$G = 6.67 \times 10^{-11} \frac{N \cdot m^2}{kg^2}$ ← note units

Newton #3

$$\vec{F}_a = -\vec{F}_b = \left(\frac{G M_a M_b}{r^2}\right) \hat{r}_{ab}$$

$$\hat{r}_{ab} = -\hat{r}_{ba}$$

$$\vec{F}_a = -\left(\frac{G M_a M_b}{r^2}\right) \hat{r}_{ba} \qquad \hat{r}_{ba} = \frac{\vec{r}_a - \vec{r}_b}{r}$$

curiously...

$$M_a \vec{a}_a = \vec{F}_a \qquad M_b \vec{a}_b = \vec{F}_b$$

$$= \frac{G M_a M_b}{r^2} \hat{r}_{ab} \qquad = -\frac{G M_a M_b}{r^2} \hat{r}_{ab}$$

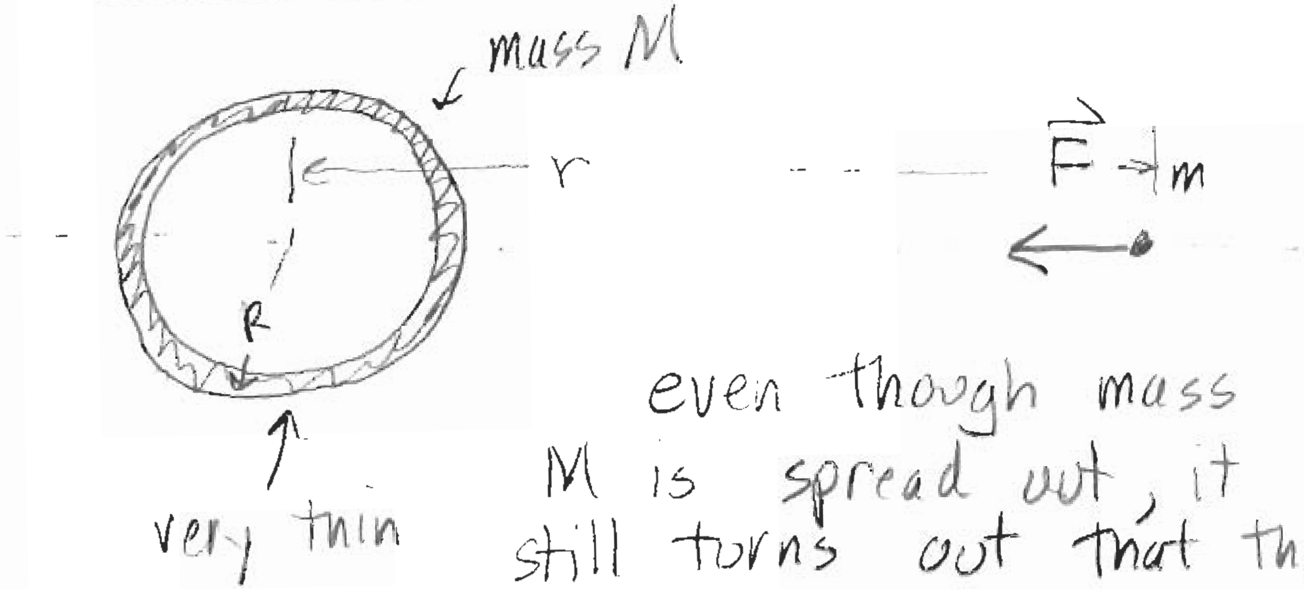
$$\vec{a}_a = \frac{G M_b}{r^2} \hat{r}_{ab} \qquad \vec{a}_b = \frac{-G M_a}{r^2} \hat{r}_{ab}$$

↑ independent of M_a ↑ independent of M_b

a's acceleration depends on r & M_b — vice versa

these "curve space"

Uniform Shell of Mass

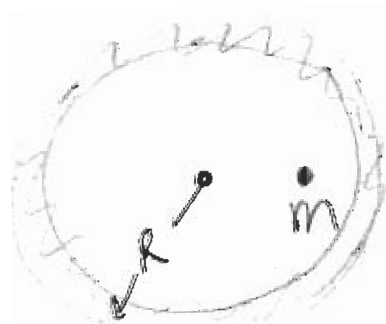


even though mass M is spread out, it still turns out that the force on m is the same as you'd get if M were concentrated at its center.. (as long as the shell is uniform and spherical) WHY? Calculus

$$\vec{F} = -G\frac{Mm}{r^2}\hat{r}$$

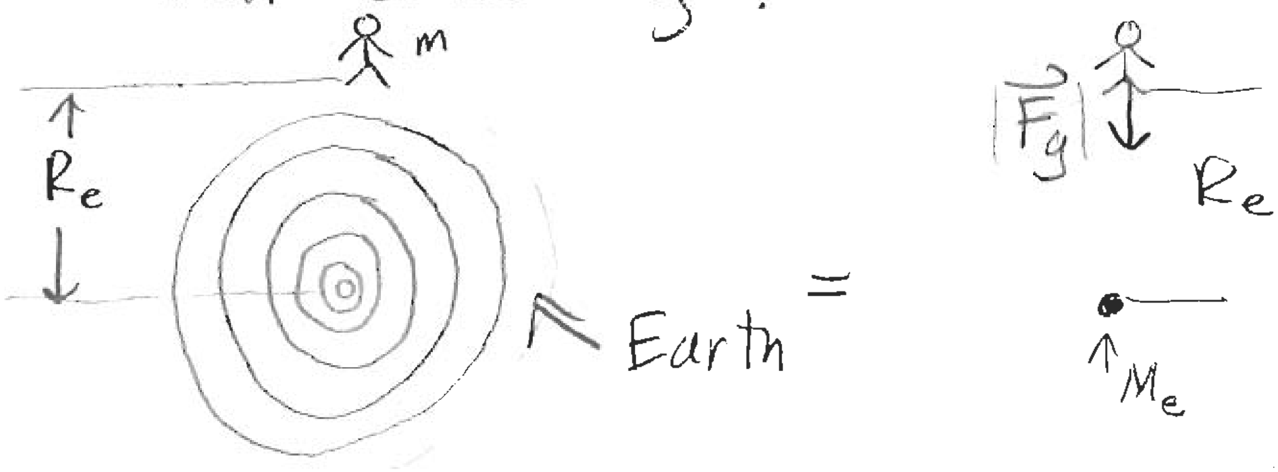
True as long as $r > R$

when $r < R$



when inside the spherical shell, (uniform mass), m feels **no** **force**!

What causes g?



$$|\vec{F}_g| = G\frac{M_e m}{R_e^2} = mg$$

Cavendish
$6.67 \cdot 10^{-11}$

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

$9.8 \frac{m}{s^2}$ (→ g)

$R_e = 6.37 \cdot 10^6 m$

$$M_e = \frac{(6.37 \cdot 10^6)^2}{6.67 \cdot 10^{-11}} \cdot 9.8$$

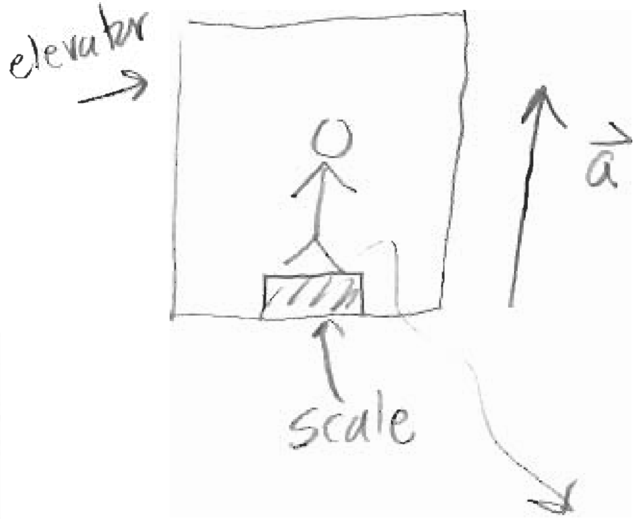
→ order of magnitude

$$\simeq \frac{(6 + \overset{.48}{2 \cdot 6 \cdot 0.4})^2 \cdot 10^{12}}{6.7 \cdot 10^{-11}} \cdot 10$$

$$\boxed{M_e \simeq 6 \cdot 10^{24}\ kg}$$

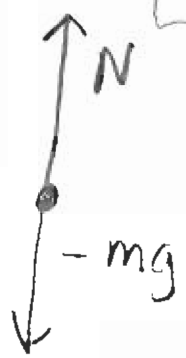
$\approx$ 10 moles of kilograms

A bit more about gravity



what do they read on the scale

⇒ SCALES MEASURE THE NORMAL FORCE



$$N - mg = ma$$

$$\boxed{N = m(g+a)}$$

Suppose: you weigh 100 lbs ← measure of force

note

$1 \text{ lb} = 4.45 \text{ N}$ ← $1 \text{ Newton} = \frac{kg \cdot m}{s^2}$

↑ not a measure of mass

English unit of mass = 1 slug

g in English ... 32 ft/s^2

$$1 \text{ pound} = 1 \frac{\text{slug} \cdot \text{ft}}{s^2}$$

so, if $a = 2 \text{ m/s}^2$

$$N = m(g+a) \ldots$$

$$W = 100 \text{ lbs} = mg$$

$$m = \frac{100}{g} = \frac{100}{32} = 3.13 \text{ slugs}$$

$$1 \text{ slug} = 14.6 \text{ kg}$$

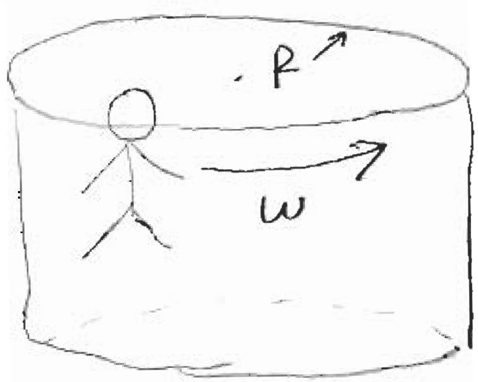
$$m = 3.13 \times 14.6 = 45.6 \text{ kg}$$

$$N = 45.6(9.8+2) = 539 \text{ N}$$

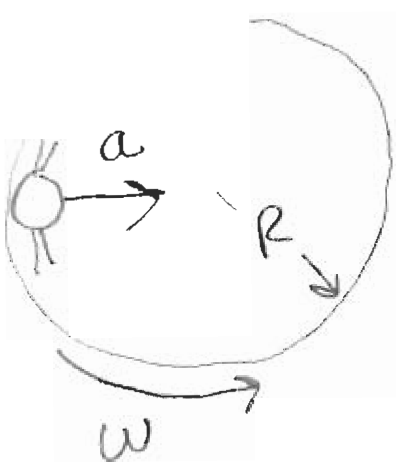
$$N = \frac{539 \text{ N}}{4.45 \text{ N/lb}} = 121 \text{ lbs}$$

Thing: suppose $a = -g$? $a = -2g$?

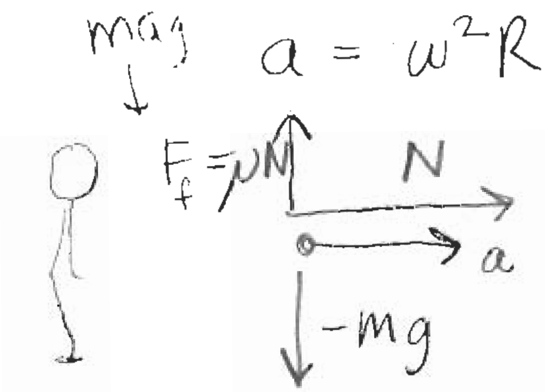
Spinning Terror

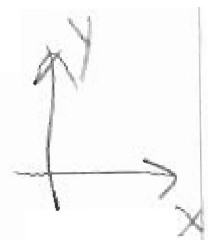


if ω big enough person sticks to the wall! How fast?



$$a = \omega^2 R$$





$$N = ma = m\omega^2 R \qquad \mu N - mg > 0$$