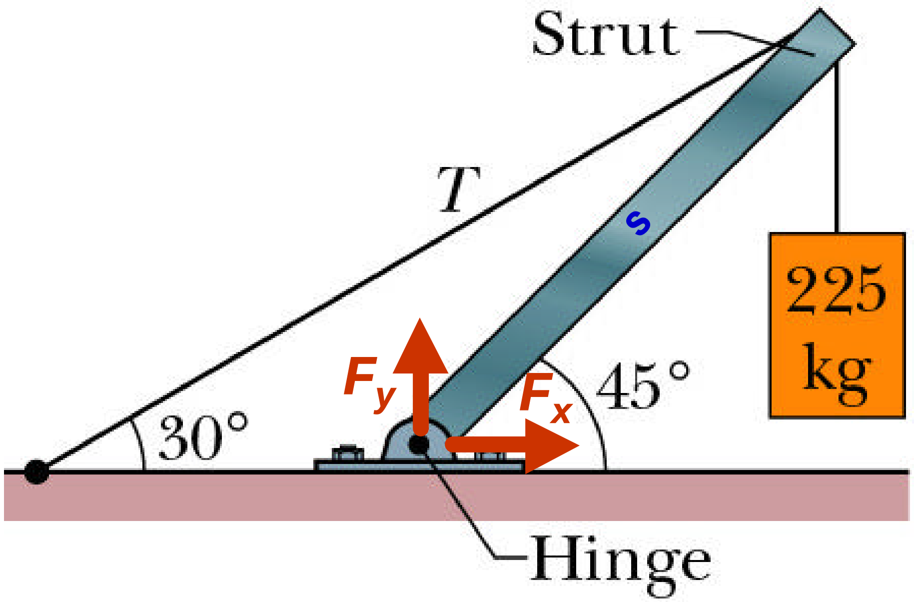
Remember

- **Midterm 2 to be taken one week from today**
- **Will cover mainly chapter 7 – 13**
  - **But understanding previous chapters may be needed**
- **Check website at **Exam Specifics for midterm 2**
  - **Practice exam and solutions**
  - **Exam Guide**
- **Important issue is to be able to do problems**

Today

- **Hand in HW 7**
- **Finish chapter 13 …**
  - **Ch 7 – 13 emphasized in midterm 2**
- **Go on to gravity**

Problem 13-25 (not assigned)



- **Strut M_s= 45kg**
  - Take length *s*
- **Find**
  - tension, *T*
  - Force components at the hinge

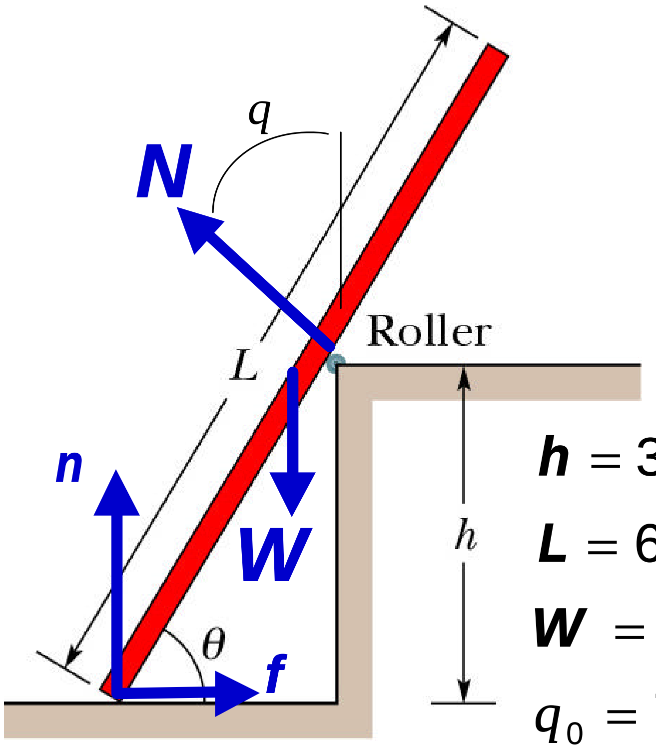
The system is in equilibrium. A concrete block of mass 225 kg hangs from the end of the uniform strut whose mass is 45.0 kg. Find

(a) **the tension T in the cable and the**

(b) **horizontal and**

(c) **vertical force components on the strut from the hinge.**

Problem 13-29 (not assigned)



$h = 3.05m$

$L = 6.10m$

$W = 445N$

$q_0 = 70°$

A uniform plank, with a length L of 6.10 m and a weight of 445 N, rests on the ground and against a frictionless roller at the top of a wall of height h = 3.05 m. The plank remains in equilibrium for any value of q > 70° but slips if q < 70°.

Find the coefficient of static friction between the plank and the ground.

- Frictionless at the roller
- Find that if $q<q_0$, the plank slips
- What is m_s for the plank contact with ground?

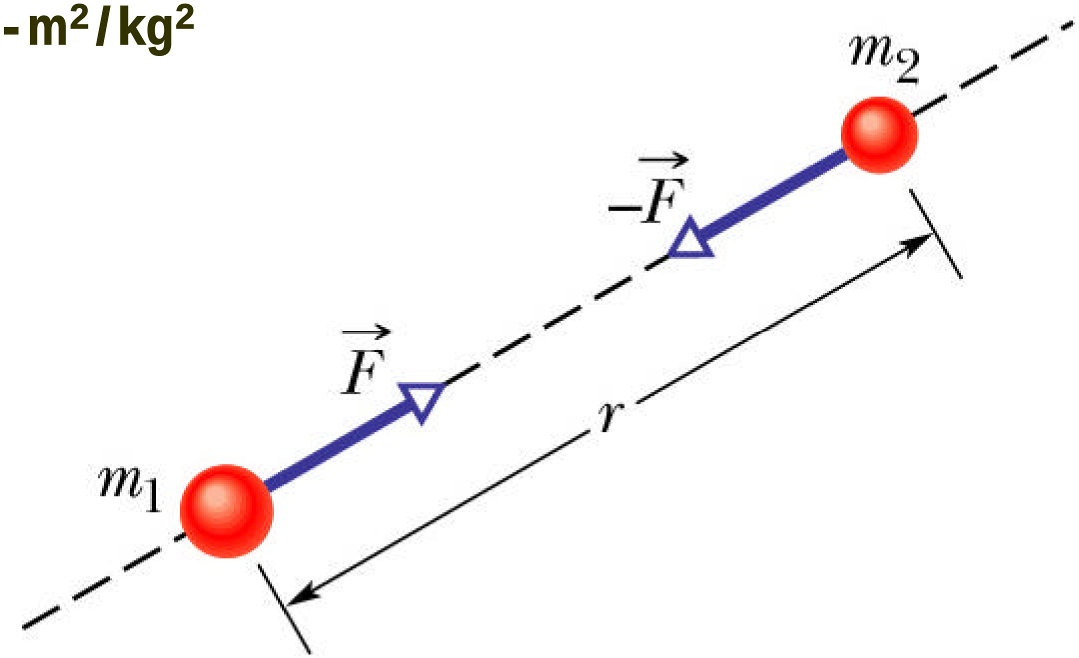
Ch 14 - Gravitation

- **Newton's great achievements of late 17th century science**
  - 3 laws of motion
    - To some extent, were re-statements by Galileo and others
  - law of universal gravitation
    - unique and important essential to complete the picture
- **Thus far, we have only seen the utility of Newton's Laws in describing everyday laws (on Earth's surface)**
  - investigated by many: Galileo, Toricelli, …
- **Truly earthshaking discovery was supplementing this with the Universal Law of Gravitation**
  - lots of competition: Hooke, …
  - explained astronomical descriptions of Solar system +

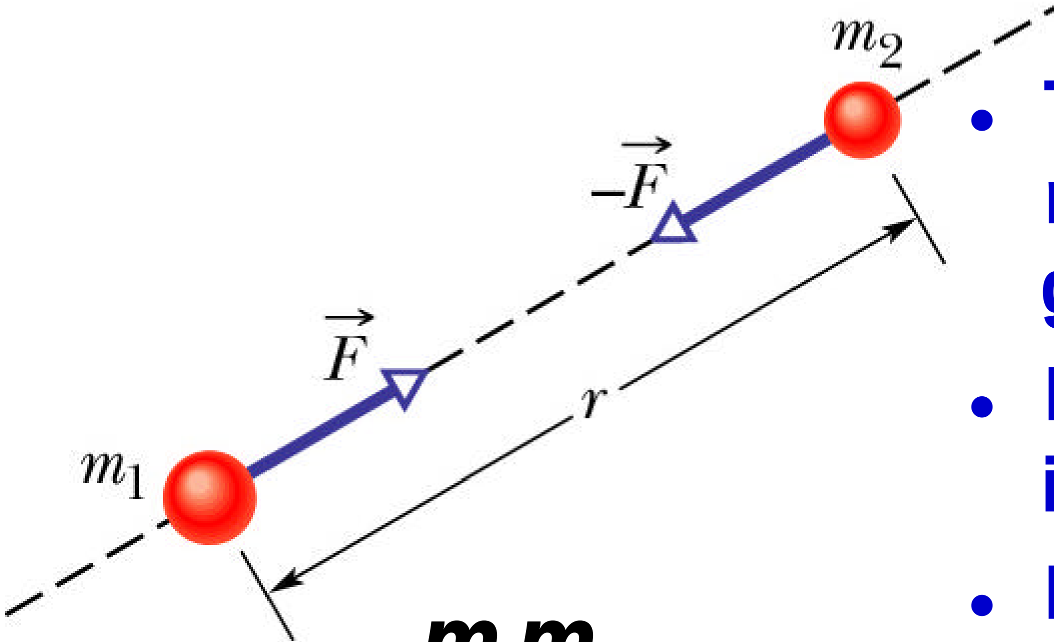
What is Gravity? (Newton)

- **Attractive force between any two mass elements of the universe; force is:**
  - always attractive
  - proportional to masses
  - inversely proportional to square of separation
  - dependent on a new universal constant, *G*
    - G = 6.67×10^{-11} N-m^2/kg^2

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



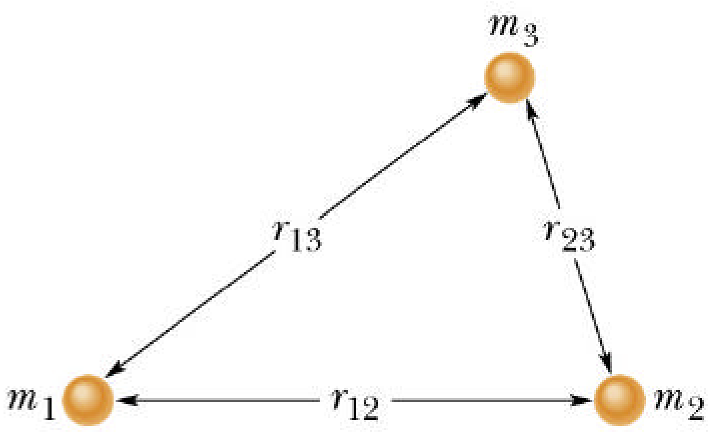
Gravity Potential Energy



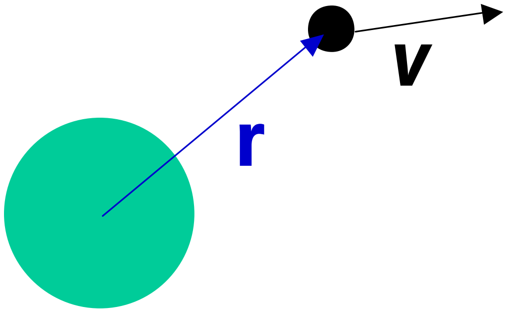
- This must be the right potential … it gives the right force
- Note path independence …
- Note text examples

$$U = -G\frac{m_1 m_2}{r}$$

$$F_r = -\frac{dU}{dr} = -G\frac{m_1 m_2}{r^2}$$



Energies of Any Body and Escape Velocity



- Note that *E<0* corresponds to <u>bound</u> body (planet, etc)
- *E>0* is <u>unbound</u> body
- Escape from surface of Earth requires *E > 0*

$$K = \tfrac{1}{2} mv^2$$

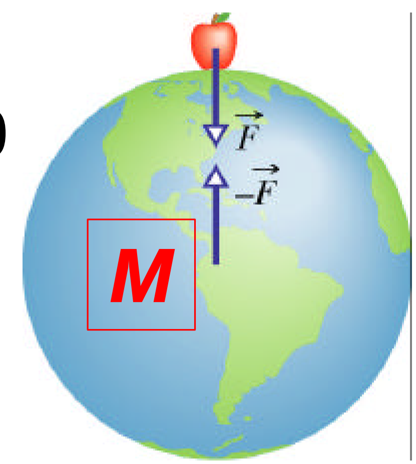
$$U = -G\frac{Mm}{r}$$

$$E = K + U = \text{const.}$$

$$E > 0$$

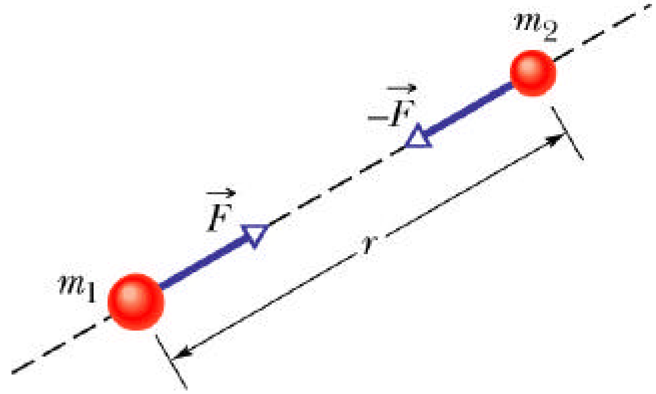
$$\tfrac{1}{2} mv_{esc}^2 - G\frac{Mm}{R} = 0$$

$$v_{esc} = \sqrt{\frac{2GM}{R}}$$



Applicability of Newton's Gravity

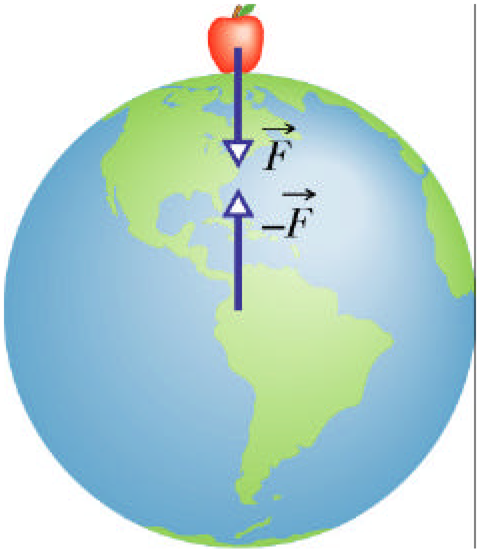
$$F = G\frac{m_1 m_2}{r^2}$$



- Still (with modifications from General Relativity) accepted as the basic force law
- Applies in <u>all</u> known circumstances
  - ◆ Earth's surface
  - ◆ Inside the Earth
  - ◆ Solar System
  - ◆ Grand Universe…

- Important general law of force
- Similar form for electricity, …

Gravity at surface of the Earth



$$G\frac{Mm}{R^2} = mg$$

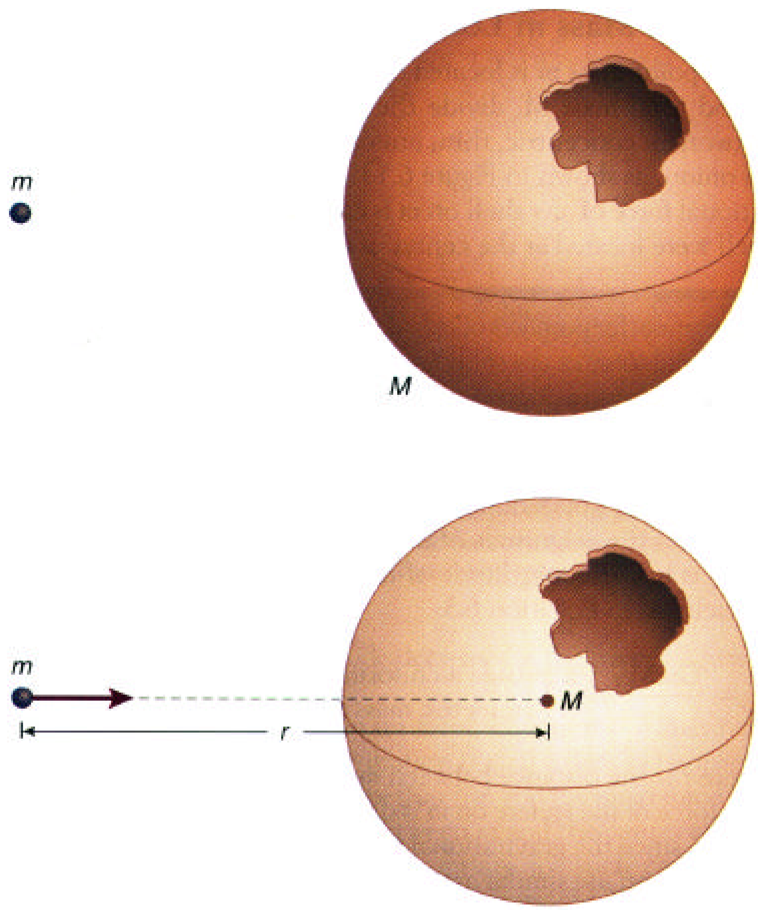
$$g = G\frac{M}{R^2}$$

M = *Earth mass*
R = *Earth radius*
G = *universal gravitational constant*

- Many subtleties
  - Density vs *r* (look into here)
  - Rotation of Earth (small)
  - slightly nonspherical shape
  - …
- ALL SMALL!!

- **Assertion**
  - All mass of Earth can be considered to be at the center when seen from outside
  - Can be proven!
  - Unexpected result for force on object inside Earth

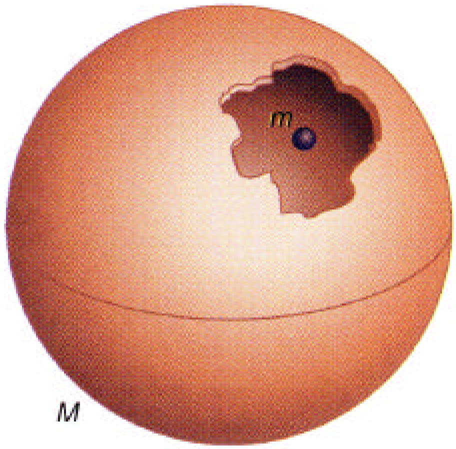
<u>Shell</u> of Mass from OUTSIDE



- **Force on *m* is as if <u>all</u> the mass *M* were concentrated at the center of the sphere**
  - ***ie*, at center of mass**

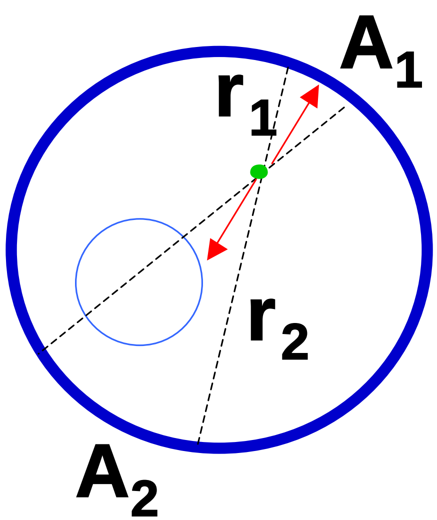
$$F = G\frac{mM}{r^2}$$

Shell of Mass from INSIDE



$$\frac{A_2}{A_1} = \frac{r_2^{\,2}}{r_1^{\,2}}$$

$$\frac{F_2}{F_1} = \frac{\frac{A_2}{r_2^2}}{\frac{A_1}{r_1^2}} = \frac{\frac{A_2}{A_1}}{\frac{r_2^2}{r_1^2}} = 1$$



- Forces on *m* from opposite pieces of surface cancel
- No net force on *m* INSIDE shell!

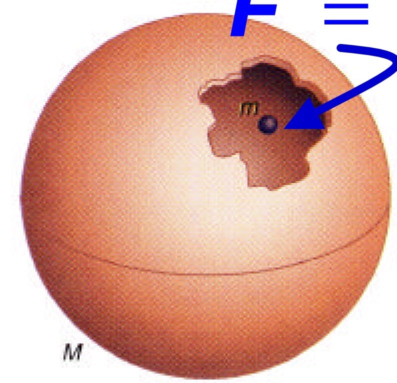
- cone through *m* intercepts the sphere in two places
- Area on shell surface intercepted by cone ~ r^2
- Magnitudes of forces on *m* by pieces of surface 1, 2

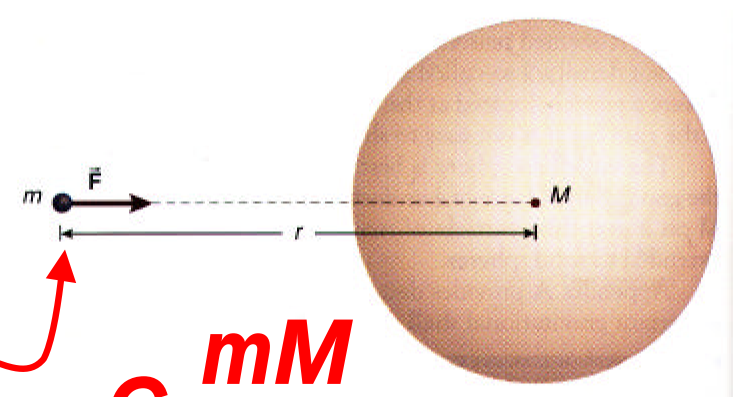
$$F_{1,2} = G\frac{mm_{1,2}}{r_{1,2}^{\,2}}$$

Shell of Mass from INSIDE and OUTSIDE

- **Summarize: for a uniform shell of mass**
  - Any mass <u>inside</u> feels <u>no</u> force
  - Any mass <u>outside</u> feels a force as if all of M were concentrated at center of the sphere (shell)
- **Can be proven in each case mathematically by integrating over all the mass in the shell**
  - Try if you like!

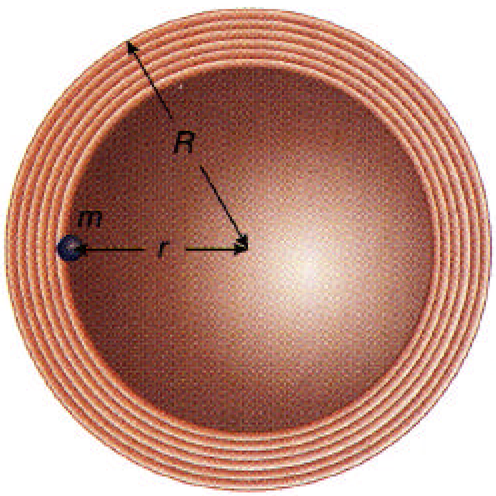
$F = 0$



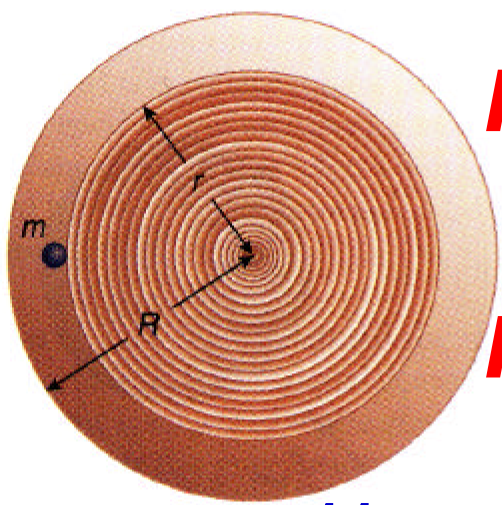


$$F = G\frac{mM}{r^2}$$

Consider Earth as continuous, uniform set of shells



- **Shells outside (*r>R*) contribute <u>NO</u> net force on *m***
- **Shells inside (*r<R*) act as if all their mass concentrated at the center**
- **Only that part of the Earth mass inside *r* is relevant to the force on *m***
- **Check out problem 14-23**



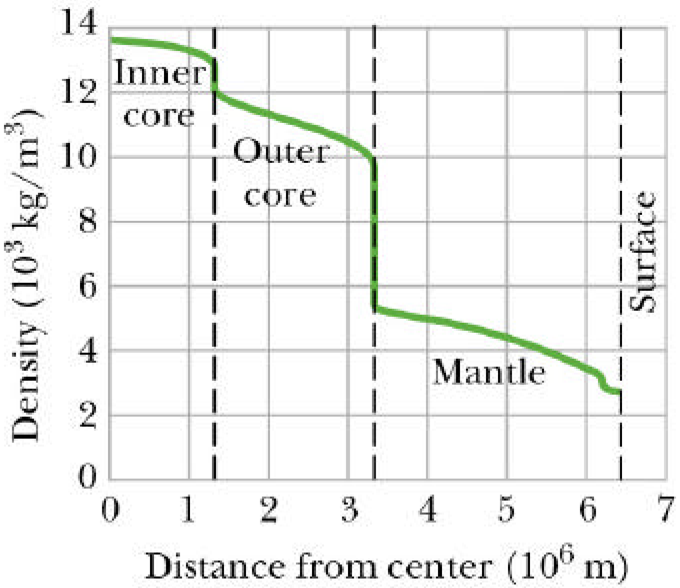
$$F = G\frac{mM_{inside\ m}}{r^2}$$

Actually Earth not uniform (next slide) but general point valid

$$F = G\frac{m}{r^2}M_{tot}\frac{\frac{4}{3}p\,r^3}{\frac{4}{3}p\,R^3} = \left[G\frac{mM_{tot}}{R^3}\right]r$$

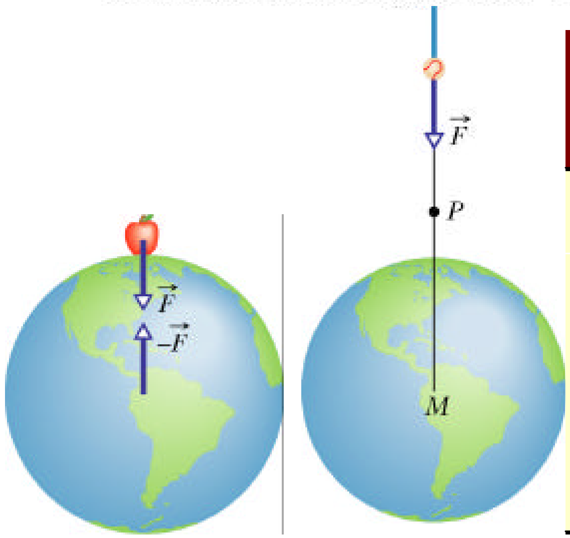
attractive to center … like spring force

Earth Structure and Empirical "Gravity"



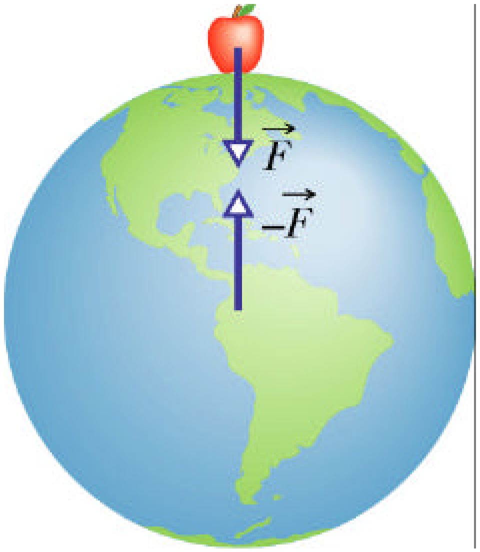
- **Radial dependence of density**
- **Earth rotation reduces effective "weight" but this effect is tiny (<.034m/s²)**
- **More important: gravitational force (and acceleration) decrease with R -- but need to go <u>very</u> high to see effect.**

$$R_{Earth} = 6370 \text{ km}$$



Altitude (km)	*a_g (m/s^2)*	*Altitude Example*
0	9.83	Mean Earth surface
8.8	9.8	Mt. Everest
36.6	9.71	Highest manned balloon
400	8.7	Space shuttle orbit
35 700	0.225	Communications satellite

Gravity at surface of the Earth



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