the movement on the input side has to be larger

$$(Fxd)_{input} = (Fxd)_{output}$$

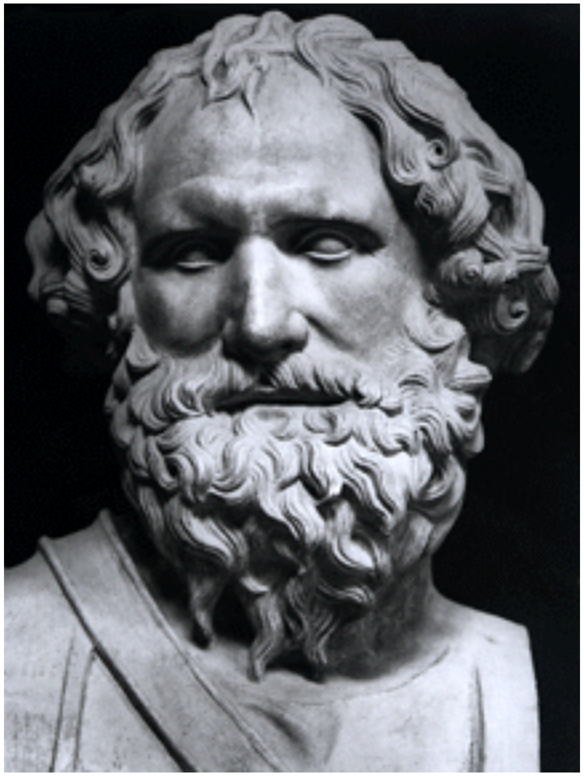


With the car jack, a 50N force acting over 25 cm becomes a 5000N force acting over 0.25 cm

Archimedes

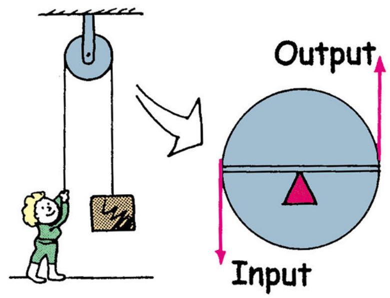
- Discovered the principle of the lever and once stated
  - “Give me a lever and I can move the world”
- Also discovered the principle of bouyancy
  - and is credited with shouting “Eureka*” as he ran naked from his bath, after discovering this principle → Don’t try this at home!

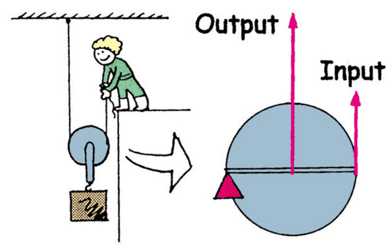
*“I have found it”



Pulleys

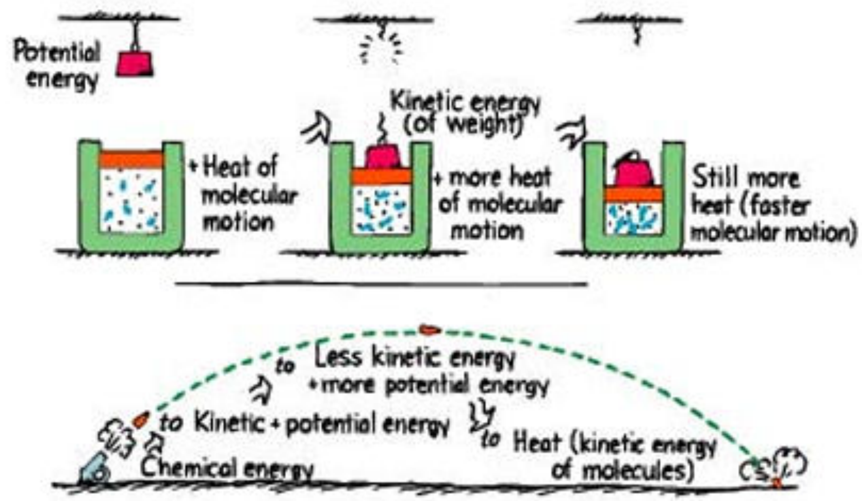
- A simple pulley can be used to change the direction of a force
- With this arrangement, a load can be lifted with half of the input force (the tension in the rope provides the other half)
- A block and tackle is a system of pulleys that multiplies force
- Note that energy is not multiplied. It takes the same amount of work to raise the 500 N weight





Efficiency

- Mostly we've been talking about ideal machines, where 100% of input energy goes to output work
- But in any real transformation of energy, some energy is dissipated to molecular kinetic energy, i.e. thermal energy
- We define the efficiency by



$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

Sources of energy

- Except for nuclear energy, essentially all of our energy sources derive the sun
  - including coal, oil, wood, hydroelectric, wind
  - (geothermal energy indirectly from nuclear)
    - this answered a question that arose in the 1800's; why is the interior of the Earth still hot?
- Sunlight can be directly transformed into electricity by photovoltaic cells, like those in solar-power calculators
  - about 1 kilowatt per square meter available in sunlight
  - photovoltaic cells typically around 30% efficient
- Oil is running out, so you hear a lot about running cars on hydrogen
- But hydrogen is not a source of energy, but rather a way of storing it
- You can produce hydrogen by the process of electrolysis on water
  - $H_20 \text{->} H_2 + O$
- But it takes an energy input to bring about the electrolysis, and if you use coal, then that does nothing to solve the greenhouse gas problem

Material from here on not on the first exam

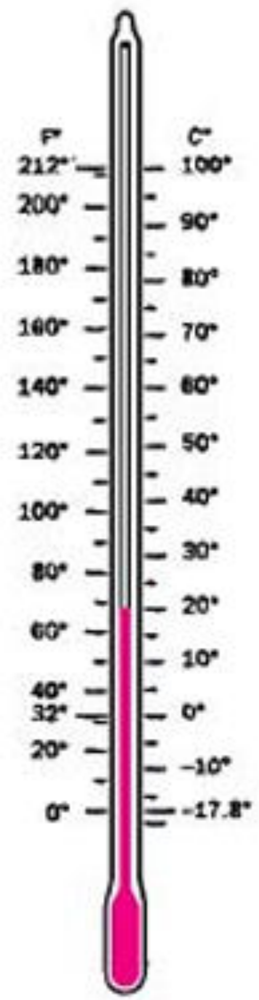
- Part of Thursday's lecture will be a quick review
- The exam will be 40 multiple choice questions, based on the lectures, the homework, the videos
- Seats will be assigned
- Please bring a picture ID with you
- You will have from approximately 10:25 to 11:35 to work on the exam

Temperature

- The quantity that indicates how warm or cold an object is compared to some standard is called temperature
- We use a device graduated in a scale to measure the temperature
  - a thermometer works by means of expansion or contraction of a liquid, usually mercury or colored alcohol
- The most common temperature scale in the world is the Celcius (also called Centrigrade) scale named after Anders Celcius
  - 100 degrees between the freezing point of water and its boiling point
- But in the United States, the Farenheit scale is more common, named after the German physicist Farenheit
  - in this scale, water freezes at 32 degrees and boils at 212 degrees
  - 0^{o} is the temperature of the coldest salt water solution
  - in official use only in the US and in Belize

Conversions

- Temperature (C) = 5/9 X (temperature (F) -32^{o})
- The two are equal at -40^{o}, cold no matter what scale you use to quote it
- You should know how to convert from one to the other



Temperature and heat

- Temperature is proportional to the average kinetic energy per particle in a substance
  - how fast the atoms are moving in a gas or liquid or how fast the atoms are vibrating in a solid
- Thermal energy refers to the sum of the kinetic energy of all particles in a substance
- If I take a cup of hot water and pour out half of it, the temperature of the remaining half is still the same, but the thermal energy has been cut in half
- When we measure the temperature of a object, thermal energy flows between the thermometer and the object
- Eventually the thermometer and the object come to thermal equilibrium
  - same average kinetic energy per particle

States of matter

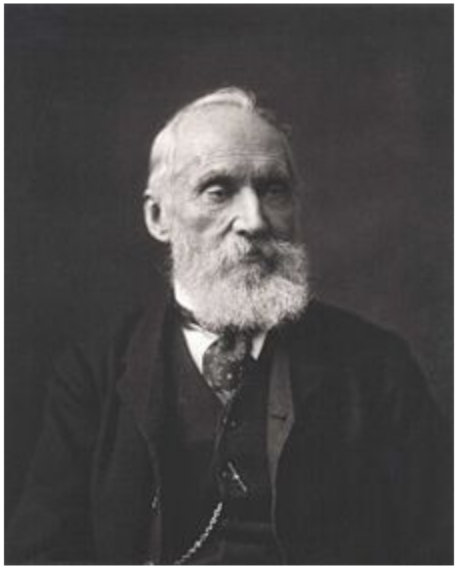
- As the temperature of an object increases, a solid object will melt and become a liquid; with more heat input the liquid will vaporize and become a gas
- As the temperature is increased further, molecules dissociate into atoms and atoms lose some or all or their electrons, thereby forming a cloud of electrically charged particles, or a plasma
- Plasmas exist in stars, where the temperatures can reach millions of degrees
- There is no upper limit on temperature

- Four states of matter
  - solid
  - liquid
  - gas
  - plasma

hottest temperature ever generated on Earth is ~2 billion degrees C

Absolute zero

- In the 19th century, physicists found something amazing
- Suppose you start with a gas at 0^{o} C
- The volume decreases by a fraction 1/273 for every degree decrease in temperature
- This implied that if a gas were cooled to -273^{o} C, it would decrease to zero volume
    - of course, by this point the gas would have turned into a liquid, but it brings up the idea that, while there is no upper limit to temperature, there is a lower limit
- At -273.15^{o} C, molecules have lost all available kinetic energy
    - It's impossible to remove any more heat
- This temperature is called absolute zero
- The Kelvin temperature scale uses absolute zero as the zero of the temperature scale (but the degrees are the same size as for the Celcius scale)
- The temperature scale is named after Lord Kelvin, another illustrious Scottish physicist



originally William Thomson

The Quest for Absolute Zero

Temperature and kinetic energy in a gas

- Temperature is proportional to the average kinetic energy per particle in a substance
  - how fast the atoms are moving in a gas or liquid or how fast the atoms are vibrating in a solid
- Average kinetic energy of a gas molecule

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

$$KE_{average} = \frac{3}{2}k_B T$$

  - k_B=1.38X10^{-23} J/^{o}K
  - Boltzmann's constant
  - T is the temperature in degrees Kelvin

- Suppose I have 22.4 liters of air at room temperature (300^{o}K)
- What is its energy content?
- To make it simple, assume that the air is all nitrogen (instead of 80%)
- 22.4 liters is one mole or 6.02E23 atoms

$$KE_{molecule} = \left(\frac{3}{2}\right)k_B T = \left(\frac{3}{2}\right)\left(1.38X10^{-23} J/K\right)\left(300^o K\right)$$

$$KE_{molecule} = 6.2X10^{-21} J$$

$$KE_{N2} = 6.02X10^{23} xKE_{molecule} = 3739J$$

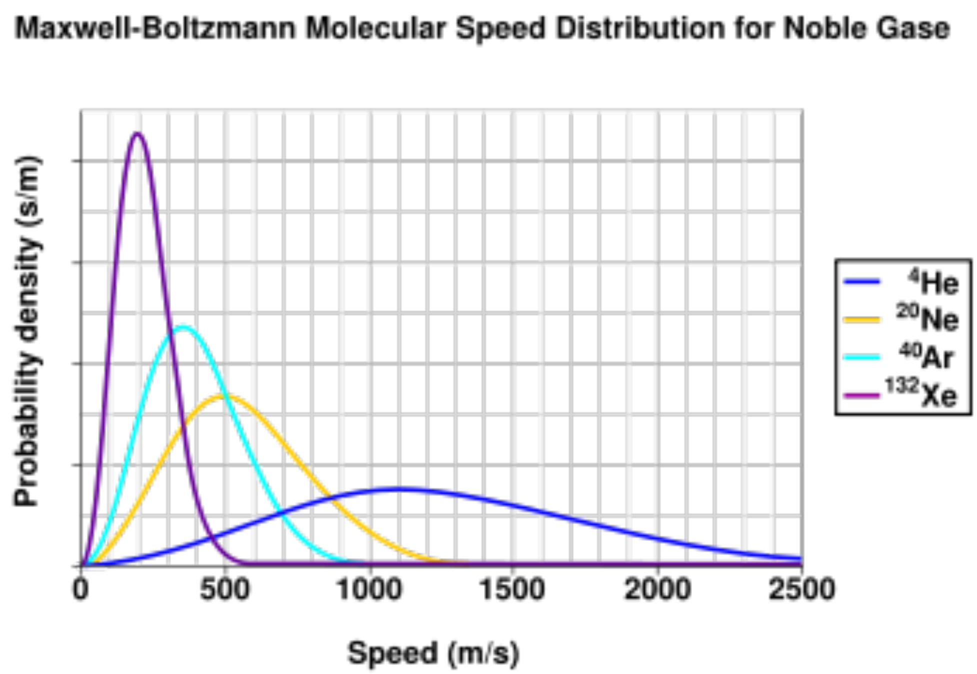
- What is the average speed of a N_2 molecule?

$$KE_{molecule} = \frac{1}{2}m_{N2}v^2$$

$$v \approx 500m/s$$

Maxwell-Boltzmann distribution

- We calculated the average velocity for a N_2 molecule at room temperature, but the velocities are actually spread over a Maxwell-Boltzmann distribution
- Note that the average velocity depends on the mass
  - which you would expect if the average kinetic energy does not



Note that the average speed for He atoms is much higher than the other (heavier) atoms. If you breathe in Helium and talk, your voice gets ‘squeaky’