APB Giancoli

Ch4: Newton's Laws

1st Law $\Sigma\vec{F}=0 \Leftrightarrow \vec{a}=0$

$\Leftrightarrow$ ($\vec{v}=0$ static equilibrium
OR
$\vec{v}=$ constant dynamic equilibrium)
speed & dir, straight line

- Law of <u>Inertia</u> - stubborness
  - resistance to change in motion
  - property of matter
- <u>mass</u> is a measure of inertia

CISE:
- 1kg, elephant
- next time questions
- Burt equilibrium
- plane
- gymnast 1kg → 10N $w=mg$

CISE - PB

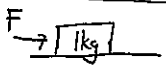
CISE cart

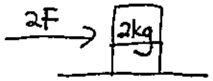
$F=ma$ & APC

$T\neq mg$

2nd Law $\Sigma\vec{F}=m\vec{a}$

$1N = 1kg\,m/s^2$

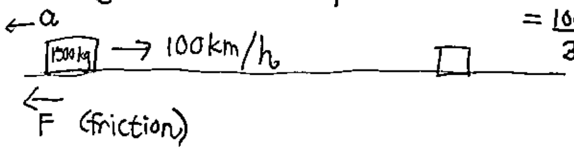




$\vec{a}=\frac{\vec{F}}{m}$

ex 3 car 1500kg

avg force to stop it from 100km/h in 55m?



$= \frac{100\,000\,m}{3600\,s} = \frac{250}{9}\,m/s = 27.8\,m/s$

$a \Rightarrow F$

$v_f^2 = v_0^2 + 2a\Delta x$

$0 = \left(\frac{250}{9}\frac{m}{s}\right)^2 + 2a(55m)$

$a = \boxed{-7.01\,m/s^2}$

$\Sigma F \overset{ma}{=} 1500kg \cdot -7.01\,m/s^2 = \boxed{-1.1\times10^4\,N}$

(estimate: $30m/s \to 0\,m/s$
$\bar{v} = 15\,m/s = \frac{50m}{\Delta t}$
$= \frac{\Delta x}{\Delta t}$
$\Delta t \approx \cancel{3}4s$
$a = \frac{\Delta v}{\Delta t} = \frac{30}{\cancel{5}4} \approx 7.5$)

3rd Law $\vec{F}_{H\,on\,T} = -\vec{F}_{T\,on\,H}$

- every action has an equal and opposite reaction
- always on <u>different</u> objects. Don't cancel out!

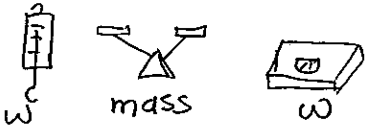
* see APC ~~rock~~ block & mason example

* about tension

- CISE
  - apple - earth pull same
  - horse - cart don't cancel
  - tension - Tarzan/horse, spring scale Ch3

4-6 Vocab

Question: measures?



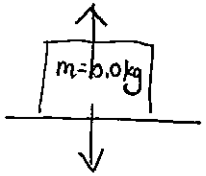
Weight

Support / normal force, apparent weight (spring scale reading)

tension

$g = 10\ m/s^2$

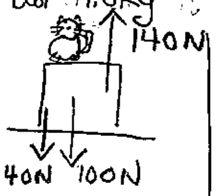
ex6



w = ? 100N

n = ? 100N

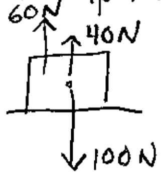
cat 4.0kg



w = 100N

n = 140N

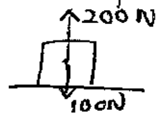
Pull up 40.0N



w = 100N

n = 60N

(ex7) Pull up 200N



What happens?

$\Sigma F = 100N$

$a = \frac{\Sigma F}{m} = 10\ m/s^2$ upward

ex8 Apparent weight

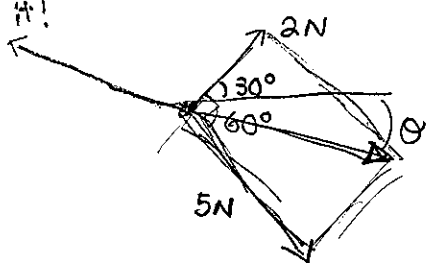
See APC Ch3 P1b cat in elevator

4.7 Free-body diagrams

- translational motion, consider as point particle

ex9 Use spring scales to show $\vec{F}$ vector addition works!

Try it!



$\Sigma F = \langle 2\cos30° + 5\cos60°, 2\sin30° - 5\sin60° \rangle$

$= \langle \sqrt{3} + \frac{5}{2}, 1 - \frac{5\sqrt{3}}{2} \rangle$

$= \langle 4.23, -3.33 \rangle$

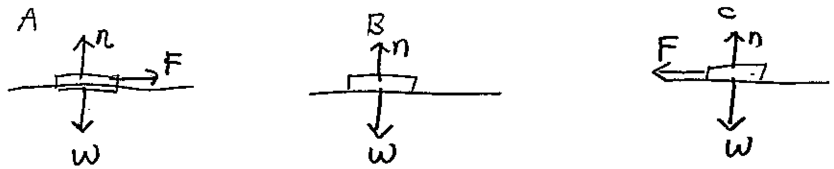
$F = \sqrt{28.98}\ N = 5.38N$

$\theta = 38°$

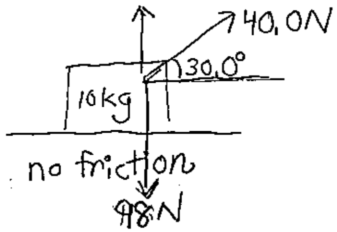
ex10 Hockey Puck on ice

Correct free-body diagram?

const. speed: B slowing down: C



- Problem-solve: 1) free body 2) $\Sigma F = ma$ & kinematic 3) x & y separately ex11



a) $\vec{a}$? b) $\vec{n}$? c) If pull harder, $\vec{n}$ will ↑ (↓) same?

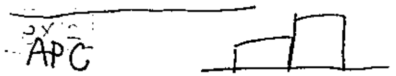
a)
$\Sigma F_y = 0$
$\Sigma F_x = ma_x$

$$a_x = \frac{40\cos 30^\circ}{10\,kg} = \boxed{3.46\,m/s^2}$$

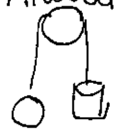
b) $40\sin 30^\circ + n = 98$ c)

$n = 98 - 40\sin 30^\circ$
$= \boxed{78.0\,N}$

APC



Atwood's machine

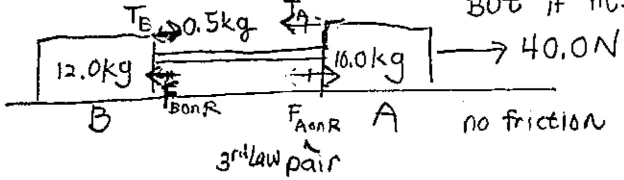


(like ex13)

Atwood

ex12

rope in equilibrium? No! (so if $m \neq 0$, $a \neq 0$, $T_{Right} \neq T_{Left}$)
But if $m = 0$, $\Sigma F = 0$



a) a_A ? a_B ? (same)

$\Sigma F = ma$

$$a = \frac{40}{22.5} = \boxed{1.78\,m/s^2}$$

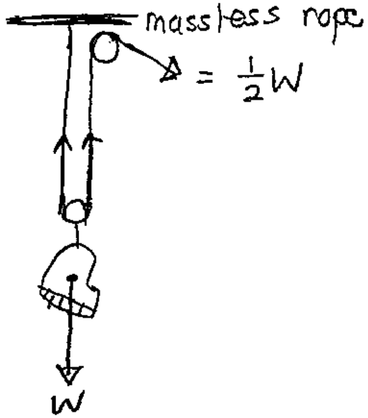
b) T_{right} ? T_{left} ?

$$\underbrace{T_A - F_{BonR}}_{0.84} \overset{\Sigma F}{=} \underbrace{(0.5kg)(1.78\,m/s^2)}_{0.89}$$
check OK

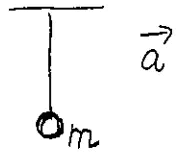
$F_{BonR} = T_B = m_B a_B$
$= 21.\bar{3}\,N$

$40 - T_A = \underset{17.8}{m_A a_A} \Rightarrow T_A = 22.\bar{2}N$

ex14 Pulley: less force, more distance
See CISE animated



ex15 Accelerometer



$\theta = ?$
a) when car $a = 1.20\,m/s^2$
b) when constant $v = 90\,km/h$
($\Sigma F = 0 \Rightarrow \theta = 0$)

$\Sigma F_y = 0$
$T\cos\theta = mg$

a) $\Sigma F_x = ma$
(left by inertia, $T\sin\theta$ is the pull that makes it move right with car)

$T\sin\theta = ma$

$\frac{\cancel{m}g}{\cos\theta}\sin\theta = \cancel{m}a$

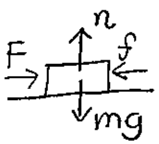
$\tan\theta = \frac{a}{g}$

$\theta = \boxed{\tan^{-1}\left(\frac{a}{g}\right)}$
$= 7.0^\circ$

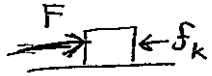
4.8 Friction & Inclines

not moving

$f=0$



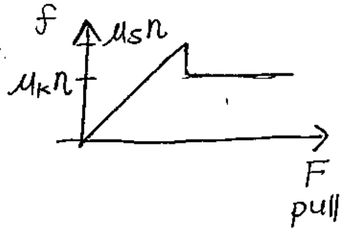
$f_s \le \mu_s n$



$f_k = \mu_k n \approx$ constant

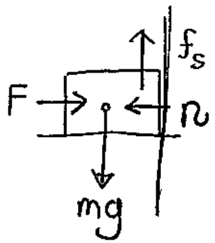
$\mu_k < \mu_s$

	μ_s	μ_k
wood on wood	0.4	0.2
ice on ice	0.1	0.03
rubber-dry concrete	1.0	0.8
joints in limbs	0.01	0.01



ex 17 $\mu_s = ?$, $m = 10.0\text{kg}$

Press box to wall with how much force to keep from slipping. $\mu_s \ge ?$
200N



$f_s = mg$

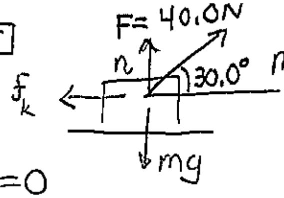
$\le \mu_s n$

$\mu_s \ge \frac{mg}{n}$

$\frac{100N}{200N} = 0.5$

(but $F\uparrow\ n\uparrow\ f_s\uparrow$??
No
$f_s \le \mu_s n$
NOT equal)

ex 18



$m = 10.0\text{ kg}$ $\quad \mu_k = 0.30$

$a = ?$

$\Sigma F_y = 0$

$n + F\sin\theta = mg$

$\Sigma F_x = ma$

$F\cos\theta - \underbrace{f_k}_{\mu_k n} = ma$

$$a = \frac{F\cos\theta - \mu_k(mg - F\sin\theta)}{m}$$

$$= \frac{\overset{34.6}{40\cos 30°} - 0.3\,(\overset{23.4}{10\times 9.8 - 40\sin 30°})}{10}$$

$$= \boxed{1.1\,m/s^2}$$

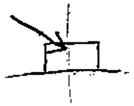
Bonus: constant velocity a) F in terms of weight, μ_k, θ
b) θ for F_{min}?

Ch5

Giancoli

-Already described in Ch 3 vectors 5-1 5-4 $\frac{v^2}{r}$ proof

ex19 Push or pull a sled?

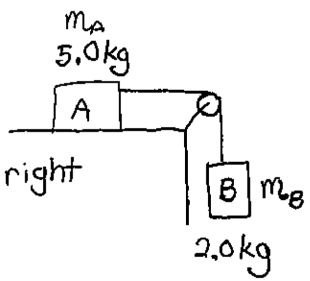


increases n, friction

$\Rightarrow F\uparrow$ to accelerate or maintain speed

$n\downarrow \Rightarrow f_k\downarrow \Rightarrow F\downarrow$

ex20



$\mu_k = 0.20$

moving right

$T = ?$

$a = ?$

$\Sigma F = Ma$

$m_B g - \mu_k (m_A g) = (m_A + m_B)\, a$

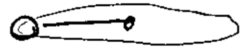
$\Rightarrow a = \boxed{1.4\ m/s^2}$

$m_B g - T = m_B a$

$\Rightarrow T = \boxed{17N}$

OR $T - m_A g \mu_k = m_A a$

ex1 R=0.600m



150g

2.00 rev/second

$a_c = ?\ \frac{v^2}{R} = \left(\frac{2\times 2\pi 0.6}{1s}\right)^2 \frac{1}{0.6}$

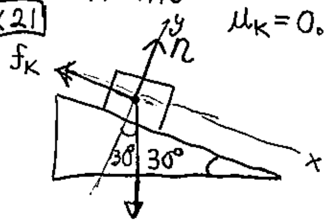
$= \boxed{94.7\ m/s^2}$ (m doesn't matter)

• Is there an outward force? No! (inertia)

It's ΣF to center that makes the curve

ex3 $T = m a_c$ to center $= 0.15\times 94.7 = \boxed{14.2\ N}$

ex21 Incline



$\mu_k = 0.10$ sliding down

$a = ?$

$\Sigma F_y = 0$

$n = mg\cos\theta$

$\Sigma F_x = ma$

$\cancel{m}g\sin\theta - \mu_k(\cancel{m}g\cos\theta) = \cancel{m}a$

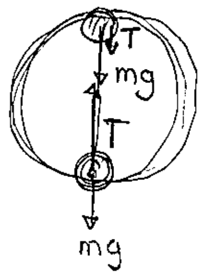
$a = g(\sin\theta - \mu_k\cos\theta)$

$= 9.8\left(\frac{1}{2} - 0.1\,\frac{\sqrt{3}}{2}\right)$

$= \boxed{4.1\ m/s^2}$

<u>Vertical Circles</u>

ex4 • Ball on string. m, R



a) v_{min} to continue in arc?

$\Sigma F_R = mg = m\frac{v^2}{R}$

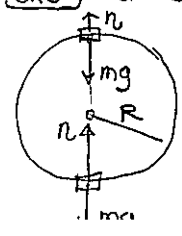
$v_{min} = \boxed{\sqrt{gR}}$

b) T_{bottom}?

$T - mg = m\frac{v^2}{R}$

$T = \boxed{m\left(g + \frac{v^2}{R}\right)}$

ex5 Ferris wheel



R given

a) n_{Top}?

c) v_{max} to prevent flying off?

b) n at bottom?

a) $mg - n = m\frac{v^2}{R}$

$n_T = m\left(g - \frac{v^2}{R}\right)$

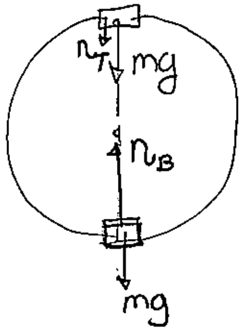
b) $n - mg = m\frac{v^2}{R}$

$n_B = m\left(g + \frac{v^2}{R}\right)$

c) $v_{max} = \sqrt{Rg}$ ΣF... $\Rightarrow$ negative n (seatbelt to hold down)

APB Ch4 5 P3

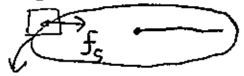
(a) Loop-the-loop rollercoaster



a) n_T b) n_B c) v_{min} to keep from falling out? (same as tension example)

5-3 (Banked) Curves

ex6 1000kg m $R = 50m$



$v = 15 m/s$ constant

Will it skid?

a) $\mu_s = 0.60$ (dry pavement)

b) $\mu_s = 0.25$ (icy)

a) No

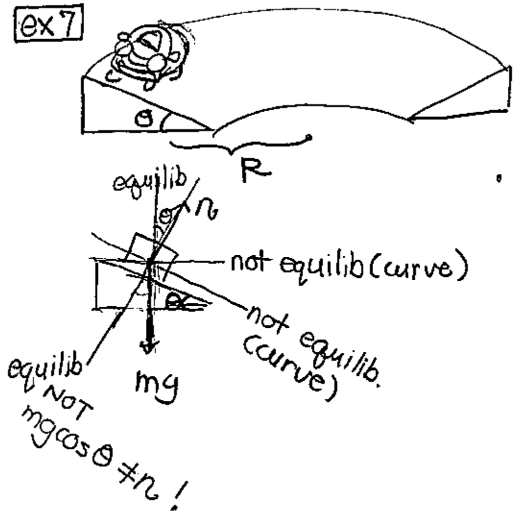
b) yes

$\Sigma F_r = m a_r$

$\underbrace{\mu_s \cancel{m}g}_{\text{max force possible}} = \cancel{m}\frac{v^2}{r}$

$\mu_s \geq \frac{v^2}{rg} = \frac{15^2}{50 \times 9.8} = 0.459$

ex7



Banked Curve

No friction needed

($\vec{n}$ pushes radially)

- Find θ for constant v, R

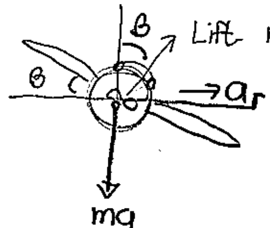
$\Sigma F_n = 0$ $\qquad \Sigma F_R = m\frac{v^2}{R}$

$mg = n\cos\theta$ $\qquad n\sin\theta = m\frac{v^2}{R}$

$\hookrightarrow \cancel{m}g\tan\theta = \cancel{m}\frac{v^2}{R}$

$\theta = \boxed{\tan^{-1}\left(\frac{v^2}{gR}\right)}$

Banked Curves in Airplanes - See APC



Lift makes it curve $\vec{a}_c$. Q) when $\beta = 84°$, black out?

Pilot's apparent weight

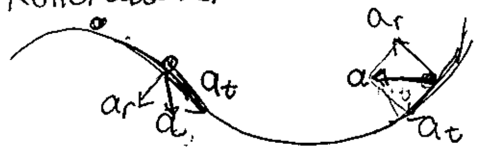
$L\cos\beta = mg$

$n = L = \frac{mg}{\cos\beta} = 9.6\,mg$ yes

heart can't pump blood to brain

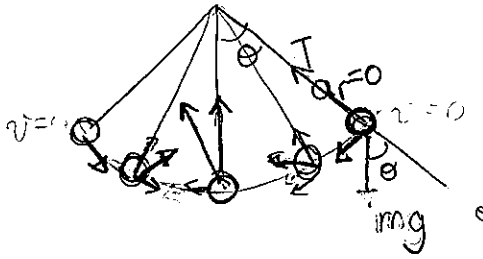
5-4 Nonuniform Circular Motion

Rollercoaster



$\vec{a} = \vec{a}_t + \vec{a}_r$

Pendulum Bonus in Test 1



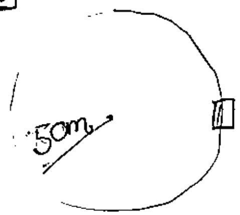
$\sim \vec{a} \neq m\vec{g}$

$\vec{a} = \vec{a}_t$

equilibrium (no component of $\vec{a}$ in that dir)

$\Rightarrow T = mg\cos\theta$

ex8



0 ~ 15 m/s in 5 s

a) $a_t = ?$

b) $a_r = ?$ when $v = 15\,m/s$

c) $a = ?$ when $v = 15\,m/s$?

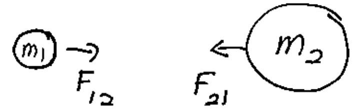
$\cdot\ a_t = \frac{15\,m/s}{5\,s} = 3.0\,m/s^2$

$a_r = \frac{15^2}{50} = 4.5\,m/s^2$

$\Rightarrow a = \sqrt{9 + 4.5^2} = \boxed{5.4\,m/s^2}$

5-5 Newton's Universal Law of Gravitation

$\vec{F}_g = -G\,\frac{m_1 m_2}{r^2}\,\hat{r}$



equal & opposite. Attractive.

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

- inverse square law
- for uniform sphere, same as if all mass at CM
- Cavendish experiment found G

HW Bonus (Read book)

(B1) How did Newton figure out $F_g \sim \frac{1}{r^2}$?

Show calculations

Ch5 (ex4) Moon goes around Earth every $T = 27.3$ days

1.48 Earth Moon distance $R_{EM} = 384000$ km

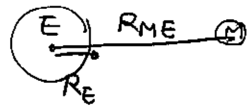
(Hipparchus lunar eclipse? (B2) parallax? -trigonometry)

- 1st Earth's circumference

(B3) Eratosthenes

$$a_c = \frac{v^2}{r} = \frac{\left(\frac{2\pi \times 3.84 \times 10^8\,m}{27.3 \times 24 \times 3600\,s}\right)^2}{3.84 \times 10^8}$$

$$= 2.72 \times 10^{-3}\,m/s^2$$



$$a_c = \frac{2.7 \times 10^{-3}}{9.8}\,g = \frac{1}{3600}\,g$$

$$\frac{R_E}{R_{EM}} = \frac{6380\,km}{384000\,km} \approx \frac{1}{60}$$

$R_{ME} = \frac{1}{60} R_E$

$\Downarrow$

$F_M \sim \frac{1}{60^2} F_E$

$\Rightarrow$ further, gravity drops by $\frac{1}{r^2}$

$\therefore\ F_g \sim \frac{1}{r^2}$

(B4) How did Cavendish measure G (diagram)

(Q) a) Why is $g = 9.80\ m/s^2$? $\quad g = G\frac{m_E}{R_E^2}$

b) How scientists figured out M_E (Cavendish was first once G was measured, R_E already known, g by dropping)

$$m_E = \frac{gR_E^2}{G} = \frac{9.80 \times (6.38 \times 10^6 m)^2}{6.67 \times 10^{-11}}$$

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

$\boxed{ex 9}$ Attraction between 50kg & 70kg on a bench

$r \approx 0.5m$ (from CM, side by side)

$$F_g = G\frac{m_1 m_2}{r^2} \approx 10^{-6} N$$

(Q) $$g_{Moon} \stackrel{?}{=} \frac{G\frac{M_M}{R_M^2}}{9.80}\ g_{Earth}$$

$$= \frac{1}{6}\ g_{Earth}$$

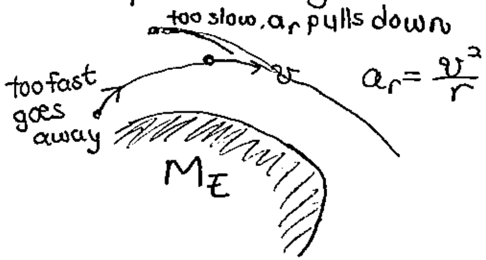
@ CISE Ch7 @

(• Weight of Space shuttle on Earth is W (big)
• Weight in orbit 200 km above Earth? 94%)

Space Shuttle orbits at 200km above Earth's surface

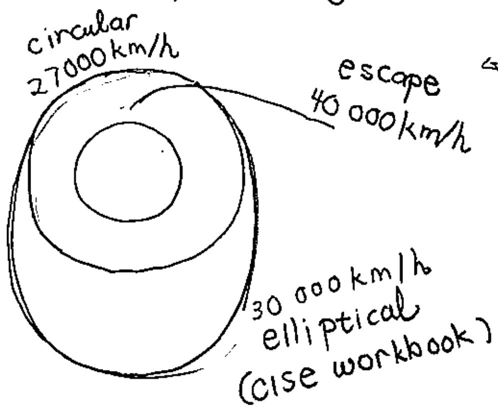
a) Why are astronauts floating?

- Not 0 gravity. They're falling around the Earth.
- See CISE pictures. Speed is fast enough to match curvature.
- If $v=0$, would drop down
  (speed v by launch & inertia keeps it going)



$a_r = \frac{v^2}{r}$

Launch speed /angle? escape?



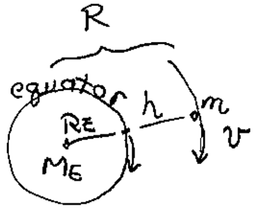
elliptical. How to calculate??

b) Is the weight up there 0%? 100%? (94%)

$$\% = \frac{\cancel{G}\frac{m_E}{(r_E+h)^2}}{\cancel{G}\frac{m_E}{r_E^2}} = \left(\frac{r_E}{R_E+h}\right)^2 = \left(\frac{6.38\times10^6}{6.38\times10^6+2\times10^5}\right)^2 = 0.94$$

ex12 Geosynchronous satellite

- only if... above equator



a) altitude?

b) speed of satellite? $F_g = G\frac{M_E m}{r^2}$

c) compare to speed of satellite 200 km above Earth's surface $v \propto ?\ r$

a) $G\frac{M_E}{r^2} = \frac{v^2}{r}$ ← match Earth rotation

$$G\frac{M_E}{R} = \left(\frac{2\pi R}{24\times 3600\,s}\right)^2$$

$$R^3 = G M_E\left(\frac{24\times 3600}{2\pi}\right)^2 \Rightarrow R = 4.22\times10^7\,m$$

$R_E + h$ 6.67×10^{-11} 5.98×10^{24} 4 22.000 00 (42 200 km)

$$h = R - R_E = \boxed{36\,000\ km}$$

6.38×10^6 = 6 380 km

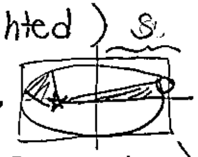
h_2 = 200 km

b) $v_{Geo} = \frac{2\pi R}{T_{day}} =$ OR $\sqrt{\frac{GM_E}{R}} = \boxed{3070\ m/s}$

c) $v_{200\,km} = \sqrt{\frac{GM_E}{R_E+2\times10^5}} =$ OR $v \sim \sqrt{\frac{1}{r}} \Rightarrow \frac{v_2}{v_{Geo}} \sim \sqrt{\frac{r_{Geo}}{r_2}}$

$$v_{200\,km} = v_{Geo}\sqrt{\frac{r_{Geo}}{r_{200km}}} = 3070\sqrt{\frac{42\,200\ km}{6580\ km}} = \boxed{7770\ m/s}$$

5-8 Keplar's Laws (1600) - Not just SUN-planet. Earth-Moon etc.
(from Tycho Brahe's data, Keplar was nearsighted)



① elliptical orbit with Sun at one focus

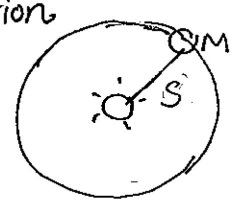
② same time, same area (conservation of angular momentum $\Sigma\tau = 0$ since $F_g \perp$ motion)

③ T = period of planet $T \sim s^{3/2}$
a = semi-major length

-1650 - Newton math - see wikipedia derived the Laws from $F_g = ma$ polar

$$\left(\frac{T_1}{T_2}\right)^2 = \left(\frac{s_1}{s_2}\right)^3$$

Derived for Uniform Circular Motion



$$\Sigma F = ma$$

$$G\frac{M_s \cancel{M}}{s^{\cancel{2}}} = \frac{\cancel{M}}{\cancel{s}}\left(\frac{2\pi s}{T}\right)^2$$

$$G\frac{M_s}{s} = \frac{4\pi s^2}{T^2} \Rightarrow T^2 = k s^3$$

$$\therefore T \sim s^{3/2}$$

ex4 Msun? $R_{ES} = 1.5\times10^{11}\ m$ (85) How to measure R_{ES}?

$$M_s = \frac{4\pi^2 s^3}{G T^2} = \frac{4\pi^2 (1.5\times10^{11})^3}{6.67\times10^{-11}(365.25\times24\times3600)^2}$$

$$= \boxed{2.0\times10^{30}\ kg}$$

* Deviations from Keplar (perturbations) due to other planets attracting ⇒ led to discovery by telescope of Neptune, Uranus, (Pluto)

• Moon rises an hour later each day. $T = 24h, 50min$

$\boxed{5\text{-}10}$ Four Fundamental Forces in Nature

1) Gravitational ~ celestial
2) Electromagnetic ~ contact force, chem
3) Strong nuclear force (proton / neutron)
4) Weak nuclear force (supernova energy given off)

neutron ○ ~ ⊕ & energy →
⊖ → beta decay

• 1960s electroweak theory
• Hope for GUT grand unified electroweak & strong
TOE theory of everything - all four