MOTION

- Speed: rate at which something moves:
  - speed = distance/time (m/s, miles/hour, km/hr)
- Velocity: Speed with a direction
  - 70 mph south on I-35 is very different than 70mph north
- Acceleration: a change in velocity
  - Speed up, slow down, OR change direction
  - Units of (m/s)/s thus m/s^2

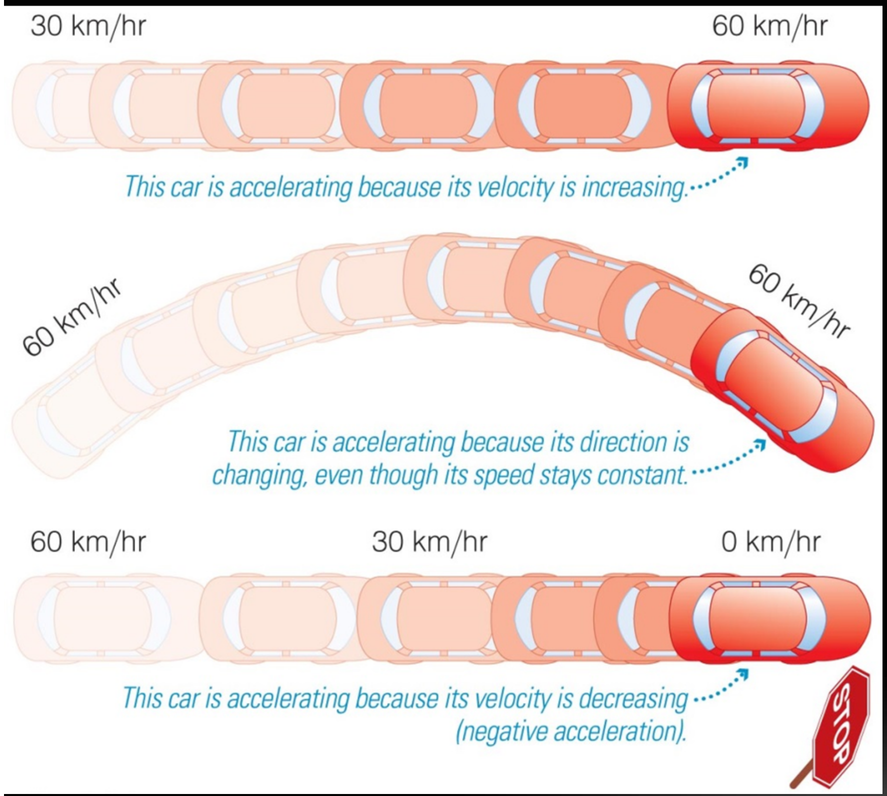


Fig.4.1

ACCELERATION OF GRAVITY

- All falling objects accelerate at the same rate (not counting friction of air resistance).
- On Earth, $g \approx 10\ \mathrm{m/s^2}$: speed increases 10 $\mathrm{m/s}$ with each second of falling.

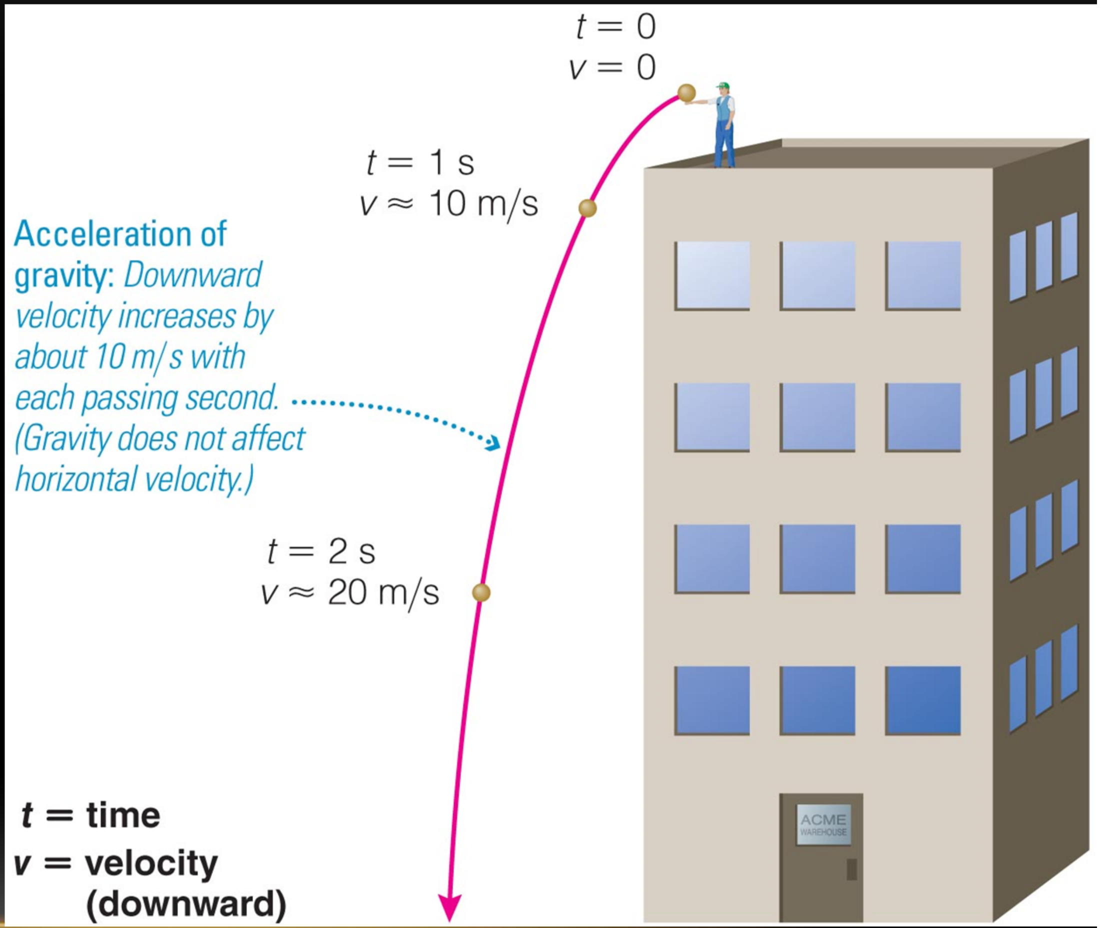


Fig.4.2

MASS DOESN'T MATTER

- Galileo showed everything falls at the same rate regardless of mass
  - If you account for air resistance: same size balls of different weights took the same time to reach the bottom

PLAY

MOMENTUM AND FORCE

- Momentum = mass x velocity.
- A net force changes momentum, which generally means an acceleration (change in velocity).
  - "Net" means extra or unbalanced: I am standing on the floor, but not falling down: why?
- The rotational momentum of a spinning or orbiting object is known as angular momentum.

MASS VS WEIGHT

- Mass—the amount of matter in an object
- Weight—the *force* that acts on an object due to that mass and some gravity

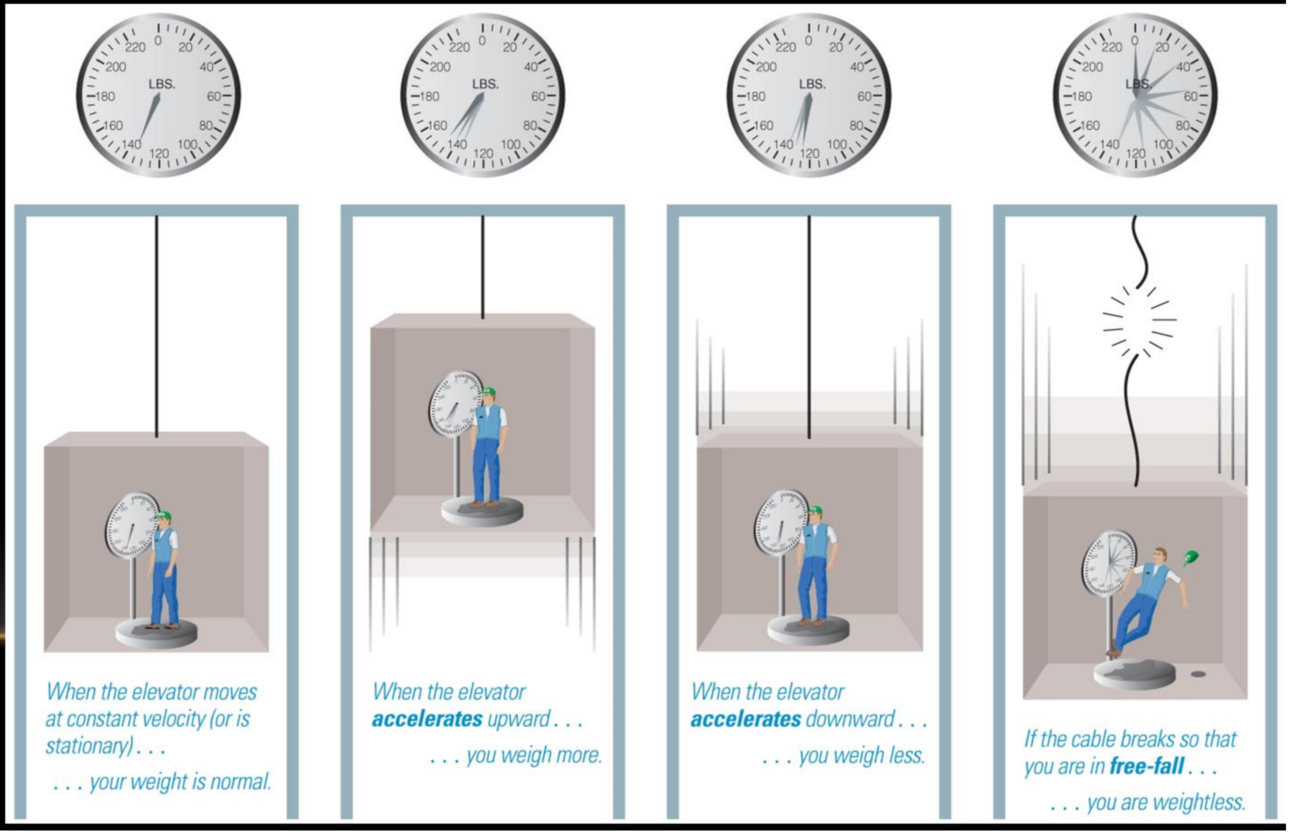
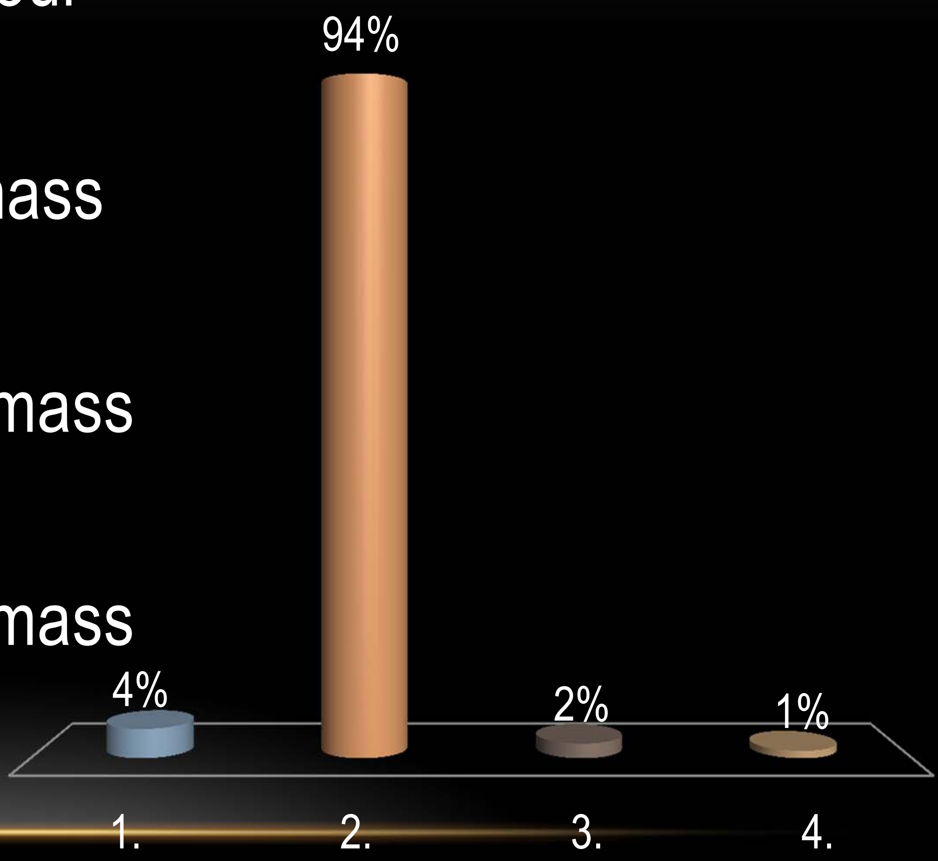


Fig.4.3

ON THE MOON:

1. your weight is the same; your mass is less.
2. your weight is less; your mass is the same.
3. your weight is more; your mass is the same.
4. your weight is more; your mass is less.



WHY ARE ASTRONAUTS WEIGHTLESS IN SPACE?

- Plenty of gravity out there
  - we'll see that gravity is what is holding things in orbits
- Weightlessness is due to constant state of free-fall
  - Things in orbit are just falling around the earth

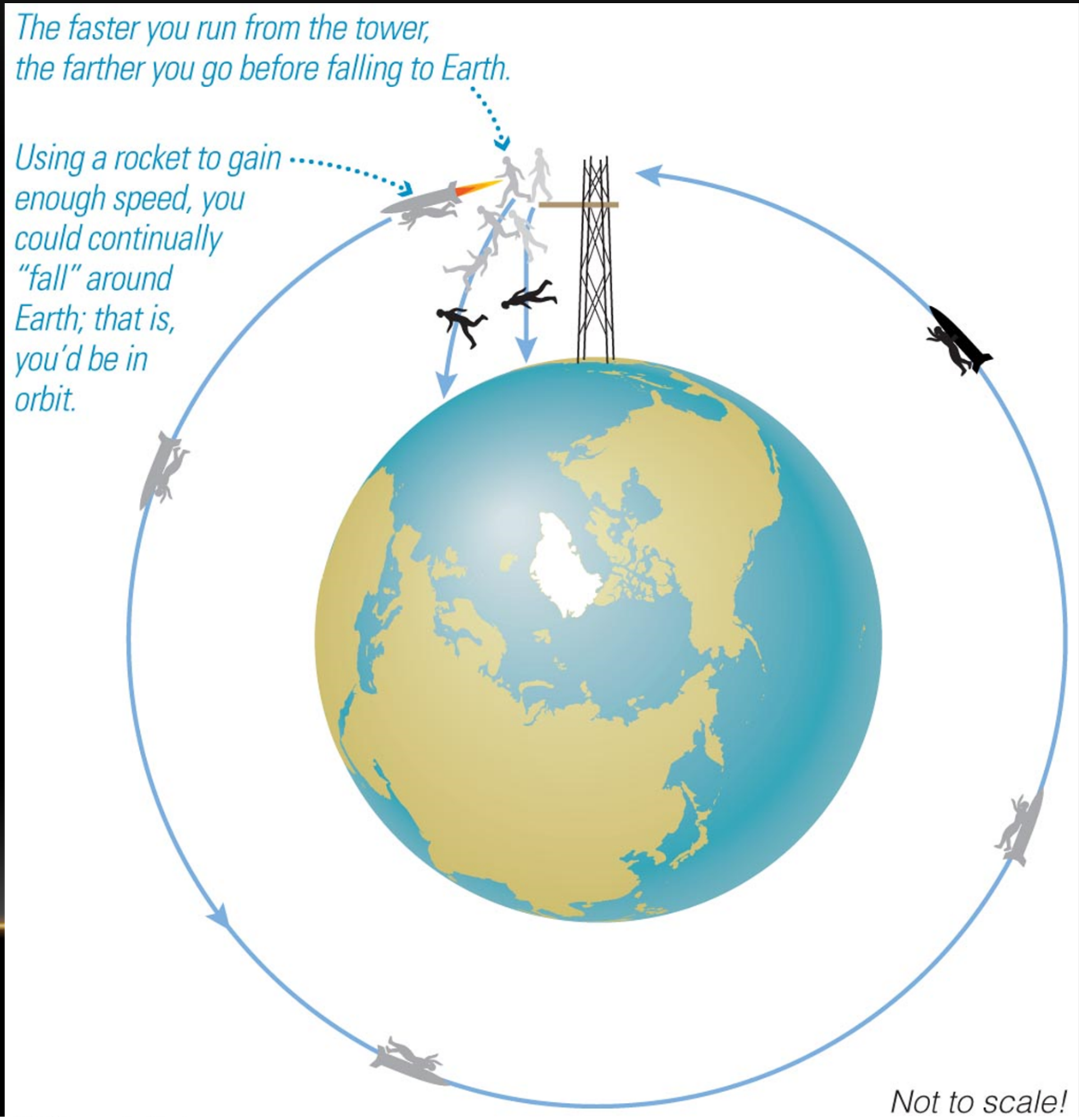
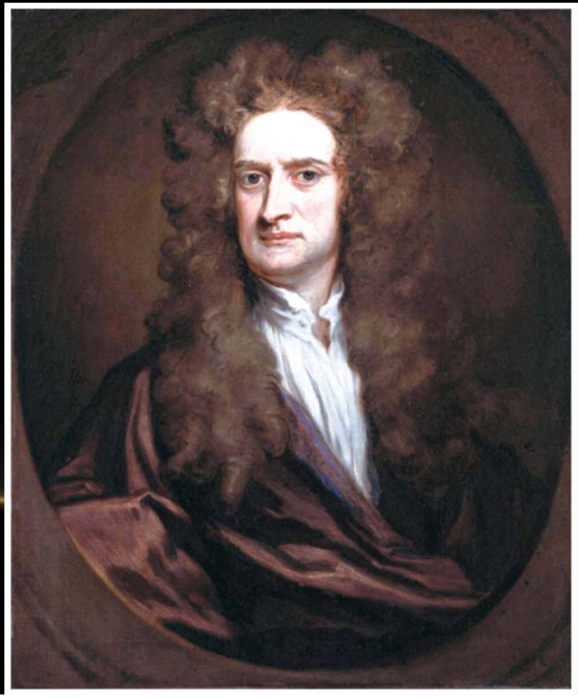


Fig.4.4

NEWTON'S LAWS

1. Law of Inertia – Unless an object is acted on by a net outside force, it will keep moving at constant speed in a straight line (if moving) or stay put (if at rest)
   - Inertia – the tendency of an object to resist a change in its motion



NEWTON'S SECOND LAW

- A net external force applied to an object causes it to accelerate at a rate that's inversely proportional to its mass

$$F/m=a$$

- Mass is not weight
  - Weight is the force gravity exerts
  - Mass is how hard it is to get something moving
- Acceleration is the change in speed

NEWTON'S THIRD LAW

- Equal and Opposite Forces
  - When an object X exerts some force on object Y, object Y will exert an equal and opposite force back on X

- *e.g.*, I lean on the wall, the wall pushes back on me and keeps me from falling over

THINGS TO CONSIDER…

A compact car and a large truck have a head-on collision. Are the following **true** or **false**?

- The *force* of the car on the truck is equal and opposite to the force of the truck on the car. T
- The *momentum* transferred from the truck to the car is equal and opposite to the momentum transferred from the car to the truck. T
- The *change of velocity* of the car is the same as the change of velocity of the truck. F
  - Hint – momentum = mass x velocity

CONSERVATION OF MOMENTUM

- Total momentum of a set of things cannot change unless an external force is acting on them
- Interacting objects exchange momentum through equal and opposite forces
- Seems esoteric: but knowing this lets us figure out many things about interacting objects

ROTATING THINGS STILL CONSERVE MOMENTUM

- Angular Momentum = mass x velocity x radius
- The angular momentum of an object cannot change unless an external twisting force (torque) is acting on it.
- Earth experiences no twisting force as it orbits the Sun, so its rotation and orbit will continue indefinitely.

THIS MAKES PLANETS KEEP GOING

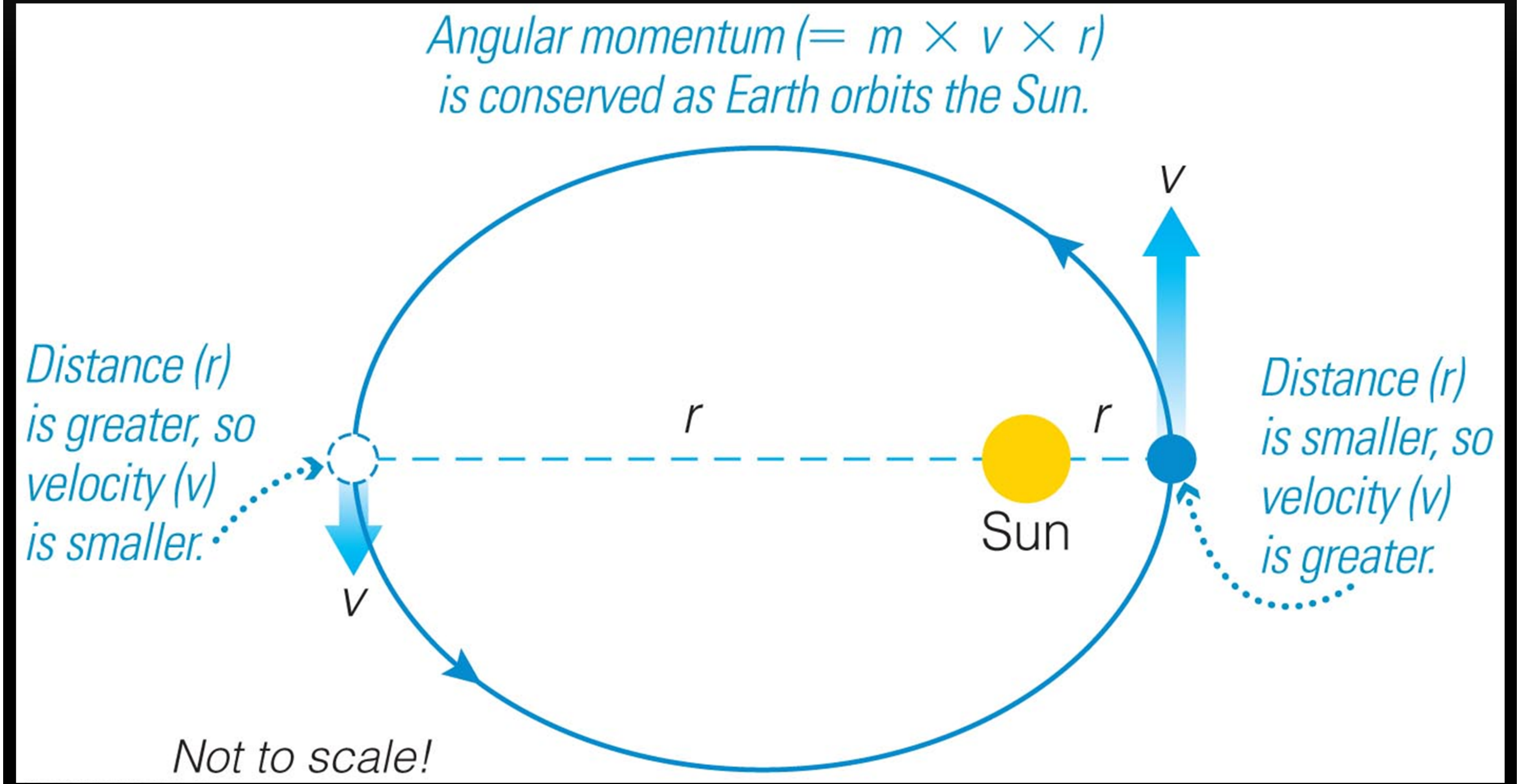


Fig.4.6

OR SKATERS DO THAT SPINNY MOVE

We'll see this in action with stars and stuff A LOT later on in the course

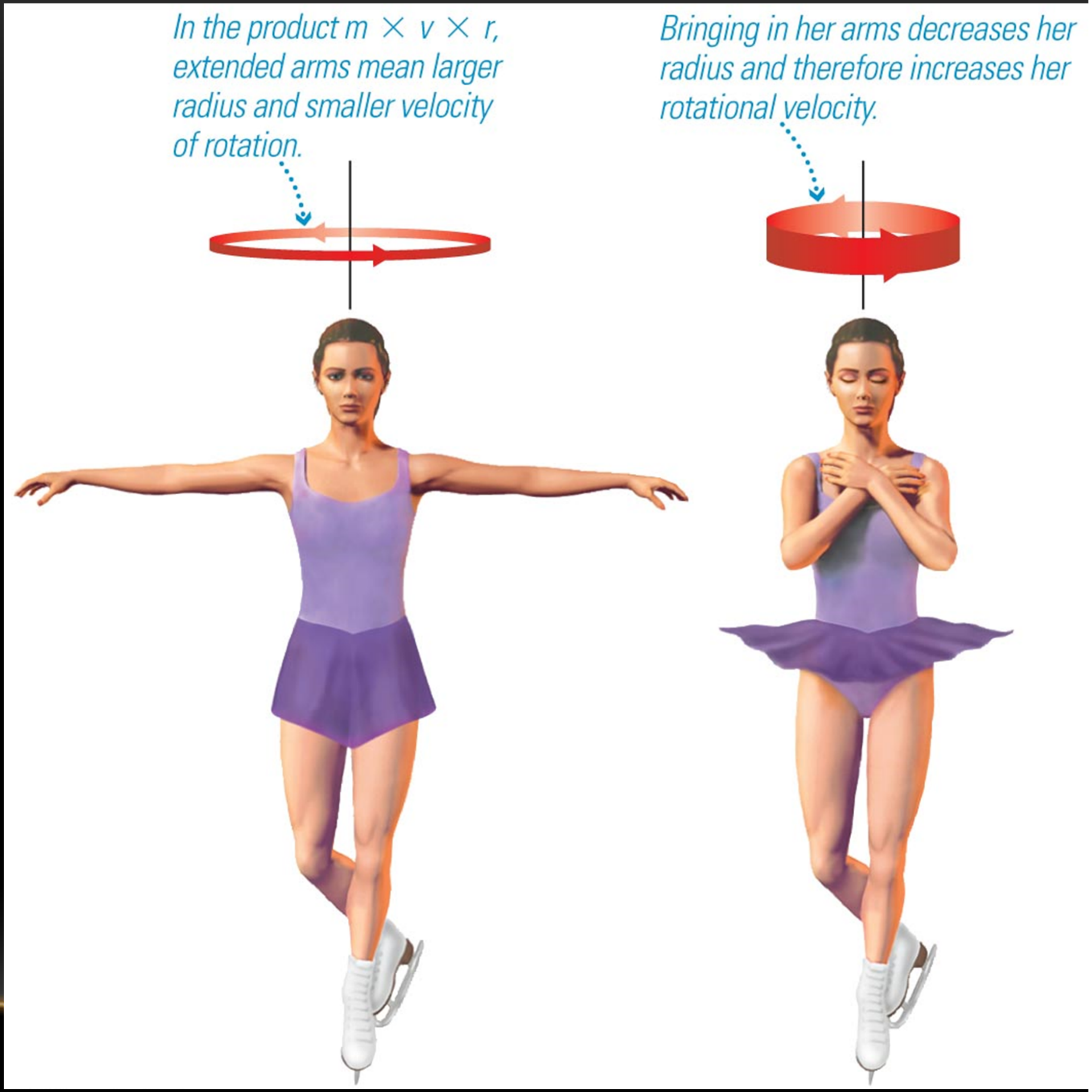


Fig.4.7

ENERGY

- Something else which is “conserved”
  - *ie*, you don’t make it or destroy it, you can simply shuffle it around

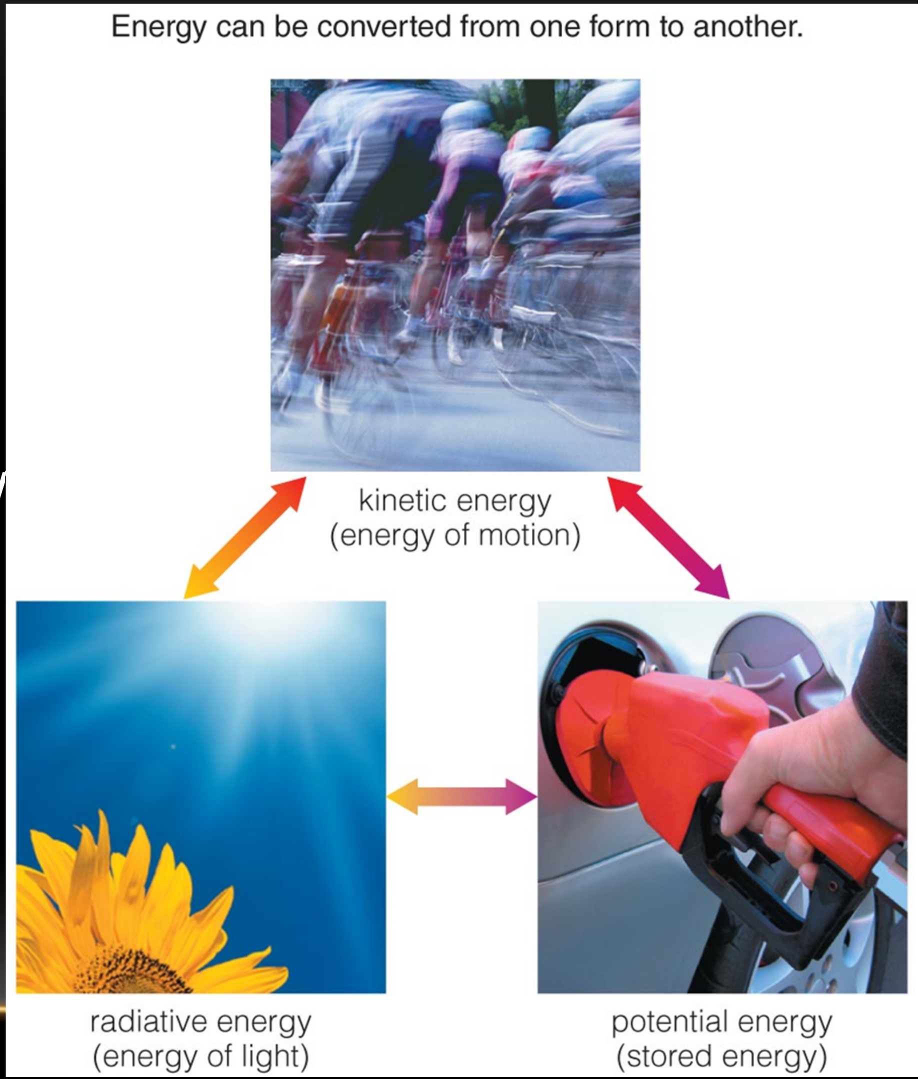
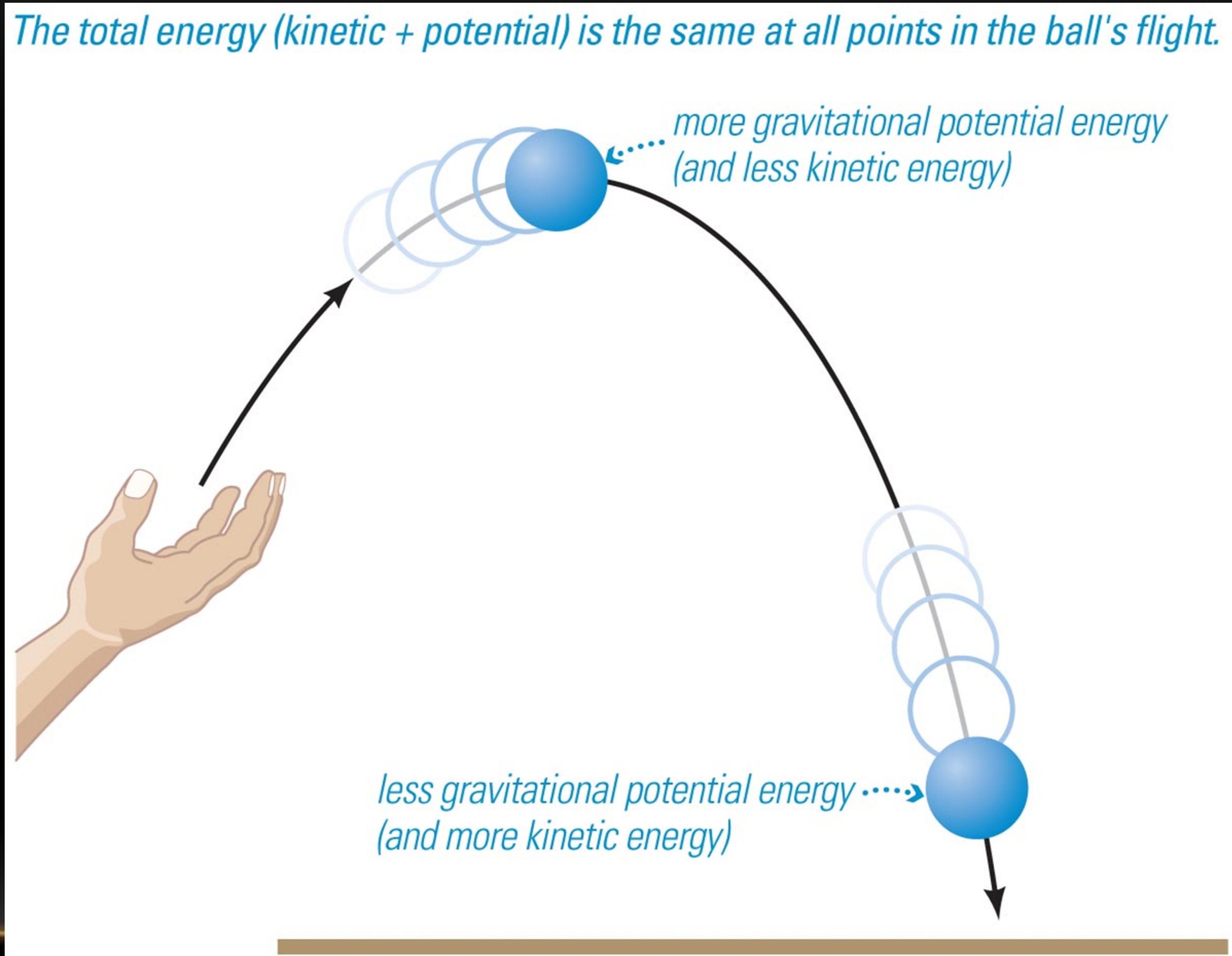


Fig.4.8

TRADING AROUND ENERGY

- For example, tossing a ball up in the air



a The ball has more gravitational potential energy when it is high up than when it is near the ground.

Fig.4.12a

THERMAL ENERGY

- Simply the sum of all the kinetic energies of all the molecules rattling around in side of things

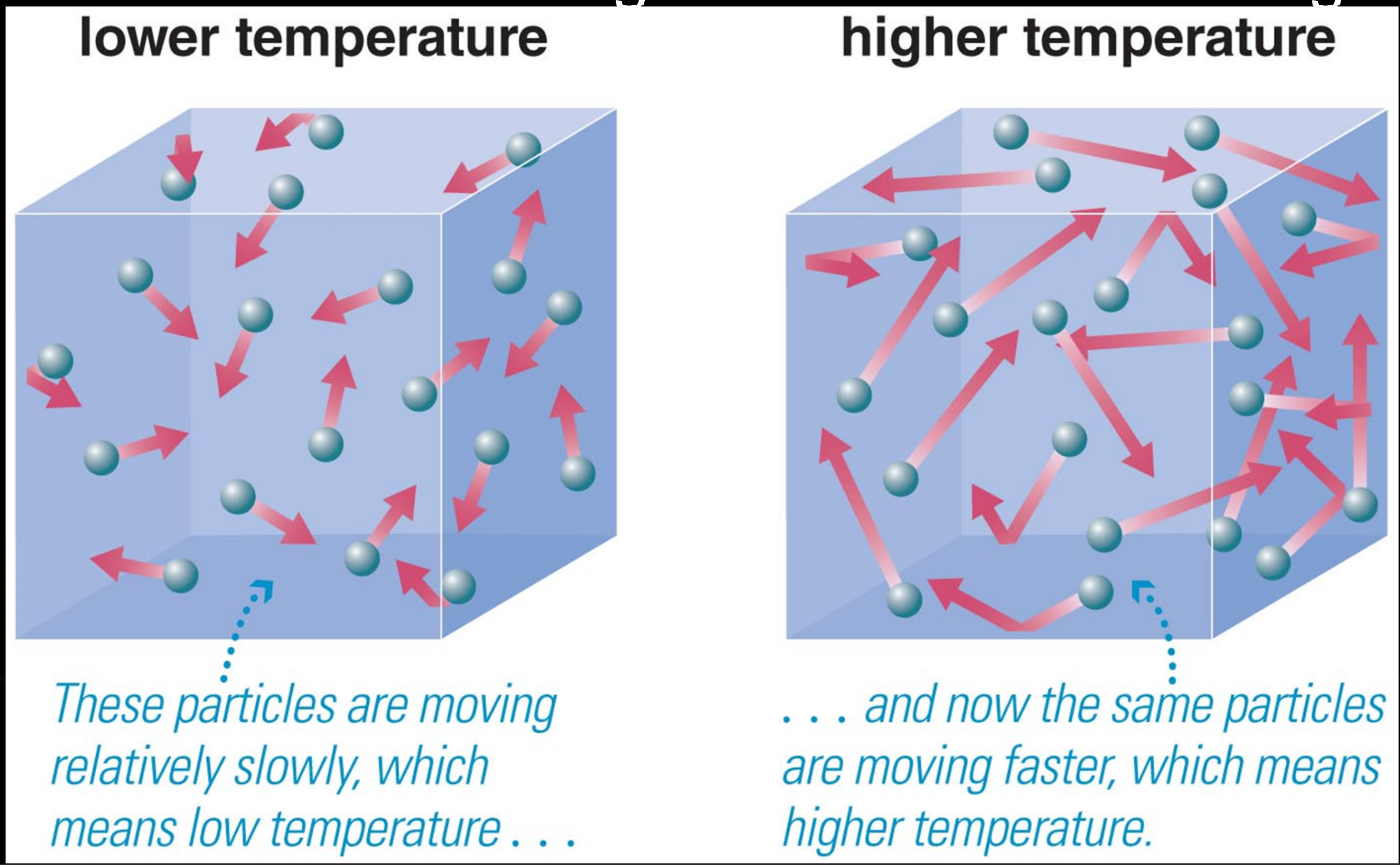


Fig.4.9

TEMPERATURE SCALES

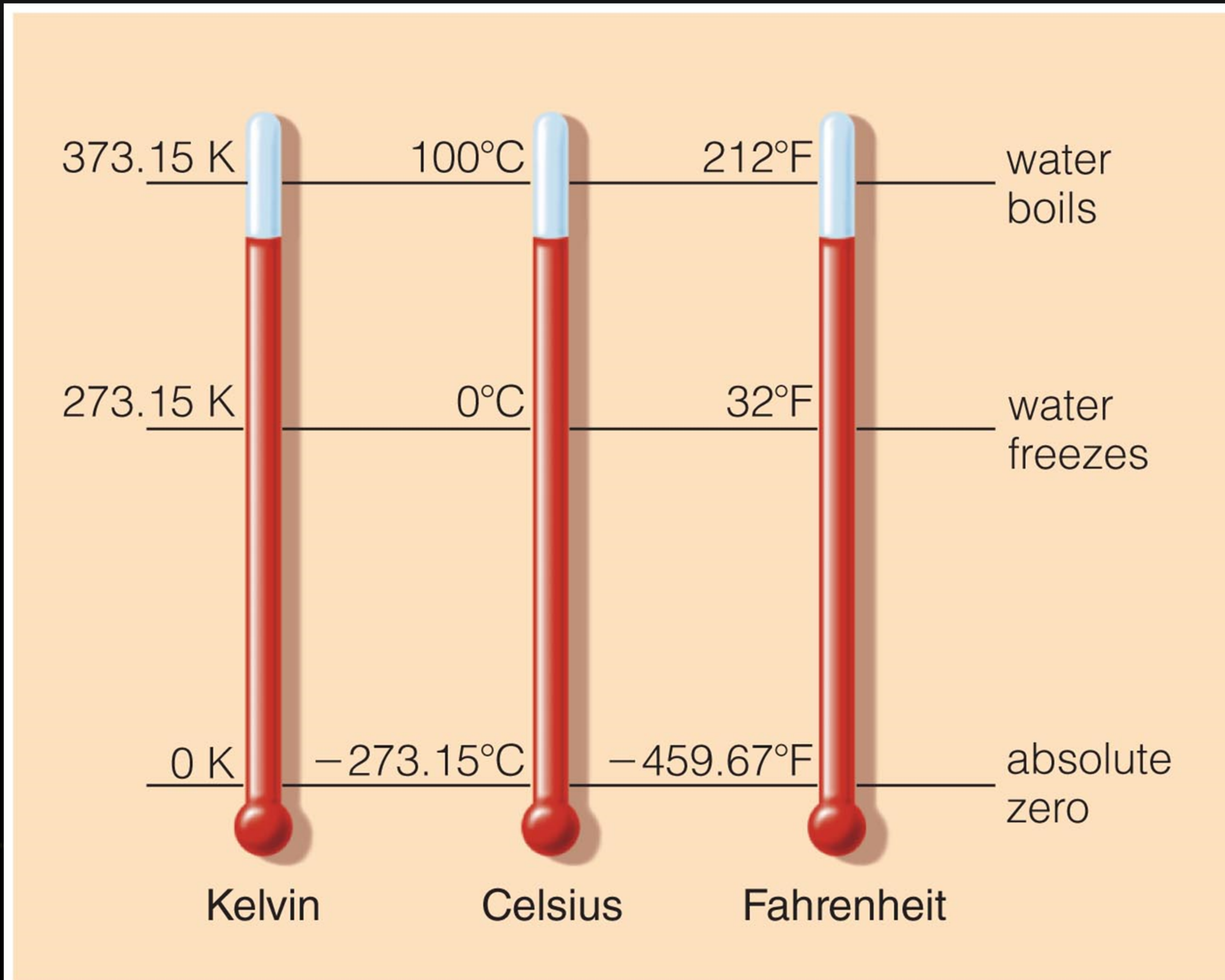


Fig.4.10

THERMAL ENERGY VS TEMPERATURE

- Thermal energy is a measure of the total kinetic energy of all the particles in a substance. It therefore depends on both *temperature* AND *density*.

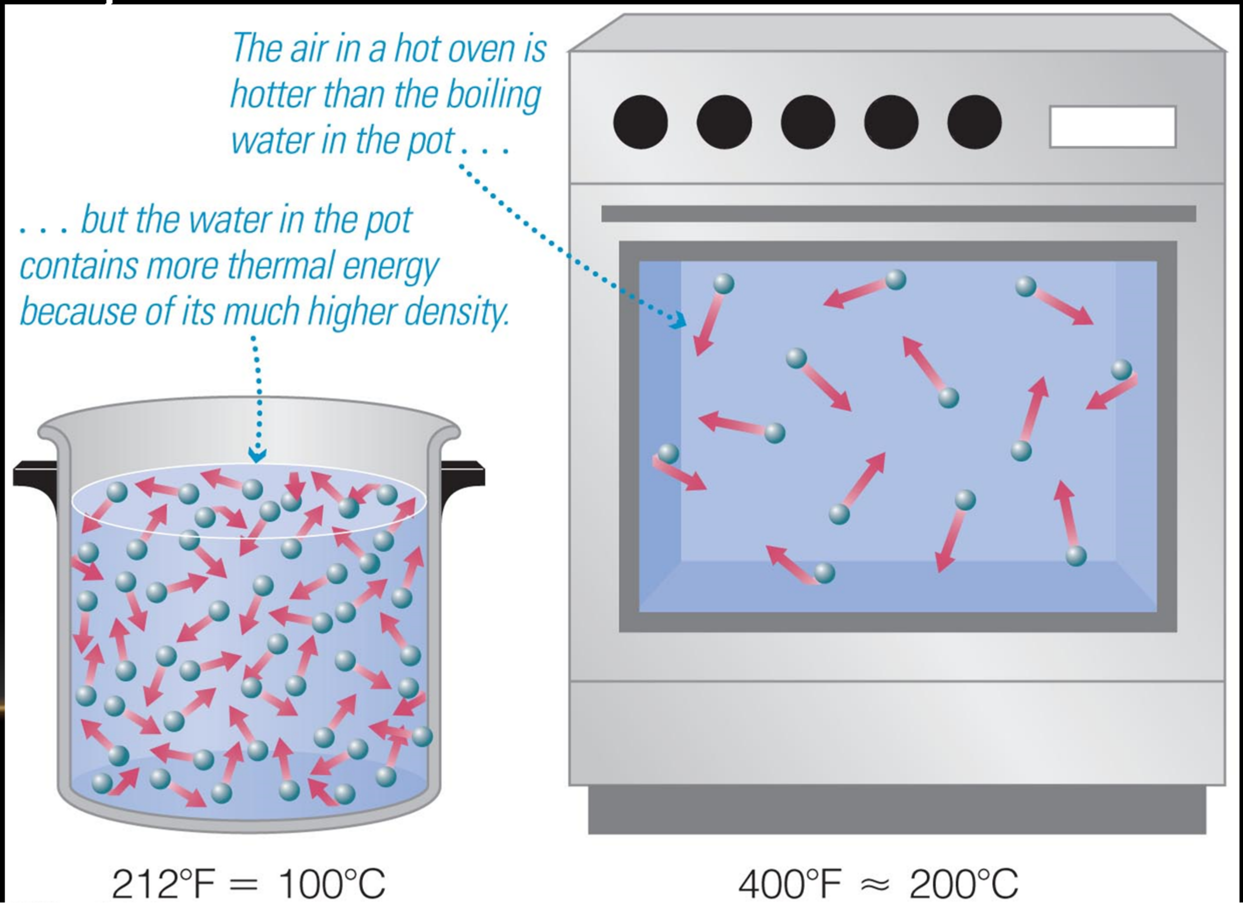
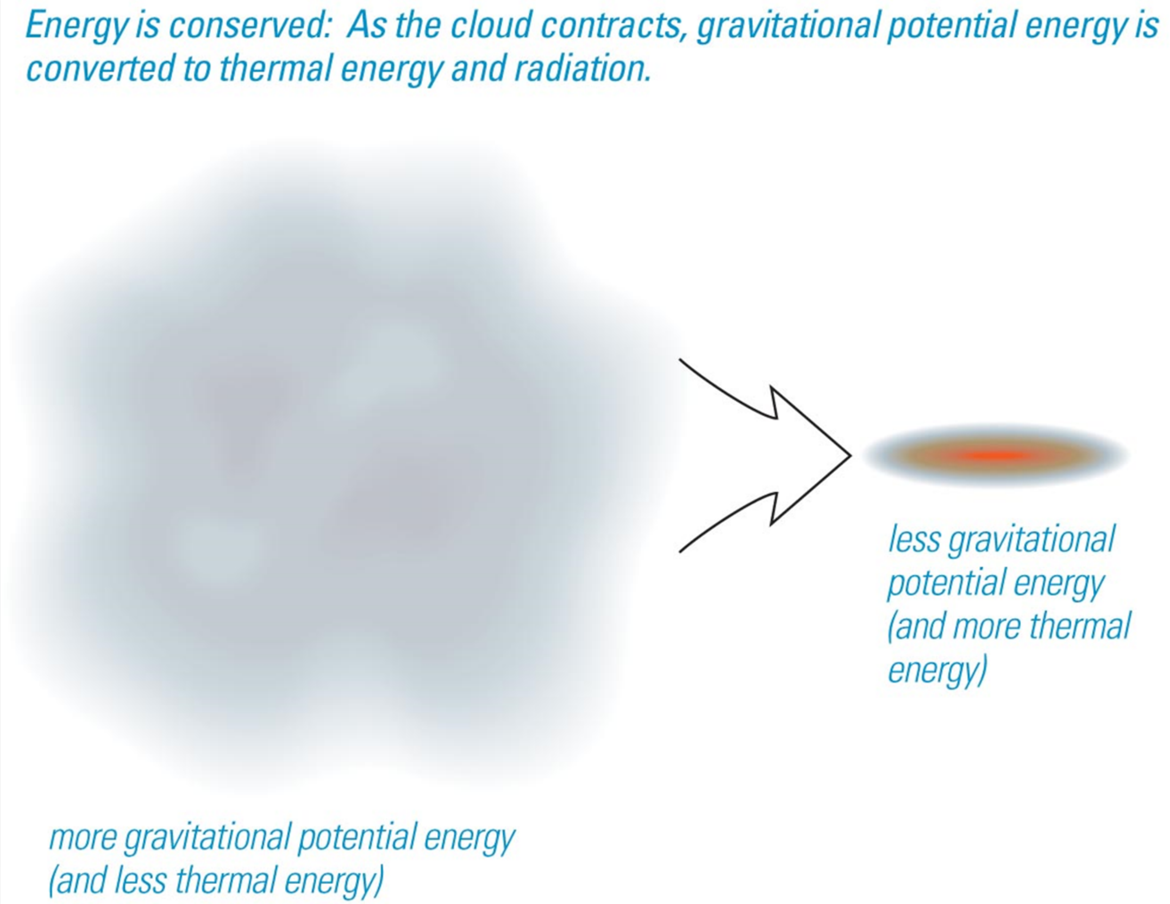


Fig.4.11

TRADING ENERGY AROUND AGAIN

- Gravitational potential energy being turned into thermal energy to make a star

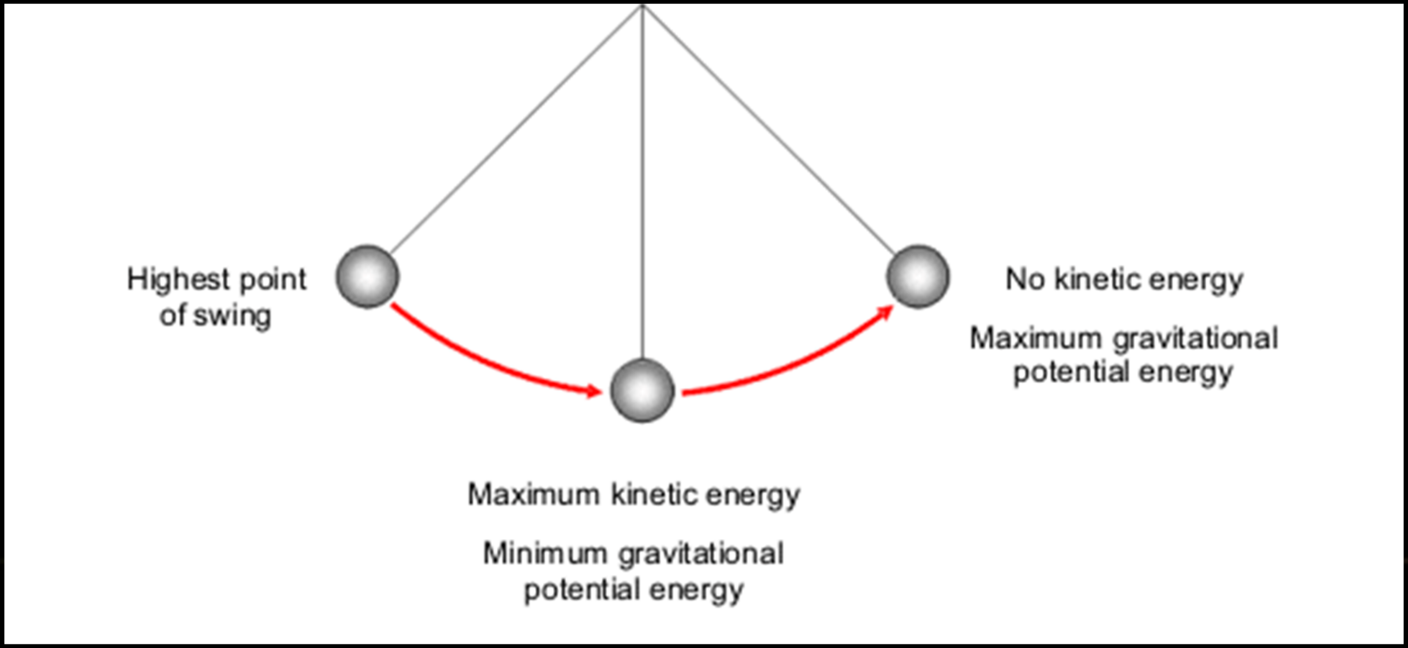


b A cloud of interstellar gas can contract because of its own gravity. It has more gravitational potential energy when it is spread out than when it shrinks in size.

Fig.4.12b

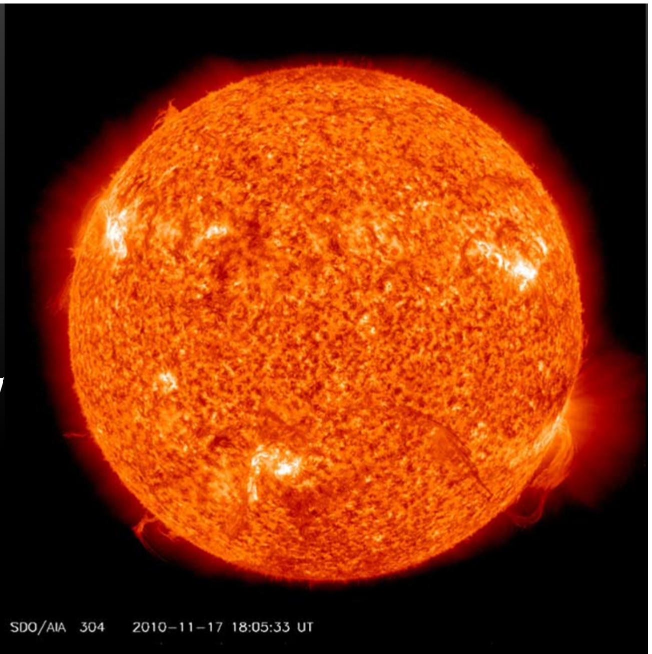
JUGGLING ENERGY…

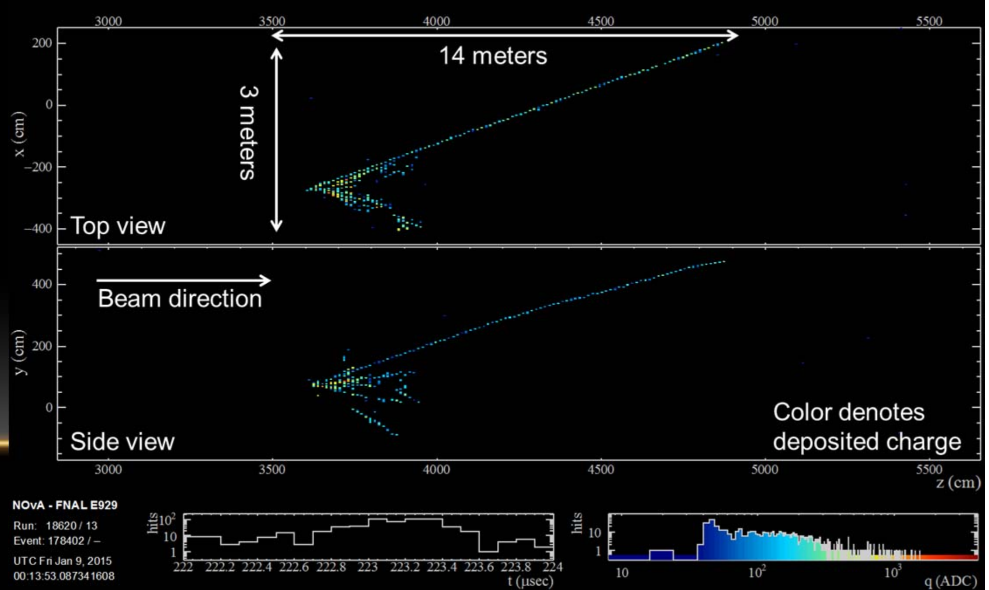
- We were talking about juggling energy between different sorts of energy…



MASS AND ENERGY

- Mass can be converted to energy
  - $E=mc^2$
  - Nuclear power, stars, etc
- And mass can be created from energy
  - Same formula: I see this all the time in my particle physics experiments





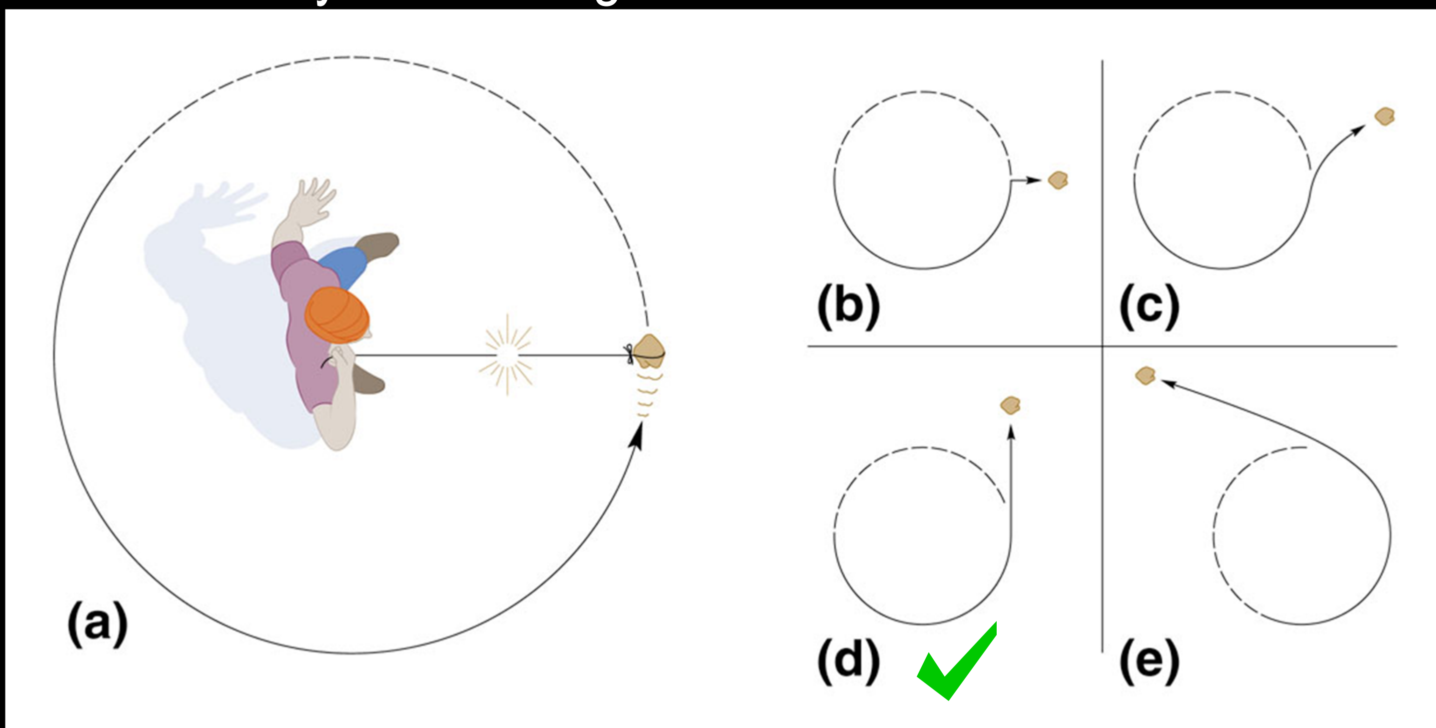
A neutrino interaction in
The NOvA experiment

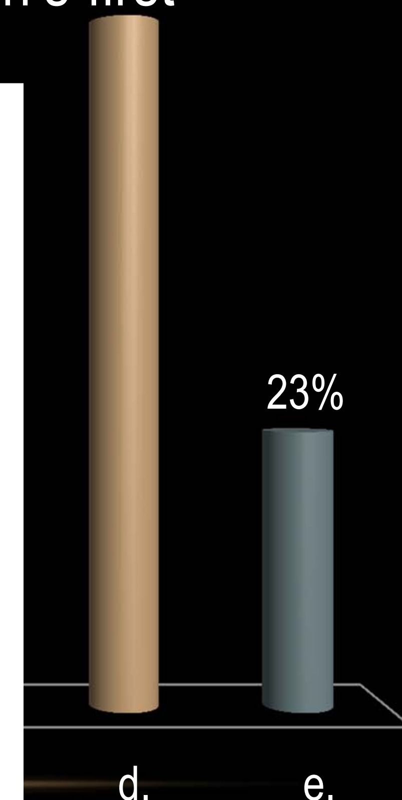
THESE "LAWS" WORK ON EARTH, BUT…

- After taking into account things like friction, Newton's Laws describe what happen around us very well
- How about the planets? Remember that Aristotle had different rules for Heavenly and Earthly things, does Newton know what's going on up there?

CIRCULAR MOTION

- Swing rock around on string
- You pull on the rock with a force through the string
- If you let go, then F=0 and a=0 – Where does Newton's first law says the rock goes?





ACCELERATION

- In this example, acceleration is changing the rock's direction (*thus velocity*), not it's speed
  - *Centripetal* force, the force needed to make something go in a circle
- Things don't change direction without being accelerated – and thus being acted on by some force

GRAVITY

- Newton's Law of Universal Gravitation:
  - Between any two objects there is an attractive force, the magnitude of which is directly proportional to the mass of each object and inversely proportional to the distance between the centers of the two objects

$$F = G\frac{m_1 m_2}{d^2}$$

GRAVITY

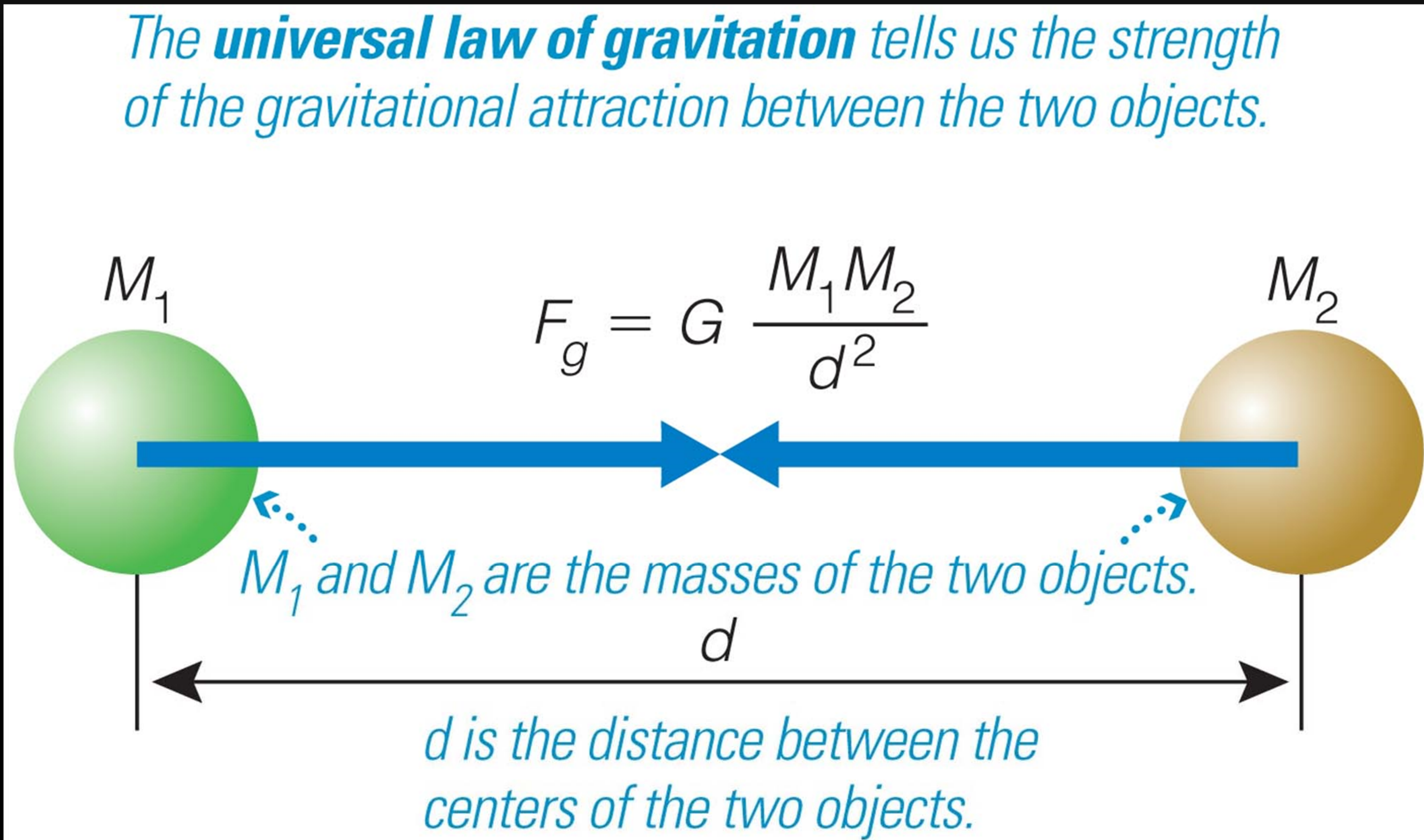
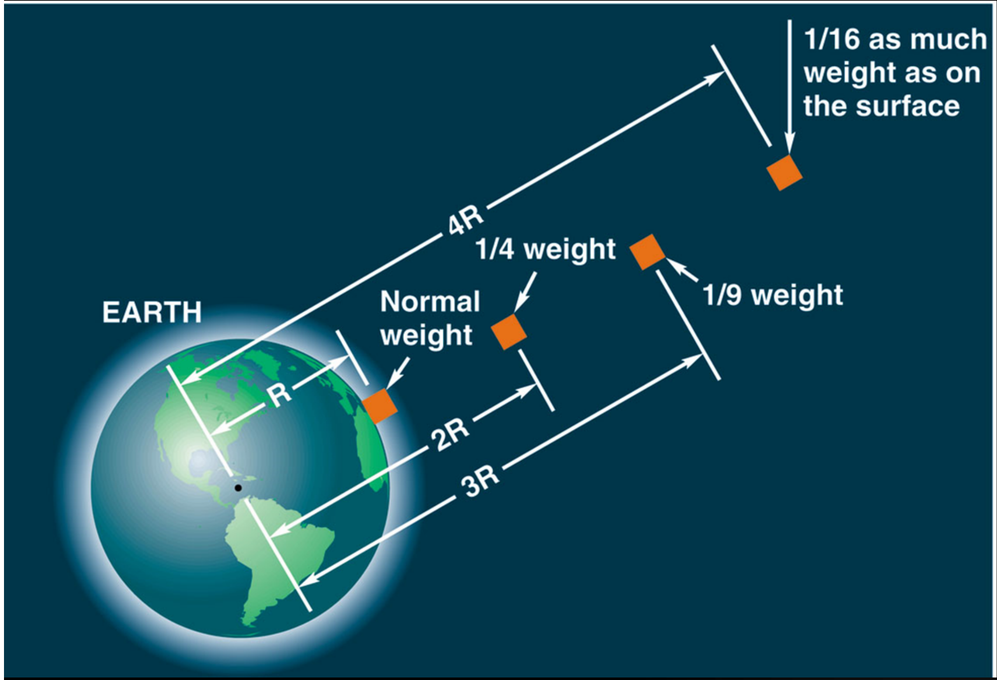


Fig.4.14

IN THIS ROOM?

- We don't feel ourselves being attracted to anything but the ground
- Look at the masses: if m_1 is you:
  - If m_2 is Earth, it's Real Big, and you feel your weight as this force going down
  - If m_2 is your neighbor, he's 150#/1.3x10^{25}# smaller than the earth
    - So his force on you is that much smaller

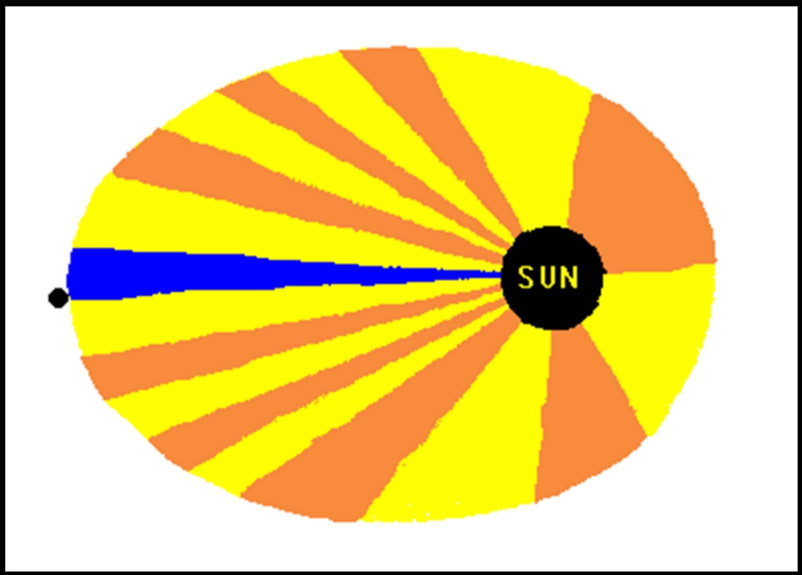
HOW TO TEST?



- Newton looked at the Moon
- Figured the Centripetal Force needed to make it go in a circle
- It's about 1/3600 of the gravitational acceleration we're feeling
- The Moon had been measured (by parallax) to be 60 Earth radii away
  - $1/60^2 = 1/3600$!

$1/d^2$

NEWTON AND KEPLER



$$p^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$$

- Kepler's laws had the planets moving in an ellipse with the Sun at one focus
- They move faster when closer to the Sun
- Newton says force of gravity is stronger then, so there is a larger acceleration
  - Explains Kepler's 2nd and 3rd laws

Generalizes 3rd law to any orbiting system!

Now we can "weigh" Jupiter, binary stars, etc