$h \ll R_e$

$$\frac{G M_e \cancel{m}}{R_e^2} = \cancel{m} g$$

$$G \simeq \frac{2}{3} \cdot 10^{-10} \frac{N m^2}{kg^2}$$

$$R_e \simeq 6380 \text{ km} = 6.38 \cdot 10^6 \text{ m}$$

$$g \simeq 9.8 \text{ m/s}^2$$

$$!! \quad M_e = \frac{g R_e^2}{G} = \frac{9.8 \cdot (6.38 \cdot 10^6)^2}{\frac{2}{3} \cdot 10^{-10}}$$

O.O.M. $\frac{10 \cdot 4 \cdot 10 \cdot 10^{12}}{\frac{2}{3} \cdot 10^{-10}}$ kg

$= 60 \cdot 10^{23}$

$\simeq 6 \cdot 10^{24}$ kg (10 moles of kg)

$= 5.98 \cdot 10^{24}$ kg

Measurement of G — Henry Cavendish

1797-8 — $\simeq 2\%$

John Michell built

2 350 lbs lead spheres

1.6 lbs

$$F = \frac{G M_e m}{r^2} \;;\; \frac{dF}{dr} = -\frac{2 G M_e m}{r^3}$$

$$|\Delta F| = \left|\Delta r \frac{dF}{dr}\right|$$

$$|\Delta F| = \frac{2 G M_e m}{r^3} |\Delta r|$$

$$\left|\frac{\Delta F}{F}\right| = \left|\frac{\Delta g}{g}\right| = 2 \frac{\Delta r}{r}$$

$$\frac{\Delta g}{g} \simeq -2 \frac{h}{R_e}$$

$h \leftarrow 1\ m$, $R_e \leftarrow 6 \cdot 10^6\ m$

1 part per million every 3 meters

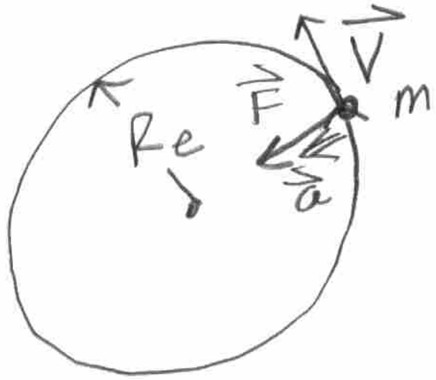
Remember $\frac{G M_e}{R_e^2} = g$

swap out !!

Example: circular orbits ...

LOW-EARTH : $r \simeq R_E$!

Low Earth Circular Orbit



$$\vec{F} = -\frac{G M_e m}{R_e^2}\hat{r}$$

$$\vec{a} = -\frac{V^2}{R_e}\hat{r}$$

Period T: $VT = 2\pi R_e$

$$T = \frac{2\pi R_e}{V}$$

Newton's 2ND Law

$$\vec{F}_{Net} = m\vec{a}$$

$$-\frac{G M_e \cancel{m}}{R_e^2}\hat{r} = -\cancel{m}\cdot\frac{V^2}{R_e}\hat{r}$$

$$V = \sqrt{\frac{G M_e}{R_e^2}\cdot R_e} = \sqrt{g R_e}$$

($\frac{G M_e}{R_e^2}$ = g)

$$T = \frac{2\pi R_e}{V} = \frac{2\pi R_e}{\sqrt{g R_e}} = 2\pi\sqrt{\frac{R_e}{g}}$$

$$\simeq 2\cdot\pi\cdot\left[\frac{6.4\cdot10^6}{10}\right]^{1/2} \simeq 6\cdot\left[64\cdot10^4\right]^{1/2}$$

$$T \simeq 6\cdot800 \simeq 4800\,s \simeq 1\text{ hr } 20\text{ minutes}$$

$$V = \frac{2\pi R_e}{T} \simeq \frac{\overset{2}{\cancel{6}} \cdot \overset{4}{\cancel{6400}}\ \text{km}}{\underset{3}{\cancel{4800}}\ \text{s}}$$

$$v \simeq 8\ \text{km/s} \quad (7.91\ \text{km/s})$$

$$\simeq 17{,}694\ \text{miles/hour}$$

Guns: $0.24 \to 1.8$ km/s

Springs: another force law.

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First Introduction — Hooke's Law

$$ma = m\ddot{x} = -kx$$

spring equation

$-$ sign: "restoring" force

kx: simple proportionality

Horizontal: