Mon Aug 27, 2012

Memory stick! + iPhone

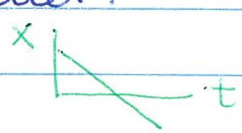
Dr. Michael Dubson & Prof Dan Dessau
This is phys 1110
Calc-based physics 1 for engineers
(Phys 2010 = algebra-based physics 1 for Life-Sci Majors)

$\boxed{\text{www.colorado.edu/physics/phys 1110}}$

- READ online lecture notes and text for Ch. 2
- Attend your recitation sec on Weds or Thurs
- SmartPhysics Prelecture & CheckPt due Fri Aug 31 8am (morning!)
- CAPA Set 1 due ~~X~~ Tues, Sept 4, at 10 pm

Introduce Dan
Show Texts
Clickers BA 3 fun CTs
Who was greatest physicist? CAPA tutorial
SmartPhysics Tutorial Demo daniel.dessau@colorado.edu

Recipe for Success
Learning = Communication = think/write
1st Tutorial activity.
Talk to neighbors!
CT 1-1 1-2 1-3
Practice quiet. 1-5 1-6 Both silently!
CT 2-2

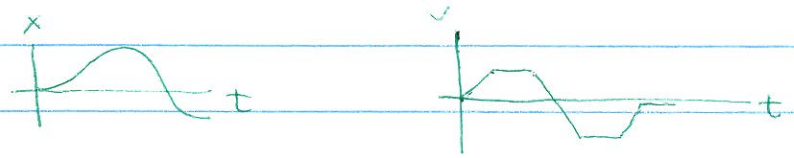


air track

Weds ~~A~~ Aug 29

- www.colorado.edu/physics/phys 1110
- READ Ch. 2 (online notes and/or text)
- Attend recitation today or tomorrow
- SmartPhysics due Fri 8 am (Sign up for DEMO vers!)
- CAPA due Tues nite, 10 pm

CT 2-5



1D Motion: Speed, Velocity, Acceleration

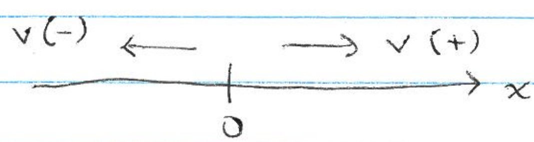
speed = $\dfrac{\text{dist. traveled}}{\text{time elapsed}}$, $s = d/t$, $s, d, t > 0$

$[s]$ = m/s, km/hr, mph, etc

average speed = $\dfrac{\text{total dist. traveled}}{\text{total time elapsed}}$

2-1a avg speed = $\dfrac{100 \text{ km}}{2.5 \text{ hr}}$ = 40 km/hr

velocity = speed AND direction



avg velocity $\bar{v} = \dfrac{\Delta x}{\Delta t}$

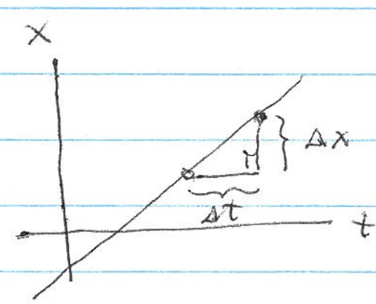
$\bar{v} = \dfrac{x_2 - x_1}{t_2 - t_1}$

$\Delta t = t_f - t_i > 0$ always

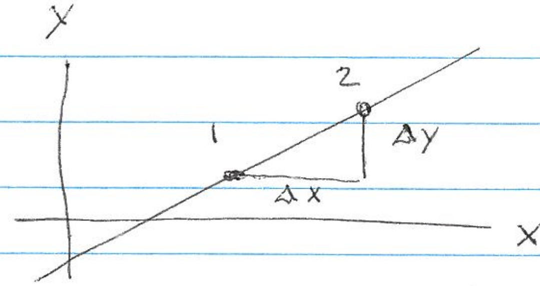
$\Delta x = x_f - x_i$ (+) or (−) or 0

2-1b $\bar{v} = 0$

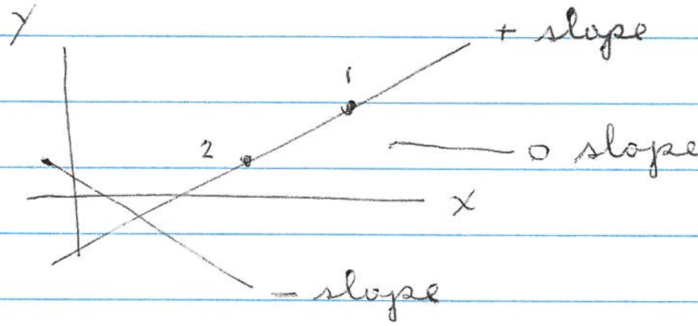
$\bar{v} = \dfrac{\Delta x}{\Delta t}$ ≡ slope of x vs. t

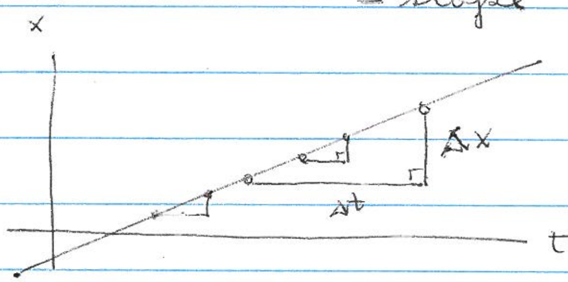


Slope



$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1}$$



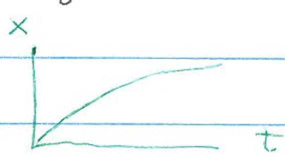


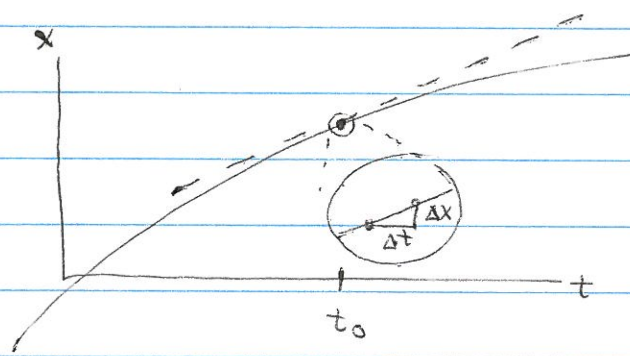
x vs t = straight ⇒

$\bar{v} = \frac{\Delta x}{\Delta t}$ = const ind of Δt

⇒ avg v = $\bar{v}$ = instantaneous v at any t

CT 2-4





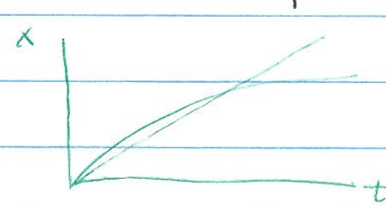
instantaneous v at $t = t_0$

$$v(t_0) = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$$

= slope of tangent line

$$v(t_0) = \frac{dx}{dt}$$ = time rate of change of position

2-5 again 2-6



acceleration = time rate of change of velocity

$$a = \frac{dv}{dt} = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \text{slope of tangent of } v \text{ vs } t$$

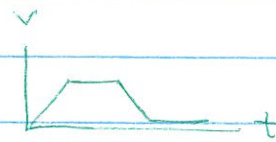
units $[a] = \frac{[v]}{[t]} = \frac{m/s}{s} = m/s^2$

$v = \text{const} \iff a = 0$

$v \nearrow \iff a > 0$

$v \searrow \iff a < 0$

2-7

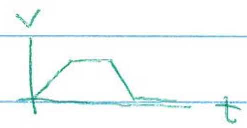


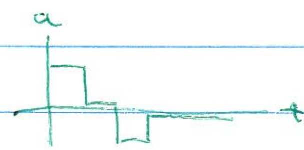
- Air track + block ①
- Catwalk : ball drop
- Paper + book

Fri Aug 31

CAPA Set 1 due Tues nite 10 pm
(auto extension to 8am Weds if miss ~~due~~ deadline

CAPA Set 2 out now

(2-7) 



1D Motion

velocity $v = \frac{dx}{dt} = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$ = slope of x vs. t

$v \simeq \frac{\Delta x}{\Delta t}$

acceleration $a = \frac{dv}{dt} \simeq \frac{\Delta v}{\Delta t}$ = slope of v vs. t

$a = 0 \iff v = \text{const}$

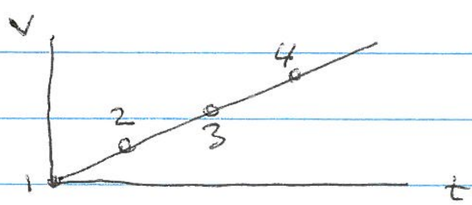
$a > 0 \iff v \nearrow$

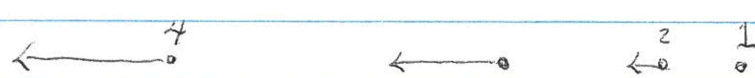
$a < 0 \iff v \searrow$

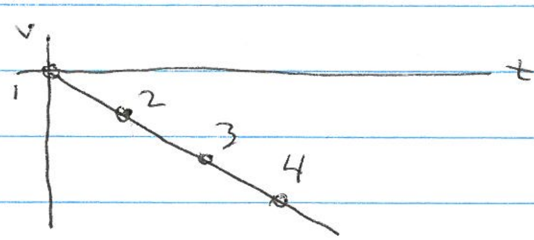
$\boxed{\text{Constant Acceleration}}$

Show w/ tilted air track

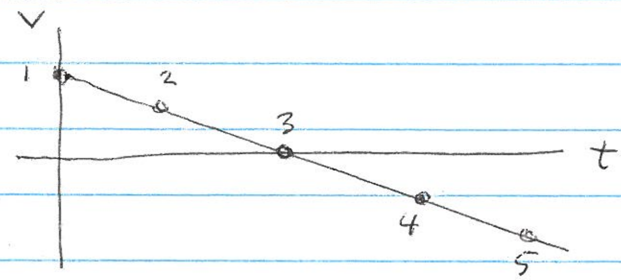
Case I 



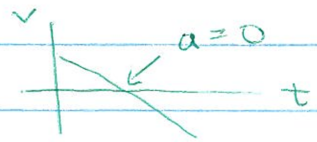
Case II 



III.



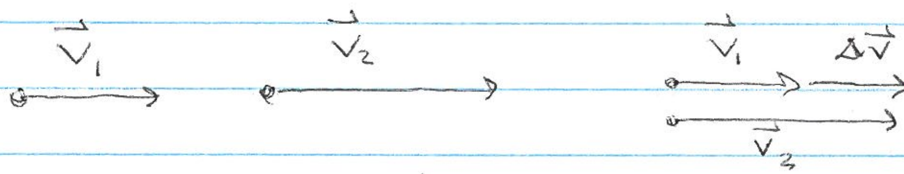
2-8a 2-8b



Direction of $\vec{a}$

$+v \longrightarrow$ } ✓ clear $+a \longrightarrow$ } huh?

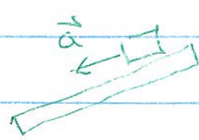
$-v \longleftarrow$ $-a \longleftarrow$



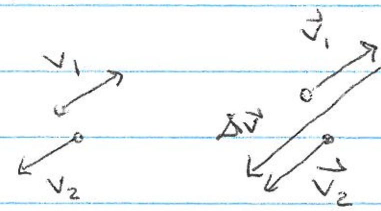
$\Delta\vec{v}$ = change in $\vec{v}$

dir. of $\vec{a}$ = dir. of $\Delta\vec{v}$

2-10



dir of $\vec{a}$

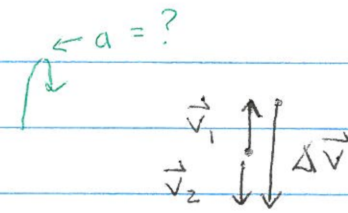


Expt'l Fact: In "free-fall", all objects near Earth's surface have same $\vec{a}$ = const w/ magnitude $|\vec{a}| = 9.8\ m/s^2$, dir. of $\vec{a}$ = down

"free-fall" = only force is gravity

Demo Paper + book CT Which falls faster?

2-11) Ball thrown up



Const a formulas for 1D Motion

$a = \text{const}$, ~~x~~ $v = dx/dt$, $a = dv/dt$ $\xRightarrow{\text{can prove}}$

a) $v = v_0 + a \cdot t$

b) $x = x_0 + v_0 t + \frac{1}{2} a t^2$

c) $v^2 = v_0^2 + 2a(x - x_0)$

d) $\bar{v} = \dfrac{v_0 + v}{2}$

Proof of (a) $a = \text{const} \Rightarrow a = \bar{a} = \dfrac{\Delta v}{\Delta t}$

$$a = \frac{v_f - v_i}{t_f - t_i} = \frac{v - v_0}{t - 0} \Rightarrow at = v - v_0$$

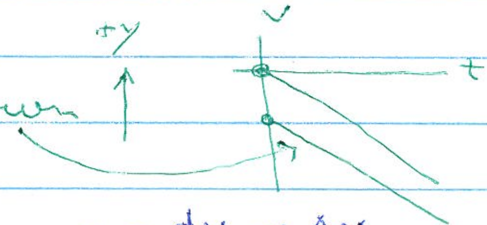
$$v = v_0 + at \checkmark$$

2-12) Dropped vs. thrown rock

Weds Sept 5

- READ Ch.3
- CAPA Set 2 Tues 10pm
- ~~X~~ SmartPhysics Lecture Fri 8 am
- Tut HW due in recitation today or tomorrow
- Bring Tutor<u>ial</u> book or pdf to recitation

CT 2-12 Ball dropped vs. thrown



1D Motion: $v = \frac{dx}{dt} \simeq \frac{\Delta x}{\Delta t}$, $a = \frac{dv}{dt} \cong \frac{\Delta v}{\Delta t}$

$a = \text{const}$ Constant acceleration formulas

$a = \text{const}$, $v = dx/dt$, $a = dv/dt \Rightarrow$

a) $v = v_0 + at$ v, t

b) $x = x_0 + v_0 t + \frac{1}{2} a t^2$ x, t

c) $v^2 = v_0^2 + 2a(x - x_0)$ v, x

d) $\bar{v} = (v_0 + v)/2$

Proof of (a): $a = \text{const} \Rightarrow a = \bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$

$a = \frac{v - v_0}{t - 0}$, $v - v_0 = a \cdot t$

$v = v_0 + a \cdot t$ ✓

Expt says: In free-fall, $|\vec{a}| = g = +9.8 \ m/s^2$

dir of $\vec{a}$ is DOWN

2-13 Sign of coords

y-direction: $y = y_0 + v_{0y} t + \frac{1}{2} a_y t^2$

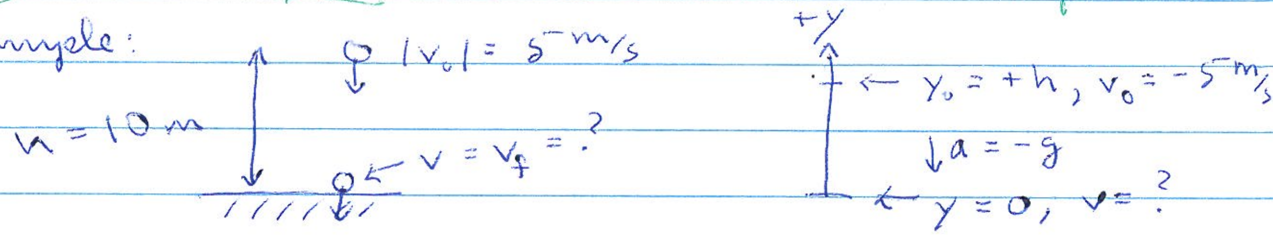
$v_y^2 = v_{0y}^2 + 2 a_y (y - y_0)$

Choice: $+y \uparrow$ $\downarrow a = -g$, $a = -9.8\, m/s^2$ **OR** $\downarrow +y$ $\downarrow a = +g = +9.8\, m/s^2$

a is $(+)$ or $(-)$, $g \equiv |a| = (+)$ always

2-14 Rock thrown downward. Which formula?

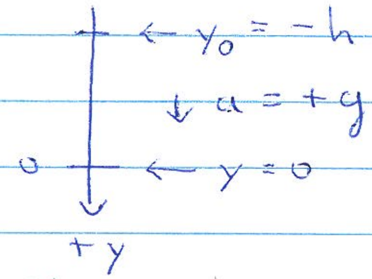
Example:



$$v^2 = v_0^2 + 2(-g)(0 - h) = v_0^2 + 2gh$$

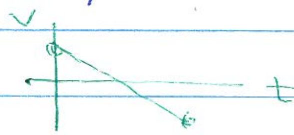
$$v = \sqrt{v_0^2 + 2gh} = \sqrt{\cancel{5}\ 5^2 + 2(9.8)(5)} \approx 15\, m/s$$

OR



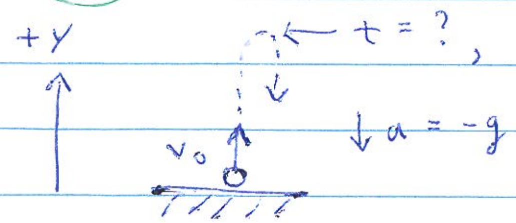
$\Rightarrow$ same result

2-16



means what?

2-19 Which one formula?



Know v, v_0, a.
seek t

$$\Rightarrow v = v_0 + a \cdot t$$

$$0 = v_0 - gt$$

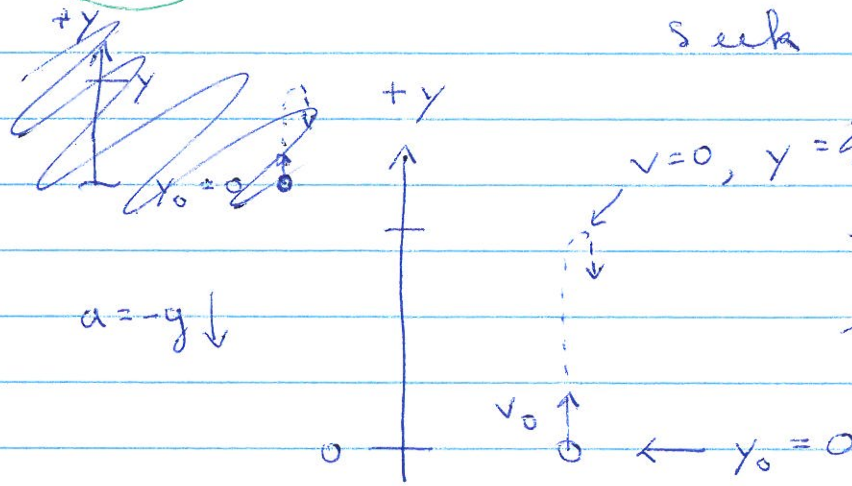
2-20 Double v_0.

What happens to t? $\boxed{t = v_0/g}$

CAPA, exams, and formulas!

2-21 Max ht? Know v_0, $v = 0$, $a = -g$, $y_0 = 0$

Seek y



$$v^2 = v_0^2 + 2a(y - y_0)$$

$$\cancel{0 = v_0^2 - 2g(y-0)}$$

$$0 = v_0^2 + 2(-g)(h - 0)$$

$$v_0^2 = 2gh$$

$$\boxed{h = \frac{v_0^2}{2g}}$$

2-22 Double v_0. What happens to h?

2-18 car/truck graph, if time?

2-18 Min distance when?

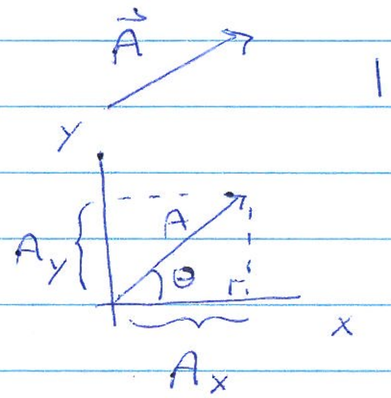
Fri Sept 7

- CAPA Set 2 Tues 10pm
- Smart Physics
- Tutorial HW
- READ Ch. 3

CT1- Car / Truck graph

vector = magnitude + direction (NOT location)

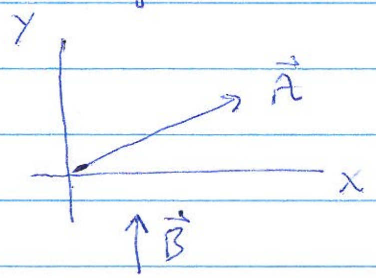
PhET Vector Addition Sim



$|\vec{A}| = A = (+)$ nbr

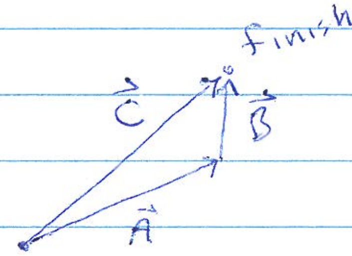
2D : $\vec{A}$ given by A, θ or A_x, A_y

Graphical Vector Addition

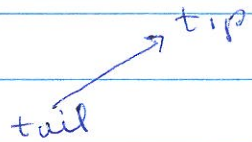


$\vec{C} = \vec{A} + \vec{B}$

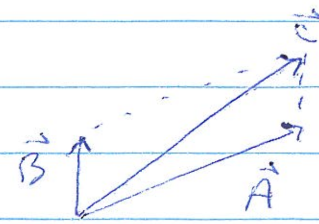
$= \vec{B} + \vec{A}$ (sim)



"tip-to-tail"



"parallelogram"



(V-1) $\vec{A} + \vec{B} = 0$

(V-2) $\vec{A} + \vec{D} = \vec{B} + \vec{C}$

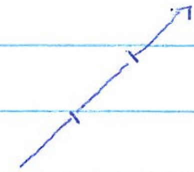
(silent vote)

$\vec{S} = \vec{A} + \vec{B} + \vec{C} + \vec{D}$ (sim)

• Negative of a vector $\vec{A}$ ↗ $-\vec{A}$ ↙

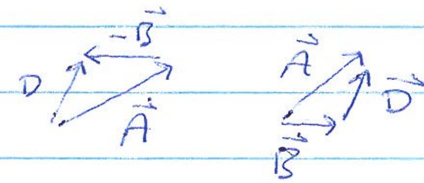
• nbr x vector

$b = 3$, $\vec{A}$ ↗ $b\vec{A}$ =



• vector subtraction : $\vec{A} - \vec{B} = \vec{A} + (-\vec{B})$

$\vec{A} - \vec{B} = \vec{D}$

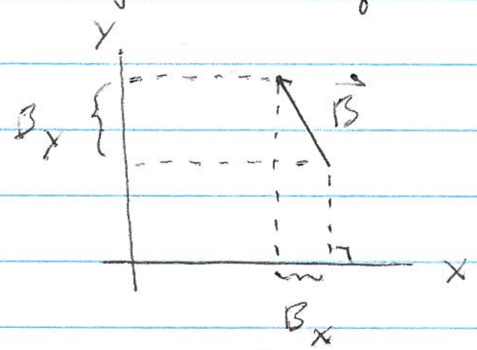


V-4 $\vec{s} = \vec{A} + \vec{B} - \vec{C}$

V-5 $A \cos \theta$ ("cozy side")

signed nbr

Components of a vector



$B_y > 0$

$B_x < 0$

V-6 $A_y = -A \cos\theta$

Vector Addition by components

$\vec{A} + \vec{B} = \vec{C} \iff$ Proof by diagram

PhET sim

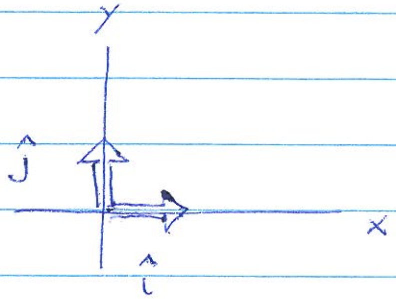
$A_x + B_x = C_x$

$A_y + B_y = C_y$

V-7 $S_x = ??$

unit vectors $\hat{i}, \hat{j}, \hat{k}$ <u>or</u>

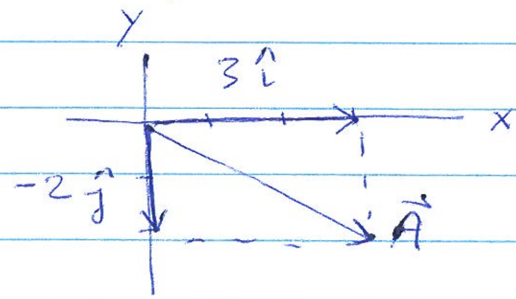
$\hat{x}, \hat{y}, \hat{k}$



$|\hat{i}| = 1$

$\vec{A} = A_x \hat{i} + A_y \hat{j}$

Example: $\vec{A} = 3\hat{i} - 2\hat{j}$



V-8 How many of these make <u>no</u> sense?

Mon Sept 10

READ Ch. 3 2D Motion

CAPA Set 2 Tues 10 pm

SmartPhysics due 8 am Wed Sept 12

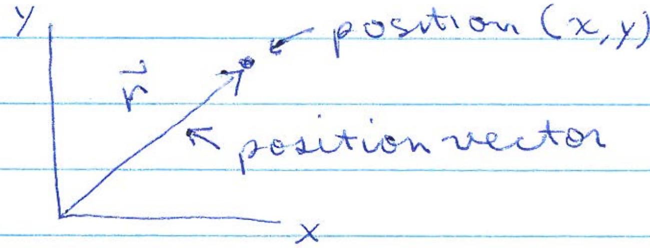
Tut HW in recitation

V-8 How many of these make no sense?

(notation)

$$\vec{A} = 3\hat{i} - 2\hat{j} = (3,-2) = [3,-2]$$
$$= A_x\hat{i} + A_y\hat{j}$$

Vectors: velocity, accevation, position



$$\vec{r} = x\hat{i} + y\hat{j}$$
$$= r_x\hat{i} + r_y\hat{j}$$

1D : x 2D: $\vec{r}$

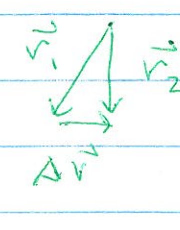
1D : $v = \frac{dx}{dt} = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$

2D (or 3D) : $\vec{v} = \frac{d\vec{r}}{dt} = \lim_{\Delta t \to 0} \frac{\Delta \vec{r}}{\Delta t}$ $\boxed{\vec{v} = \frac{d\vec{r}}{dt}}$

$$\vec{v} = v_x\hat{i} + v_y\hat{j} = \frac{d}{dt}(x\hat{i} + y\hat{j}) = \frac{dx}{dt}\hat{i} + \frac{dy}{dt}\hat{j}$$

$$\Rightarrow \left.\begin{aligned} v_x &= \frac{dx}{dt} \\ v_y &= \frac{dy}{dt} \end{aligned}\right\} \quad \vec{v} = \frac{d\vec{r}}{dt}$$

V-9



$\Delta\vec{r}$? $\quad \vec{r}_1 + \Delta\vec{r} = \vec{r}_2 \iff \Delta\vec{r} = \vec{r}_2 - \vec{r}_1$

(1D) $\Delta x = x_2 - x_1$

$$\underbrace{\vec{V}}_{\text{vector}} \overset{\sim}{=} \underbrace{\left(\frac{1}{\Delta t}\right)}_{\text{nbr}} \cdot \underbrace{\Delta\vec{r}}_{\text{vector}}$$

$$\vec{a} = \lim \frac{\Delta\vec{v}}{\Delta t} = \frac{d\vec{v}}{dt} \qquad \Delta\vec{v} = \vec{v}_2 - \vec{v}_1$$

$$\boxed{\vec{v}_1 + \Delta\vec{v} = \vec{v}_2}$$

V-10 $\Delta\vec{v} \parallel \vec{a}$ $\quad$ V-11 $\vec{v}_1 + \Delta\vec{v} = \vec{v}_2$

Show PHET lunar lander

V-12 Which is $\vec{v}$, $\vec{a}$

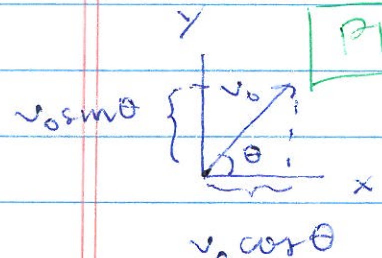
2D Projectile Motion, free-fall (<u>No</u> air resistance)

2D-1 $v_{0x} = v_0 \cos\theta$

2D-2 $y \downarrow x$ $\quad a_x = 0$, $a_y = -g$

y, $\downarrow \vec{a}$, x $\quad a_x = 0$, $a_y = -g$

PHET Projectile Motion



Key Idea

Treat x-, y-motion independently

X:

$a_x = 0 \Rightarrow$

$v_x = \text{const} = v_0\cos\theta$

$x = \cancel{x_0}^{\,0} + v_{0x} t + \frac{1}{2}\cancel{a_x}^{\,0} t^2$

$x = v_0 \cos\theta \cdot t$

2D-3

Y:

$a_y = -g$

$v_y = v_{0y} + a_y t$

$v_y = v_0 \sin\theta\, t - g t$

$y = \cancel{y_0}^{\,0} + v_{0y} t + \frac{1}{2} a_y t^2$

$= v_0 \sin\theta \cdot t - \frac{1}{2} g t^2$

Weds Sept 12

READ Ch. 3

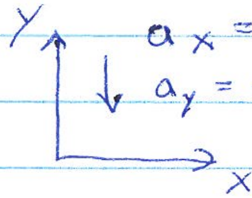
Tut HW due in recitation today or tomorrow

SmartPhysics due Fri 8 am

CAPA Set 3 next Tues 10 pm

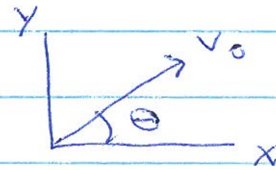
2D-3 $v_{x,\,final} = v_0 \cos\theta$

2D Projectile Motion (No air resistance)



$a_x = 0$

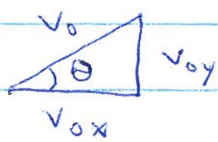
$a_y = -g$



$v_{0x} = v_0 \cos\theta$

$v_{0y} = v_0 \sin\theta$

$\vec{v}_0$ = initial velocity, $v_0 = |\vec{v}_0|$ = initial speed

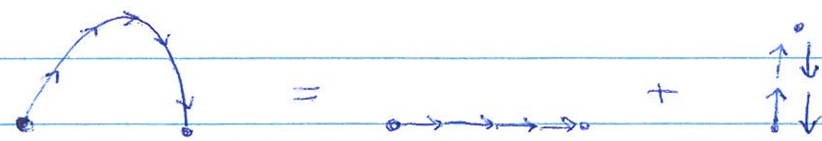


$$v_0 = \sqrt{v_{0x}^2 + v_{0y}^2}$$

$\boxed{\text{Treat } x\text{-, } y\text{-motions independently}}$

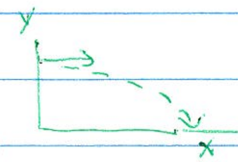
X:	Y:
$a_x = \frac{dv_x}{dt} = 0 \Rightarrow$	$a_y = -g$
$v_x = \text{const} = v_0 \cos\theta$	$v = v_0 + at \Rightarrow v_y = v_{0y} - gt$
$x = \underbrace{x_0}_{0} + v_{0x} t + \cancel{\frac{1}{2} a_x t^2}^{\,0}$	$y = \underbrace{y_0}_{0} + v_{0y} t + \frac{1}{2} a_y t^2$
$x = v_0 \cos\theta \cdot t$	$y = v_0 \sin\theta\, t - \frac{1}{2} g t^2$

Notice: x, y eq'ns are independent



2D-3 again, if necessary $\quad \vec{v} = v_x \hat{i} + v_y \hat{j}$

$$v = \sqrt{v_x^2 + v_y^2}$$

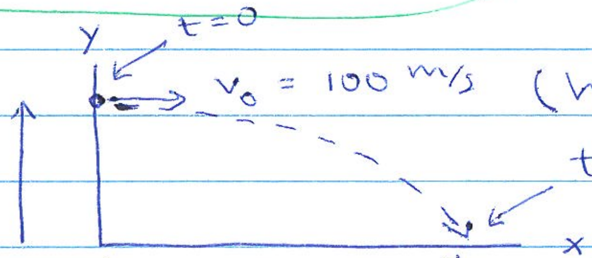
2D-4a Rifle problem  PHET sim

~~2D-5 $v = \sqrt{v_0^2 + (gt)^2}$~~

Ball Drop / Ball fire demo

Example:

$y_0 =$ 2 m



Flight ends when $y = 0 \Rightarrow$ y-motion determines t_{final}

$$\underbrace{y}_{0} = y_0 + \underbrace{v_{0y}}_{0} t - \frac{1}{2} g t^2 \Rightarrow y_0 = \frac{1}{2} g t^2$$

$$t = \sqrt{\frac{2 y_0}{g}} = \sqrt{\frac{2(2)}{9.8}} = 0.64 \text{ s}$$

Range: $x = \underbrace{x_0}_{0} + \underbrace{v_{0x}}_{v_0} t + \frac{1}{2} \cancel{a_x}^{0} t^2 = v_0 \cdot t_{flight}$

$$= (100 \text{ m/s})(0.64 \text{ s}) = 64 \text{ m}$$

2D-5 $\quad v = \sqrt{v_0^2 + (gt)^2}$

2D-6  longer flight? $\quad$ 2D-7 Min speed

2D-10 (If time). 

Shoot ~~the~~ monkey
Accelerometer (1)

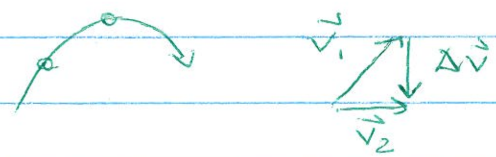
Fri Sept 14

CAPA due ~~next~~ Tues 10 pm

Smart Physics now due Mon (was due this morning)

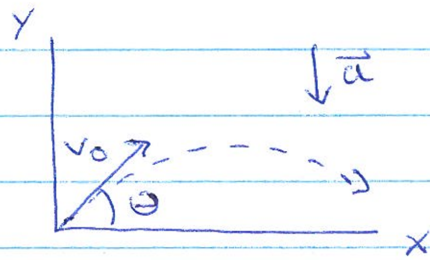
READ ch 4 Newton's Law

(2D-10)



(2D-11) T or F $|\vec{v}| = \text{const} \not\Rightarrow \vec{a} = 0$

General 2D motion w/ constant $\vec{a}$



$\downarrow\vec{a}$ $\left.\begin{array}{l} a_x = 0 \\ a_y = -g \end{array}\right\}$ but might be different!

$$\begin{cases} x = x_0 + v_{0x} t + \frac{1}{2} a_x t^2 \\ y = y_0 + v_{0y} t + \frac{1}{2} a_y t^2 \end{cases}$$

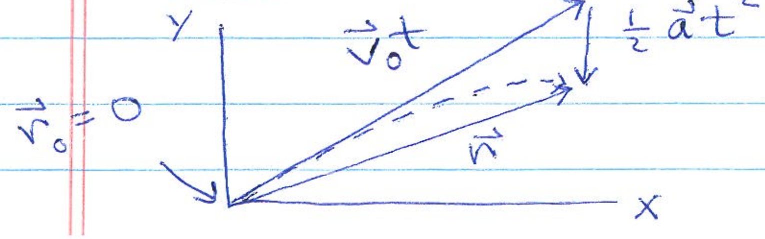
$(x, y) \rightarrow$
$\vec{r} = x\hat{i} + y\hat{j}$

$$\rightarrow \vec{r} = \vec{r}_0 + \vec{v}_0 t + \frac{1}{2}\vec{a} t^2$$

(like $\vec{S} = \vec{A} + \vec{B} \Leftrightarrow \begin{cases} S_x = A_x + B_x \\ S_y = A_y + B_y \end{cases}$)

(2D-8) $\vec{r} = \vec{r}_0 + \vec{v} t$

(2D-9) Shoot the Monkey (Demo)



Monkey falls distance
$|y - y_0| = \frac{1}{2} g t^2$
same as bullet

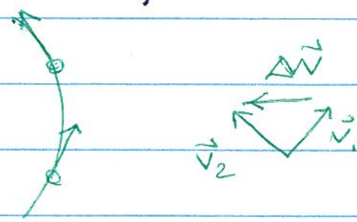
$\vec{a} \cong \frac{\Delta \vec{v}}{\Delta t}$ $\vec{v}$ can change in 2 ways

magnitude:  or

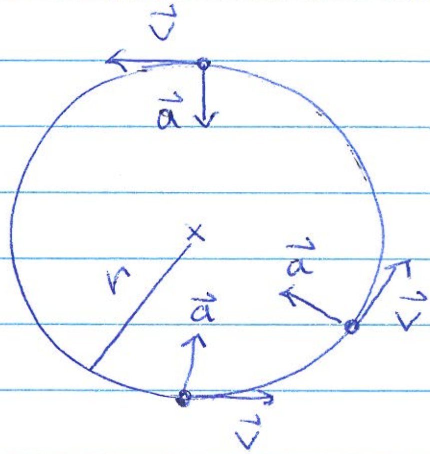
direction: 

2D-11 $|\vec{v}| = \text{const} \overset{?}{\Rightarrow} a = \text{const}$ again

2D-12



Circular Motion w/ const speed, $v = |\vec{v}| = \text{const}$



period T = time for 1 rev

$v = \frac{2\pi r}{T}$

- dir. of $\vec{a}$ = dir of $\Delta\vec{v}$ = toward center
- $|\vec{a}| = a = \frac{v^2}{r}$ (proof in notes/text)

Flask/accelerometer Demo If time

? 2D-13 ∞ $|\vec{a}|$ smallest

Newton Plague days

marble $\frac{3}{4}$ track
air track
100g / 1kg masses
ball on string

①

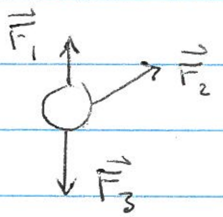
Mon Sept 17

- READ ch. 4 Newton's Laws
- Next Smart Physics ~~Fri~~ Weds 8am
- CAPA Tues 10pm / Tut HW in recitation
- Practice Exam on ~~[illegible]~~ D2L
- Exam 1 Thu, Sept 27 7:30 - 9 pm Locations to be announced

N-1 

$\vec{F}_{net} = \sqrt{2}\, F$

Force is a push or a pull.
Force is a vector

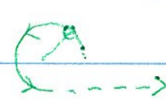


$$\vec{F}_{net} = \sum_i \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \vec{F}_3$$

Isaac Newton (British 1642 - 1727)
online pics, story of plague days

Newton's 3 Laws:

NI: $\vec{F}_{net} = 0 \iff \vec{v} = \text{const}$
(Galileo's Law of Inertia.)

N-2 Glider on an air track
N-3 strings breaks 

NII: $\vec{F}_{net} = m\vec{a}$, units $[F] = [m][a] = kg \cdot \frac{m}{s} = \text{newton (N)}$

$m = 100$ grams, weight $\simeq 1\,N$

Note: • $\vec{F}_{net} = 0 \Rightarrow \vec{a} = 0 \Rightarrow \vec{v} = \text{const}$ (NII → NI)

• $\vec{a} \parallel \vec{F}_{net}$

• $\sum_i \vec{F}_i = \vec{F}_{net} = m\vec{a} \iff \begin{array}{l} \sum F_x = m a_x \\ \sum F_y = m a_y \end{array}$

Pre-Newton: ~~"Force causes motion."~~

Post-Newton: "Force causes changes in motion." ✓

Def'n: weight $\vec{W}$ = force of gravity on object

Claim: $|\vec{W}| = \boxed{W = m \cdot g}$

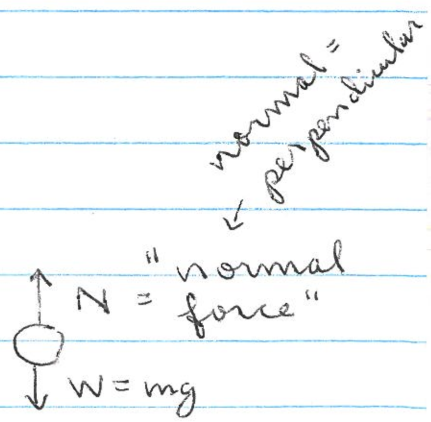
Proof: $\underbrace{F_{net}} = m \underbrace{a}$ (NII, always true.)

In free-fall: $\underbrace{F_{grav}}_{W} = m \cdot g$ ✓

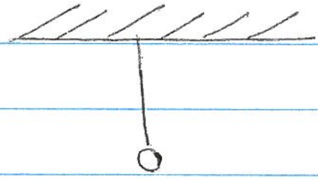
Free-body diagrams:

book on table

FBD:

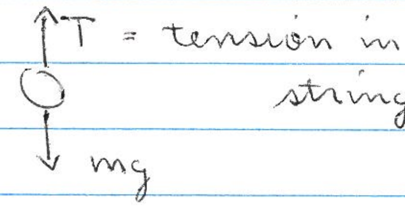


$a = 0 \Rightarrow F_{net} = 0 \Rightarrow N = mg$



ball hanging from cord

FBD:



FBD rules:

- draw blob = object
- draw arrow out of object for each force on object
- label each force arrow w/ magnitude of force (No (−) signs!)

N-4

$\downarrow v = \text{const}$

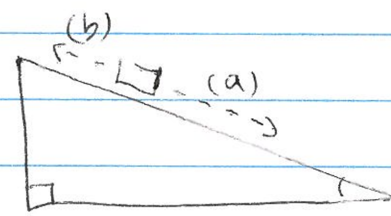
$T = mg$

N-5a (b)

$\vec{a}$? $T \gtreqless mg$?

N-7a dir. of $\vec{F}_{net}$

(b) dir of $\vec{F}_{net}$



Air track
wood block

①

Weds, Sept 19

- Exam 1 Ch. 2, 3, 4 Thu Sept 27 7:30-9pm
- READ Ch 4
- Tut HW in recitation

(N-6)  $\vec{v} = \text{const} \Rightarrow \vec{F}_{net} = 0$

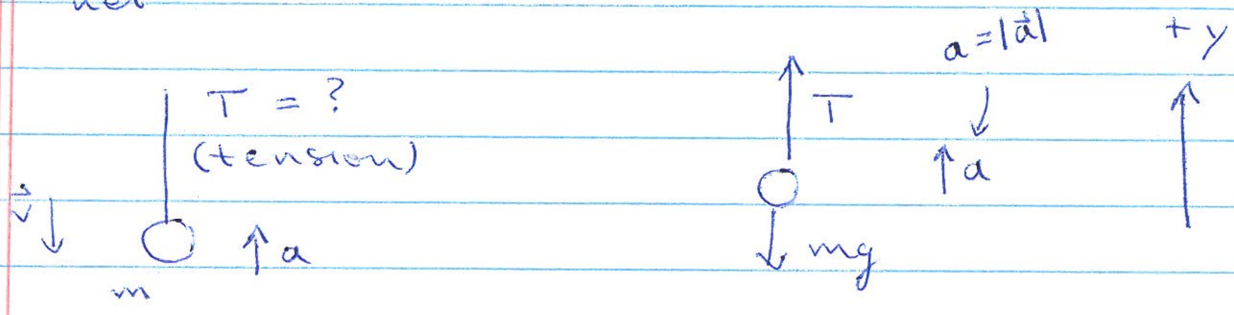
NI: $\vec{F}_{net} = 0 \Leftrightarrow \vec{v} = \text{const}$

NII: $\vec{F}_{net} = m\vec{a}$

(N-7) 

dir of $\vec{F}_{net}$

$\vec{F}_{net} = m\vec{a}$ Problems



Step ① Draw FBD

② Choose coord. sys. w/ (+) dir. = dir of $\vec{a}$

Important! Want $a_y = (+)$

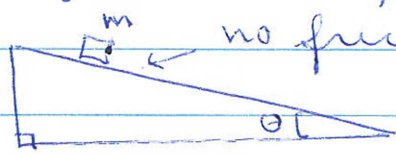
③ Write eq'ns

$\sum F_x = ma_x$ (CN-8) What is correct eq'n?

$\sum F_y = ma_y \Rightarrow +T - mg = ma$

$T = m(a+g)$

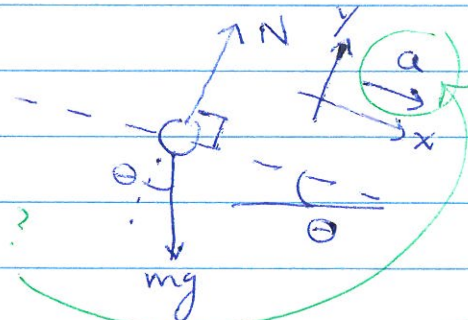
Example: Glider on tilted air track



$a = ?$

N (normal force) $= ?$

(1) FBD



(2) Coords (N-9)

dir of $\vec{a}$ = ?

(N-10) $a_x = ?$ $a_y = ?$

$$a_x = a = |\vec{a}|$$
$$a_y = 0$$

(N-11) $W_x = mg \sin\theta$, $W_y = -mg\cos\theta$

(3) Eq'm $\sum F_x = m a_x \Rightarrow +\cancel{m}g\sin\theta = \cancel{m}a$

$\sum F_y = m a_y \Rightarrow +N - mg\cos\theta = 0$

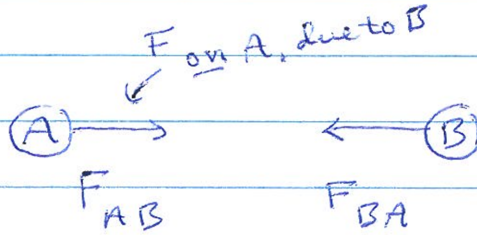
$a = g\sin\theta$

$N = mg\cos\theta$

(N-13) (a) (b) $a = 0 \Rightarrow N = mg$, $a > 0 \Rightarrow N > mg$

(N-15) Car-Truck collision (silent vote)

N III:



$$\boxed{\vec{F}_{AB} = -\vec{F}_{BA}}$$

(N-15) again, Consensus Vote $F = Ma = mA$

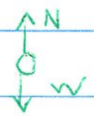
(N-16) $\uparrow N$ / $\downarrow mg$ action-reaction pair? <u>No!</u>

Forces always come in equal/opposite pairs that act on <u>different</u> objects (A)→ ←(B)

Fri Sept 21

- READ Ch. 5
- Next SmartPhysics Fri, Sept 28
- Exam 2 Thu nite Sept 27 7:30-9pm Locations on Web
- Early exam 5pm Duane

N-16 action-reaction



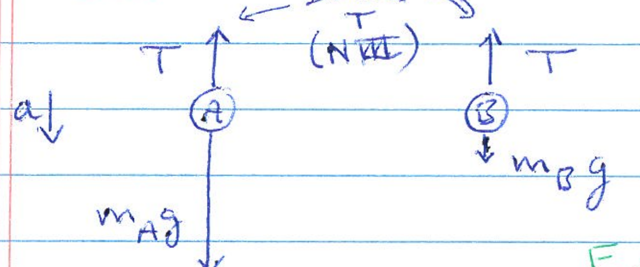
$F_{\text{on A due to B}}$

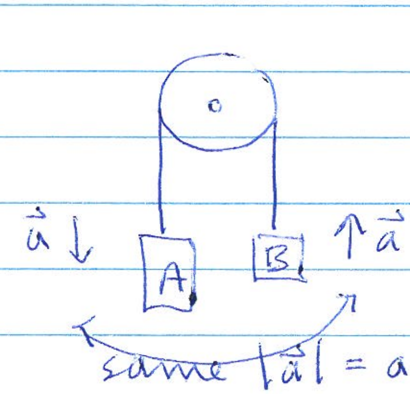
NIII: $\boxed{\vec{F}_{AB} = -\vec{F}_{BA}}$

Demos: Big vs Little Tug of War
Spring scales / suspenders

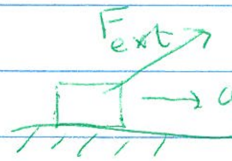
N-18 (a) (b) Skinney & Fatty

N-19 Atwood Machine





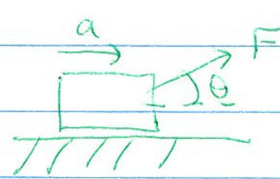
N-20 $N \gtreqless mg$



N-22 (a) (b)

$N \gtreqless mg$ y-eq'n = ?

N-24 (a) (b)



$F_{net} = ?$

y-eq'n = ?

Bucket of water

Mon Sept 24

- Exam #1 Thu nite 7:30 - 9 pm Locations on web
- Sign up for early exam 5 pm in
  if CU conflict
- CAPA due tues 10 pm / Tut HW due in recitation
- Read Ch. 5

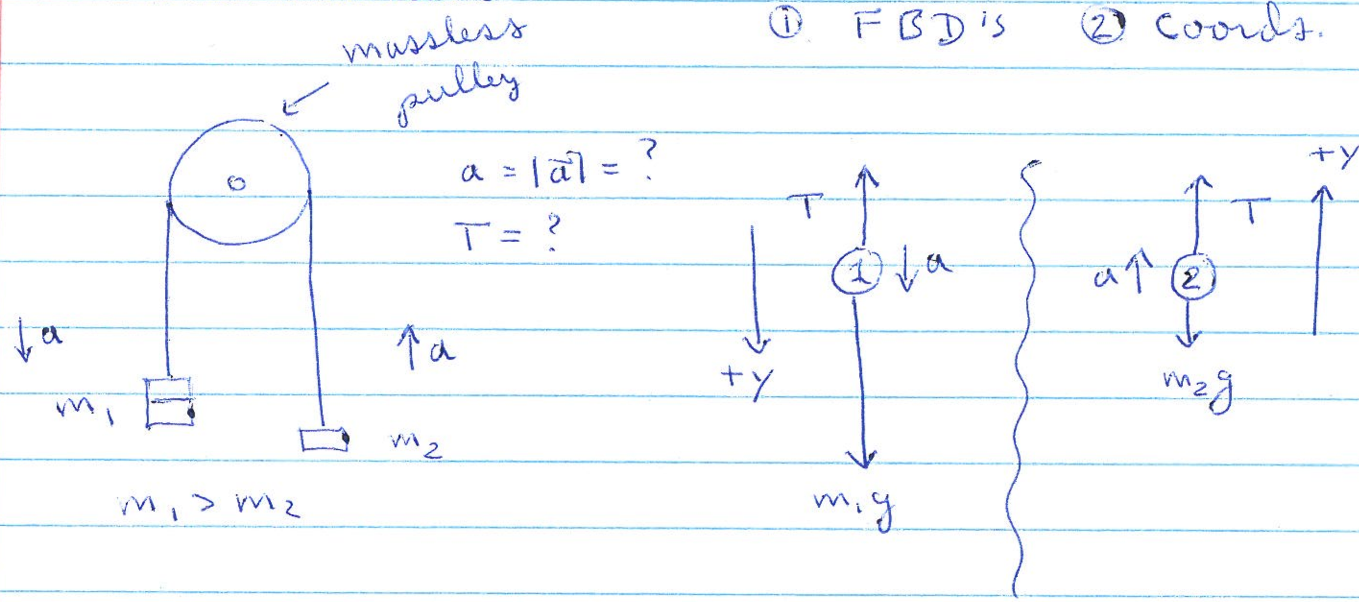
N-24 Net force on block

~~Exam 1 was hard / easy / about right~~

NA-1

Atwood Machine

① FBD's ② Coords.



same a's ⟺ string taut ; same T's by NIII

③ Eq'ns $\sum F_y = m a_y$

(1) $m_1 g - T = m_1 a$ (2) $T - m_2 g = m_2 a$

NA-2 Simultaneous Eq'ns

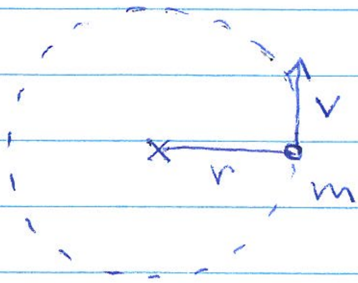
(1) + (2) $m_1 g - m_2 g = m_1 a + m_2 a$

$$a = \frac{(m_1 - m_2) g}{(m_1 + m_2)}$$

Limits: $m_1 = m_2 \Rightarrow a = 0$ ✓

$m_2 = 0 \Rightarrow a = g$ ✓

Rock on a string (no gravity)

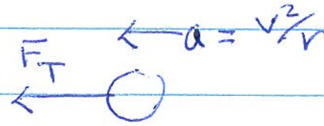


speed $|\vec{v}| = v = \frac{\text{dist}}{\text{time}} = \frac{2\pi r}{T}$

Given m, r, v, tension $F_T = ?$

T = period = time for 1 rev

FBD:



$F_{net} = ma$

coords: $x \leftarrow$

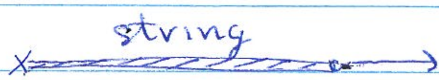
$F_T = m\frac{v^2}{r}$ ✓

F_T = centripetal force = force toward center

(centrifugal force = force away from cntr.)

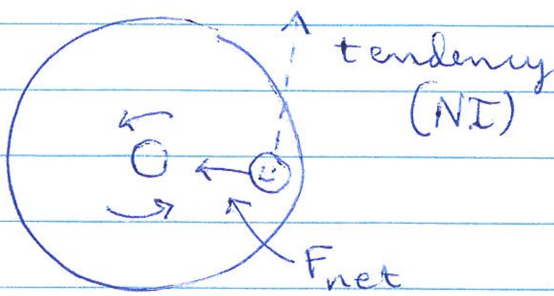
No centrifugal force on rock! (centripetal force only)

F on rock from string

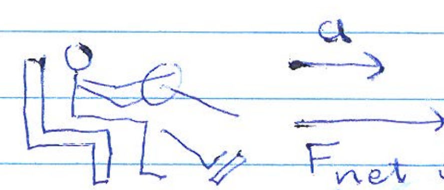


F on string from rock

Merry-go-round (Intution fails in non-inert. frame)

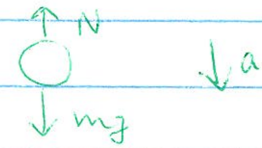


Car + Driver

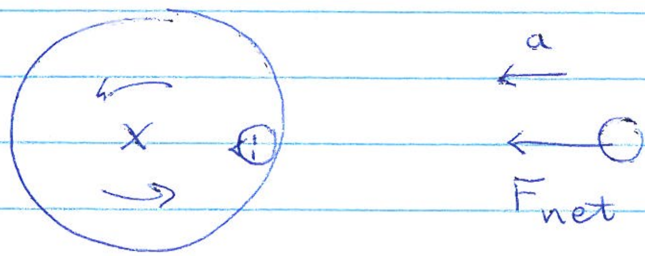


Driver says "I was pushed back in seat."

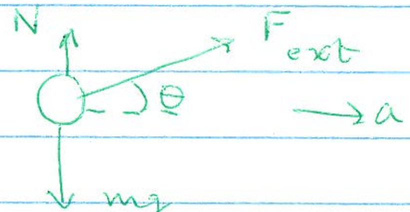
NA-5 Car on hill



NA-6 Barrel 'o fun



NA-10 (a) (b)



NA-7 (a) Bucket swung in circle

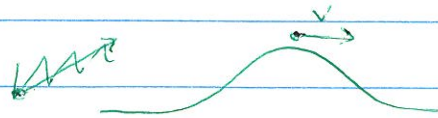
(b) N_{max}

Bucket w/ water
(1) Friction Block
Spring scale

Fri Sept 28

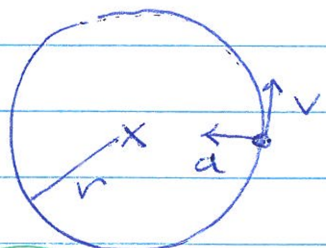
- CAPA Tues 10pm
- Smart Physics Weds 8am

NA-~~4~~5



$N > mg$

Circular Motion w/ const speed



$|\vec{a}| = a = \frac{v^2}{r}$

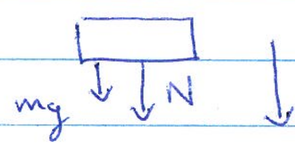
$\vec{F}_{net} = m\vec{a}$

NA-7 (a) Bucket swung in circle F_{net} max where?

Demo swing bucket

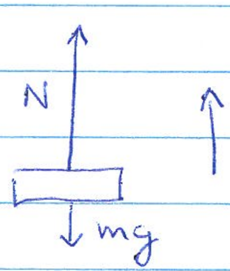
(b) N max where?

Top



$F_{net} = m\frac{v^2}{r}$

same size



Bottom

$F_{net} = m\frac{v^2}{r}$

NA8 Car vs. Monorail

Friction PhET friction sim

Sliding friction ~~&~~ or kinetic friction

empirical observation : $f = \mu_K N$ ← |normal force|

|Force$_{\text{friction}}$|

μ_K: coefficient of kinetic friction

dimensionless

$\mu_K > 0$ (usually $\mu_K < 1$)

Demo w/ blocks $f \propto N$ not Area

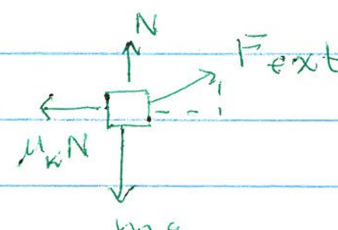
Static friction is variable.

$0 < f_{\text{static}} < f_{\text{static Max}} = \mu_s N$

μ_s: coeff. of static fric.

expt $\Rightarrow$ $\mu_s > \mu_K$ (sliding fridge)

NA-9 (a)(b) FBD w/ friction
y-equation



- Friction ramp
- wheel tan spokes
- Lamp hand-cranked lamp
- spring
- 1 kg mass

Mon Oct 1

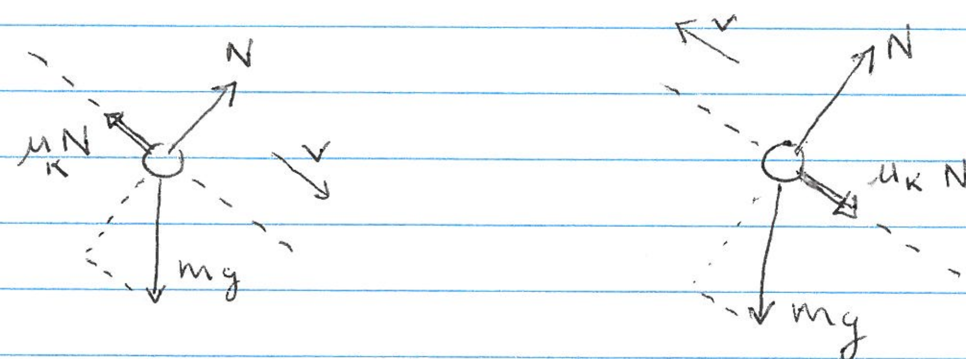
- READ Ch. 6
- Smart Physics Wed 8 am
- CAPA due Tues 10 pm
- Tut HW due in recitation

NA-11 (a) $\vec{a}$ up or down the ramp

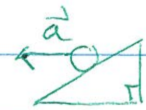
$$\left.\begin{array}{l} \text{Sliding friction: } f = \mu_K N \\ \text{Static friction: } 0 < f < f_{MAX} = \mu_s N \end{array}\right\} \mu_s > \mu_K$$

usually true. Not laws

NA-11 (a) again Draw FBD's



Car on Curve NA-13 (a)



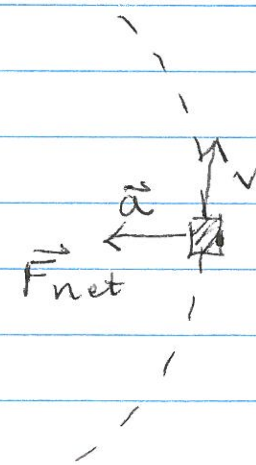
F_{fric}? Don't answer

What causes F_{net}?

(1) friction (maybe)

(2) Normal force (banked road)

N-13 (b) Direction of F_{fric}?



N-12 (a) false $F_{stat\,fric} \neq \mu_s N$

(b) true (c) (d)

$\boxed{\text{Energy}}$ Many different forms ⇒ difficult to define

- KE = kinetic energy
- thermal energy
- PE = potential energy = stored energy of position
  - gravitational PE
  - electrostatic PE
  - elastic PE
  - chemical PE
  - nuclear PE

  Stretch spring

  forms of electrostatic PE
- radiant energy = energy of light
- mass energy ($E = mc^2$)

Almost all forms of energy used by us can be traced back to the <u>sun</u>.

Sun → grass → chikens = food chemical PE → chemical PE in muscles → KE (crank) → electric light

Can you think of a form of energy, <u>not</u> solar in origin?

- Nuclear. Uranium is stellar, not solar
- Lunar tides
- Geothermal

Friction blocks

Weds Oct 3

Tut HW in recitation

Next SmartPhysics Mon 8am

READ Ch. 6

W-0 Atomic bomb U conserved?

What is energy?

Energy is conserved. $\Leftrightarrow$ E_{tot} = const for an isolated system

"Conserve Energy" says Power Co. (Nonsense! says physicist.)

1st Law of Thermodynamics

Work done = energy transferred / transformed

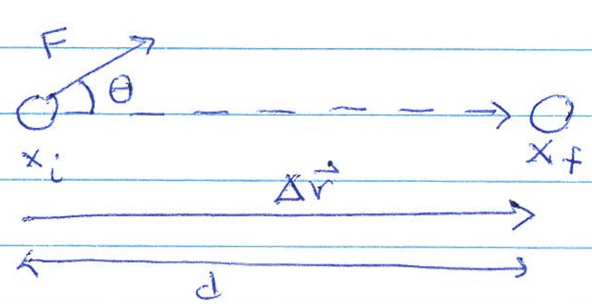
$$W = \Delta U$$

(actually $W + Q = \Delta U$) ← heat added

Def'n: work done by a force F

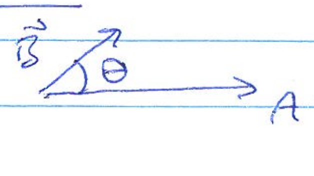
$$W_F = F_x \cdot d = F\cos\theta\, d = \vec{F} \cdot \Delta\vec{r}$$

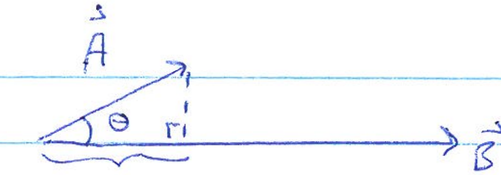
(Assumes $\vec{F}$ = const, path straight)



~~W-00 $\Delta\vec{r}$ = ?~~ (For next lecture)

Dot product $\vec{A} \cdot \vec{B} = |\vec{A}||\vec{B}| \cos\theta = A\, \underbrace{B_{\parallel}}_{B\cos\theta}$

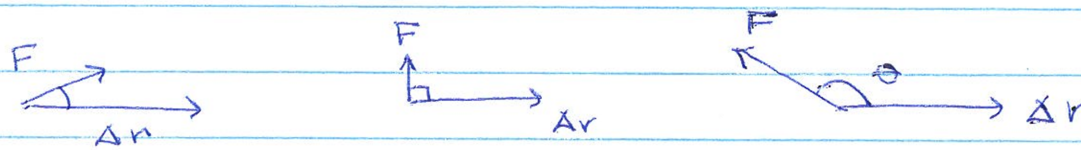




$A\cos\theta = A_{\parallel}$

$\vec{A}\cdot\vec{B} = A\,B\cos\theta$
$= A_{\parallel}B = A\,B_{\parallel}$

$W_F = \vec{F}\cdot\Delta\vec{r} = (F)(\Delta r)(\cos\theta)$



$W_F > 0$ $\qquad$ $W_F = 0$ $\qquad$ $W_F < 0$

W-1 Work done by gravity / hand / F_{net}

W-2 Work done by tension

$W = \sum_i \vec{F}_i \cdot \Delta\vec{r}_i = \int \vec{F}\cdot d\vec{r}$

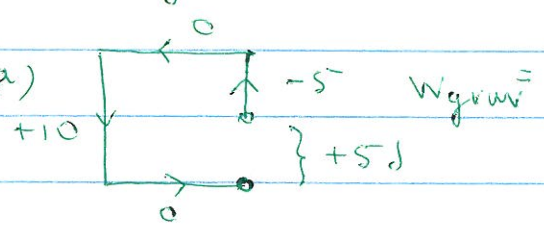
units of work $[W] = [F][x] = N\cdot m = J$ (joule)

$mgh \cong (1\,kg)(10\,m/s^2)(1\,m) = 10\,J = 1$ broken toe

W3-0 $W_{grav} = 0$

W3

(a)



$W_{grav} =$

(b)

Conservative force : work done by force depends only on $\vec{r}_i$, $\vec{r}_f$. In~~de~~dependent of path

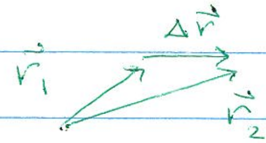
Fri Oct 5

CAPA Tues 10pm

Smart Phys Mon 8am

READ Ch 7

W-00



- 1st Law of Thermodynamics $\quad W = \Delta U$

- Work done by a force F : $W_F = \vec{F} \cdot \Delta\vec{r}$
  (if $\vec{F}$ const, $\Delta\vec{r}$ straight)

- Force F is <u>conservative</u> if W_F is path-independent.

Def'n: $KE = \frac{1}{2} m v^2$

units $[KE] = [m][v^2] = \underbrace{kg \cdot \frac{m}{s^2}}_{[m a] = F} \cdot m = N \cdot m$

= joules <u>same</u> units as work

Work - KE Thm

$$\boxed{W_{net} = \Delta KE}$$

Always! Even when friction

true if object is "point-like", no internal parts

Work done by net force

Examples w/ Block/table/glider/track

W-4

$W_{net} = W_{grav} = 0 \;, \quad \Delta KE = 0$

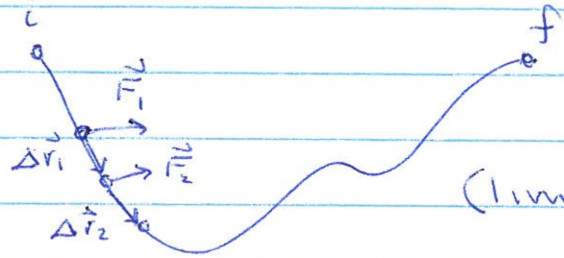
W-5

w/ friction

W-6 $\quad W_{Fric} = +\Delta KE,\ -\Delta KE$?

$W_{net} = \underbrace{W_{grav}}_{0} + \underbrace{W_{fric}}_{(-)} = +\Delta KE$

General def'n of work done by a force F



$$W_F = \sum_{i=1}^{N} \vec{F}_i \cdot \Delta\vec{r}_i$$

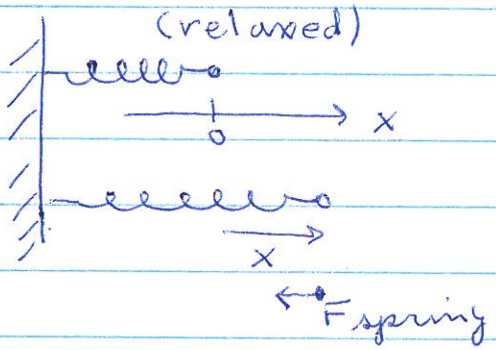
(limit $N \to \infty$, $\Delta\vec{r} \to 0$)

$$W_F = \int_i^f \vec{F} \cdot d\vec{r}$$

~ OK even if $\vec{F} \neq$ const, path curved.

Hooke's "Law"

$$\boxed{F_{spring} = -k \cdot x}$$



k = spring const

[k] = N/m

big k ⟺ stiff spring

small k ⟺ weak spring

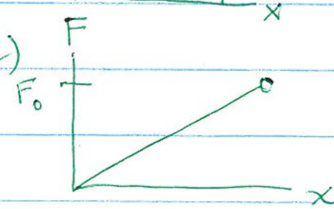
PhET springs Hooke's Law

W-9 sign of work done by hand

W-10 (a)

$$W = F_0 \frac{x}{2} + 2F_0 \frac{x}{2} = 1.5\, F_0 x$$

W-10 (b)



$$W = \frac{1}{2} F_0 x = \frac{1}{2}(kx)\,x$$

$$= \frac{1}{2} k x^2$$

Work done by me to stretch or compress spring dist x

$$W = \frac{1}{2} k x^2$$

Springs ①
Bowling Ball Pendulum
Book

Mon Oct 8

READ Ch 7
CAPA Tues 10pm
Smart Physics
LA Info Session

W-11  $W = \frac{1}{2} F_0 x$

Hooke's Law: $F_{spr} = -k \cdot x$

Work done by "external agent" to stretch spring

$W_{ext} = \frac{1}{2} F_{Max} \cdot x = \frac{1}{2}(kx) \cdot x = \frac{1}{2} k x^2$

Conclusions of Ch. 7

① PE = stored energy associated w/ conservative force

gravity: $PE_{grav} = mgh$

spring: $PE_{elastic} = \frac{1}{2} k x^2$

② If system isolated & No friction:

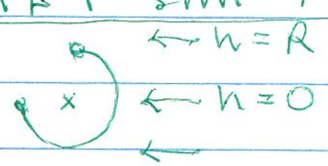
$$E_{mech} = KE + PE = \text{constant}$$

$$KE_i + PE_i = KE_f + PE_f$$

③ If system isolated & thermal energy involved

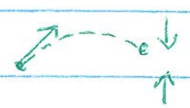
$$KE + PE + U_{thermal} = \text{const}$$

(PhET sim Masses & Springs)

E-1 

$KE_i + PE_i = KE_f + PE_f$

$KE_i + 0 = 0 + mgR$

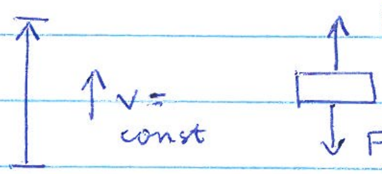
E-2  h $\quad \frac{1}{2} m v_0^2 + 0 = KE_f + mgh$

Bowling Ball Demo $\qquad$ PhET sim Pendulum

Def'n of ΔPE: $\quad \Delta PE = -W_F = +W_{ext}$

conservative force "field" $\qquad$ external agent

Lift book:

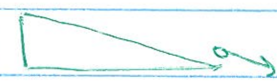


h $\quad \uparrow v = \text{const}$

$F_{ext} = mg \qquad W_{field} = -mgh$

$F_{grav} = mg \qquad W_{ext} = +mgh$

Conservative force $\Delta PE = PE_f - PE_i = W_F$ is path-independent. ~~Dep~~ Depends only on i, f positions

E-3 h  $\quad KE_i + PE_i = KE_f + PE_f$

$0 + \cancel{m}gh = \frac{1}{2}\cancel{m}v^2 + 0$

$$h = \frac{v^2}{2g} \Rightarrow \frac{h_2}{h_1} = \frac{v_2^2}{v_1^2} = \frac{(2v)^2}{v^2} = 4$$

Why $KE + PE = \text{const}$?

Work-KE Thm: $W_{net} = \Delta KE$

If friction ~~Wnet~~ $\vec{F}_{net} = \vec{F}_c + \vec{F}_{nc}$ ← non-conservative (friction)

No friction: $W_{net} = W_c = \Delta KE$

$W_c = -\Delta PE$ (Defn of PE)

$\Rightarrow \Delta KE + \Delta PE = 0 \Rightarrow$

$KE + PE = \text{const}$ $\quad$ E-4 (a) (b) (c)

If friction, $\underbrace{W_{net}}_{\Delta KE} = \underbrace{W_c}_{-\Delta PE} + \underbrace{W_{nc}}_{(-)}$

$\Delta KE + \Delta PE = \underbrace{W_{fric}}_{(-)}$ $\quad \Delta E_{thermal} = -W_{fric}$

$\underbrace{\Delta KE + \Delta PE}_{(-)} + \underbrace{\Delta E_{thermal}}_{(+)} = 0$

$KE + PE + E_{thermal} = \text{const}$

Eric Anderson Accident! Can't do HW!

Weds Oct 10 — loop-de-loops (1)

Next Smart Physics Fri 8am

Tut HW in recitation

(E-21) N III Review

- 1st Law of Thermo: $W = \Delta U$
- Work $W_F = \int \vec{F} \cdot d\vec{r}$ ($= \vec{F} \cdot \Delta \vec{r}$ sometimes)

(E-5) F ↑ F

- Work-KE Thm: $W_{net} = \Delta KE$ (E-18) $W_{fric} = W_{net}$
- Defin of PE:

$$\Delta PE = -W_{\vec{F}} = +W_{ext}$$

conservative force

$\Rightarrow$ $\Delta PE_{grav} = mg \cdot \Delta h$ $\quad \Delta PE_{spring} = \frac{1}{2} k x^2$

Conservation of Energy $\Rightarrow$ E_{tot} = const in isolated system

$KE + PE + E_{thermal} = \text{const}$

If no sliding friction, $KE + PE = \text{const}$ (E-4) E_{mech} ↗ or ↘

(E-19) $mg = kx$ $\quad + mg \cdot x \quad - \frac{1}{2} \underbrace{kx}_{mg} \cdot x$

Hanging Spring

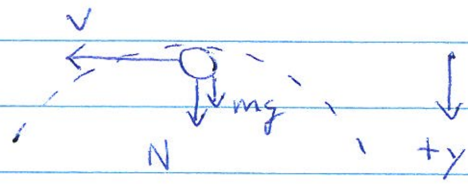
(E-8)  can you solve for h using conservation of E?

$KE_i + PE_i = KE_f + PE_f$

$0 + \frac{1}{2} k x^2 = \frac{1}{2} m \underbrace{v_f^2}_{?} + mg\underbrace{h}_{?}$ $\quad$ Know m, k, x

(E-10) Loop-de-loops (TUB?E)

(E-11) Loop-de-loops (RAM)



Need $N \geq 0$ at top

$$F_{net} = \cancel{N}^{0} + mg = m\frac{v^2}{R}$$

$$v^2 = r \cdot g \qquad v_{critical} = \sqrt{r \cdot g}$$

candy bar ①

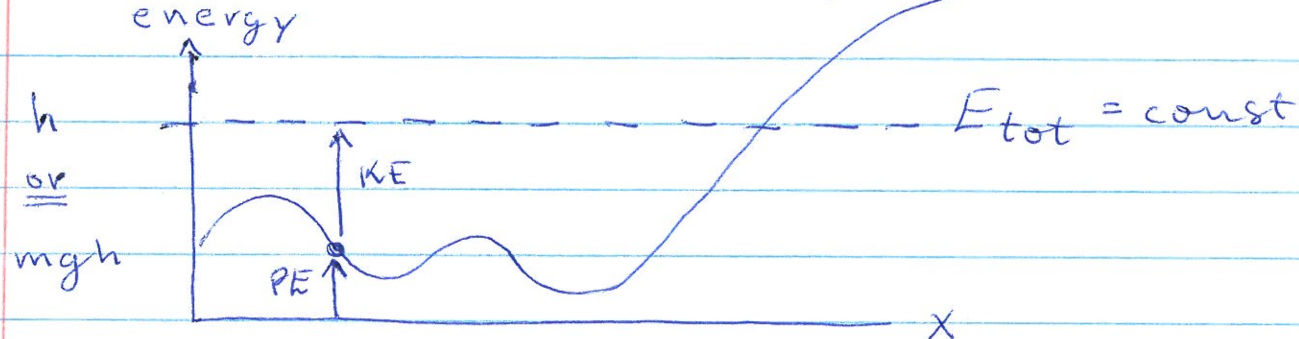
Fri Oct 12

- READ Ch. 8
- Smart Physics due
-

Gravity 1   Do not give answer yet!

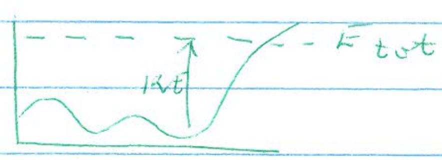
Energy Graphs:

Frictionless Roller Coaster, mass m



$$\underbrace{E_{tot}}_{(+\text{ or }-)} = \underbrace{KE}_{(+)} + \underbrace{PE}_{(+\text{ or }-)} = \text{const}$$

E-12(a)



PhET sim

energy skate park

E-13 Energy Skate Park : $E_{tot} = 0$

E-14 $E_{tot} = 0 \quad KE = -PE$

$$\text{Power} = \frac{\text{work}}{\text{time}} \qquad P = \frac{W}{\Delta t} = \frac{\Delta E}{\Delta t}$$

units $[P] = J/s = 1$ watt (W)

E-16 Power climbing stairs

$\Delta E = P \cdot \Delta t$

non-SI unit of energy = kilowatt-hour

$1\ \text{kW}\cdot\text{hr} = 1000\ \frac{J}{s} \cdot 3600\,s = 3.6 \times 10^6\ J$, cost $\simeq 10$¢

non-SI unit of energy = Food Calorie = 4186 J

$1\ \underline{C}al = 1\ k\underline{c}al$, 1 cal = 4.186 J = energy for $\Delta T = 1°C$ for 1 gram of H_2O

300 Cal candy-bar ($1.26 \times 10^6\ J \simeq \frac{1}{3}\ \text{kW}\cdot\text{hr}$)

Climb Gamow Tower

$\Delta PE = mg\,\Delta h = (68\ kg)(9.8\ m/s^2)(35\ m)$

$= 23{,}300\ J \times \frac{1\ Cal}{4186\ J} = 5.6\ Cal$

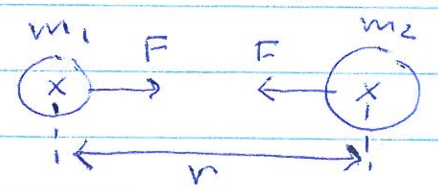
Body inefficient $\Rightarrow$ $\Delta E \simeq 30$ Cal

RMR = 70 W $\longrightarrow$ 90 W

(1400 cal/day) (1860 cal/day)

Gravity 1 (again)

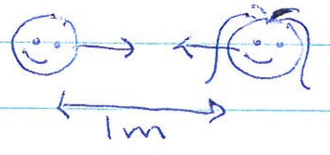
Newton's Universal Law of Gravitation



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

"Big G" G = const $= 6.67 \times 10^{-11}$ SI units

Why? Einstein 1915



$F \simeq \frac{(7\times10^{-11})(70)^2}{1^2} \simeq 3 \times 10^{-7}\,N \simeq \frac{1}{60}$ wt of hair

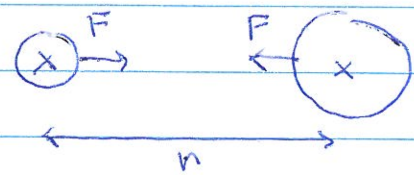
Long string for ellipse on board

Mon Oct 15 ①

- READ Ch. 8 Gravity
- CAPA Set 7 Tues 10 pm / Tut HW in recitation
- Next Smart Physics Mon Oct 22, 8am

G-2 ① ② $a_1/a_2 = ?$

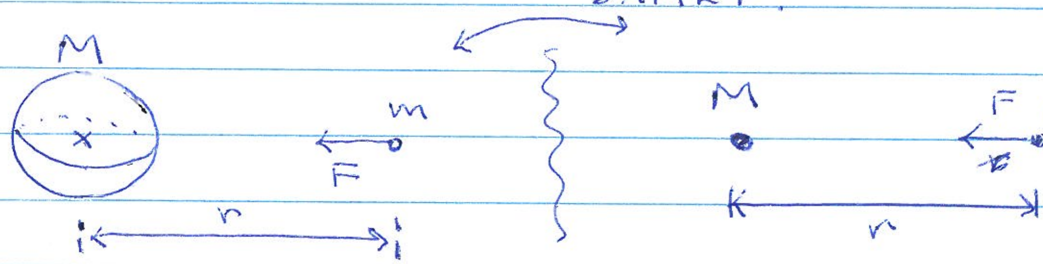
Newton's Law of Gravitation: $F = \dfrac{G m_1 m_2}{r^2}$



$G = \text{const} = 6.67 \times 10^{-11}$ SI

(Why? Einstein 1915)

SAME F!

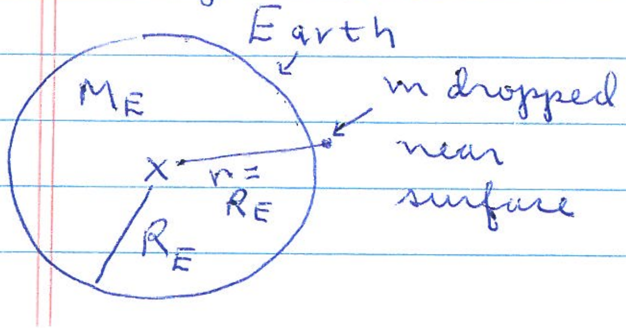


- Sphere of mass M attracts nearby m as if <u>all</u> M was concentrated at center. (Proof difficult.)

Before: Expt'l Fact: $\vec{g} = -g\hat{y} = -9.8 \frac{m}{s^2}\hat{y}$ $\uparrow +y$

for <u>all</u> m's near surface.

Why? <u>Now</u>: can derive / show why



$F_{net} = ma$

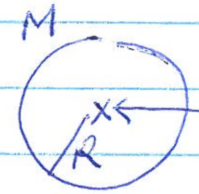
$F_{grav} = mg$ ← m's cancel!

$$\frac{G M_E \cancel{m}}{R_E^2} = \cancel{m} g$$

$$\boxed{g = \frac{GM_E}{R_E^2}}$$ ← same g for all m's

G-3 g on Planet X   G-4 Weight of satellite in orbit

If $r > R_E$



$g = \frac{GM}{r^2}$

$R_E \simeq 6400$ km, $h_{Shuttle} \simeq 400$ km

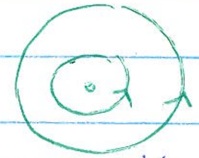
"weight" = force of gravity

"weightless" ≠ no force of gravity

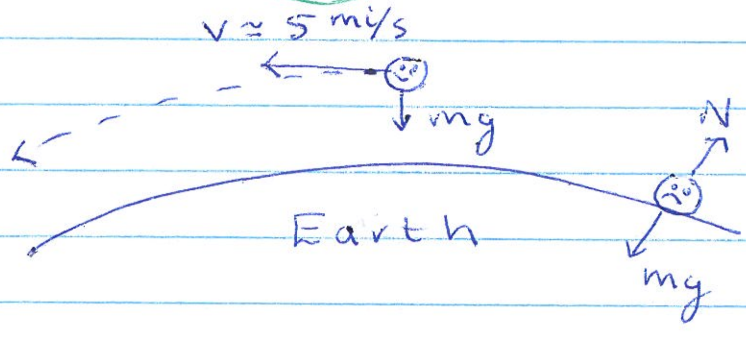
"weightless" = only force acting is gravity

= free-fall

G-5



$a_A / a_B = 4$



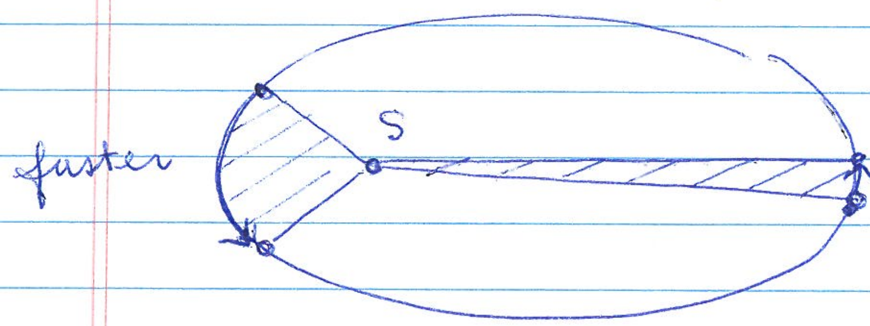
Sim: Newton's Cannon

<u>Orbits</u> Tycho vs. Kepler   Pics/Story of Tycho/Kepler

Kepler's Laws:

KI: Planet's orbit is <u>ellipse</u> w/ Sun at one focus.   Draw ellipse w/ string

K II: Line from Planet to Sun sweeps out equal areas in equal times



Same Δt, same area

K III: period T, average distance r

$$\frac{T^2}{r^3} = \text{const} = \text{same for all planets}$$

PhET sim
My Solar System

G-9 $\frac{T^2}{r^3} = \text{const}$

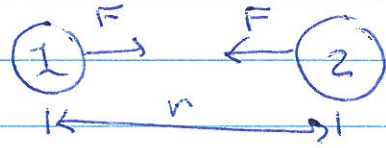
Bean bag

1

Weds Oct 17

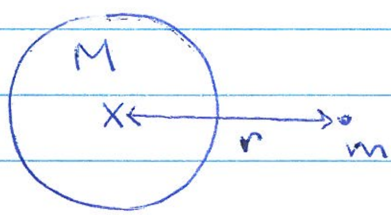
- Ch. 8
- Tut HW in recitation
- Practice Exam 2 on D2L
- Next Smart Physics Mon 8am

G-8 Projectile on Mountain



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

$\Rightarrow$ can derive g



$$F_{net} = ma$$

$$F_{grav} = mg$$

$$\frac{GM\cancel{m}}{r^2} = \cancel{m} g \qquad \boxed{g = \frac{GM}{r^2}}$$

G-6 (a) Rock / Moon g (b) g = const as rock falls

Kepler's ~~Laws~~ Rules

KI. Ellipse

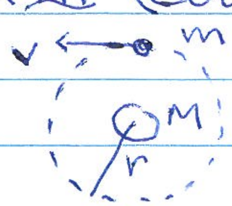
KII. equal areas / equal times

KIII. T^2/r^3 = const

PhET sim 2 body vs. 3-body problem

Newton can derive all!

KIII (Circular Orbit)



$$F_{net}^{G} = ma, \quad \frac{GM\cancel{m}}{r^{\cancel{2}}} = \cancel{m}\frac{v^2}{\cancel{r}}$$

$$v_{circ\,orb} = \sqrt{GM/r}$$

$v = \dfrac{2\pi r}{T}$ $\qquad \dfrac{GM}{r} = v^2 = \dfrac{4\pi^2 r^2}{T^2}$

period

$\dfrac{T^2}{r^3} = \left(\dfrac{4\pi^2}{GM}\right)$ = const independent of m

---

$\Delta PE_{grav} = mg\,\Delta h$ only true near Earth's surface where g = const

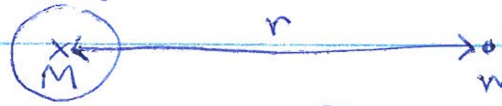
Notation $PE_{grav} = U$

Recall $\Delta PE_{grav} = \Delta U \equiv -W_{F_{grav}} = +W_{ext}$

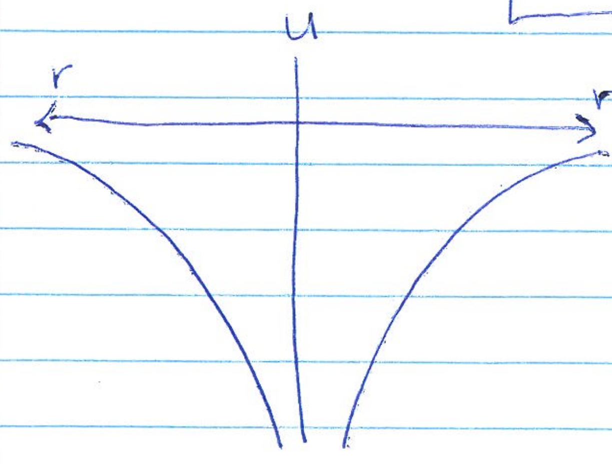
$$\Delta U = -\int_1^2 \vec{F}_{grav} \cdot d\vec{r}$$

$$U_2 - \cancel{U_1}^{\,0} = -\int_\infty^2 \vec{F}_{grav} \cdot d\vec{r} = +\int_2^\infty \vec{F}_{grav} \cdot d\vec{r}$$

Choose PE = U = 0 when $r = \infty$



Calculus $\Rightarrow$ $\boxed{U(r) = -\dfrac{GMm}{r}}$ $\xrightarrow[r\to\infty]{} 0$



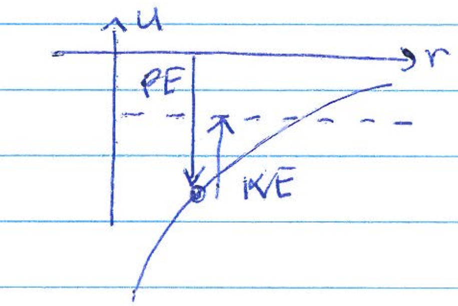
"potential well"

G10 (a) (b) work done by F_{grav}

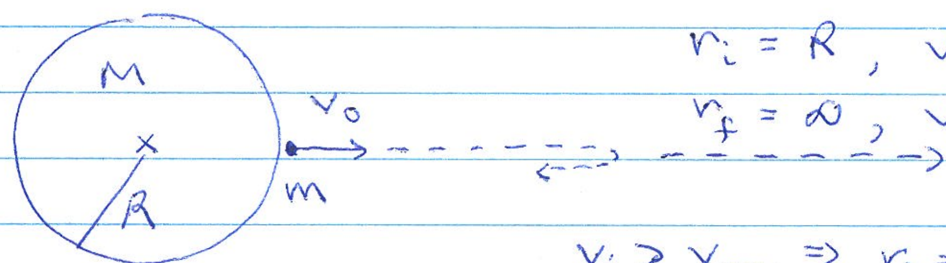
$$E_{tot} = KE + PE$$

$$\underbrace{E_{tot}}_{+ \text{ or } -} = \underbrace{\tfrac{1}{2}mv^2}_{+} - \underbrace{\frac{GMm}{r}}_{-}$$

G-11 Which is KE?



Escape Speed   Throw beanbag / PhET sim



$r_i = R$, $v_i = v_{esc} \Rightarrow$
$r_f = \infty$, $v_f = 0$

$v_i > v_{esc} \Rightarrow r_f = \infty$, $v_f > 0$

$$E_{tot} = KE_i + PE_i = KE_f + PE_f$$

$$= \frac{1}{2}mv_f^2 - \frac{GMm}{r_f}$$

G-12 $E_{tot} = 0$

$$\frac{1}{2}\cancel{m}v_{esc}^2 - \frac{GM\cancel{m}}{R} = 0 + 0$$

$$v_{esc} = \sqrt{\frac{2GM}{R}} = \sqrt{2}\, v_{\substack{circ\\orb}}$$

G-13 Dir of v_{esc}? (If time.)

2001 DVD

Fri Oct 19

- Exam 2 (Ch. 2 → 8) Thurs 7:30 – 9pm
- Early exam for CU conflict or Disability Letter
  (Sign up for early exam in lecture)
- READ Ch. 9 for Monday
- SmartPhysics Mon 8am
- CAPA Tues 10pm

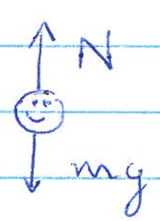
(G-19) Gravity on Shuttle Astronauts

(G-17) Equivalence Principle

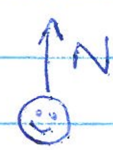
Earth

$a = 0$

$N = mg$



Space Rocket



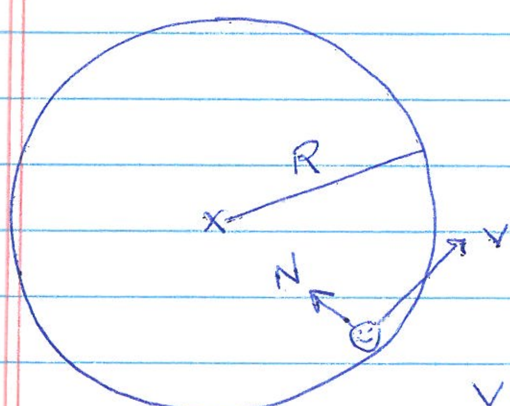
$\uparrow a = g$

$F_{net} = ma$

SAME N!

$N = mg$

(2001 Clip) Centrifuge



$F_{net} = ma$

$N = m\dfrac{v^2}{R}$ (want $N = mg$)

$N = mg$ if $\dfrac{v^2}{R} = g$

$v^2 = Rg$, $v = \sqrt{Rg} = \dfrac{2\pi R}{T}$

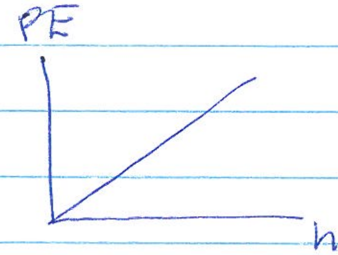
$\Rightarrow T = \dfrac{2\pi R}{\sqrt{gR}} = 2\pi\sqrt{\dfrac{R}{g}}$

(G-18) Centrifuge

②

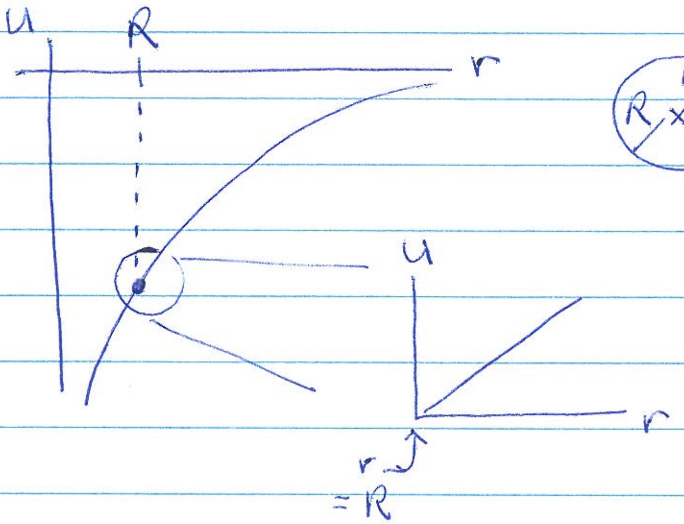
Before: $PE_{grav} = mgh$

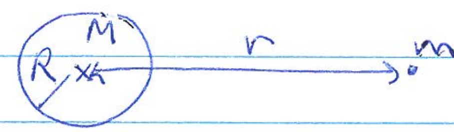
$(r = R_{Earth})$



Now: r = anything! $(r \geq R_E)$

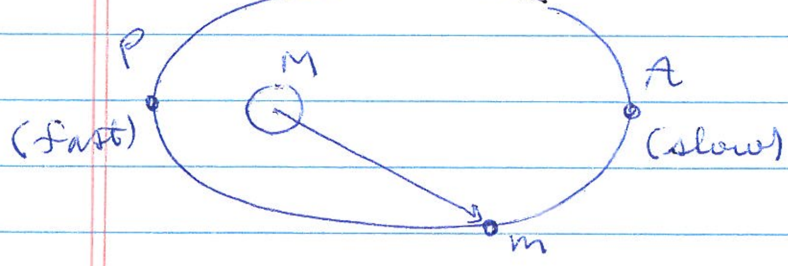
$$PE_{grav} = U(r) = -\frac{GMm}{r}$$

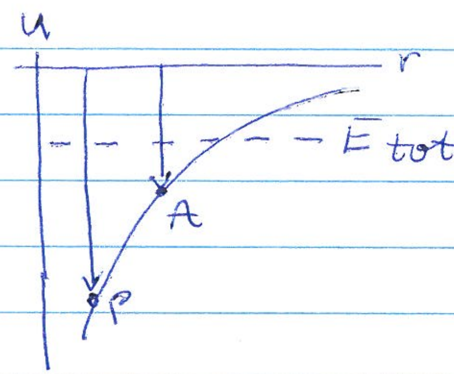




$E_{tot} = KE + PE$

$$E_{tot} = \frac{1}{2}mv^2 - \frac{GMm}{r}$$



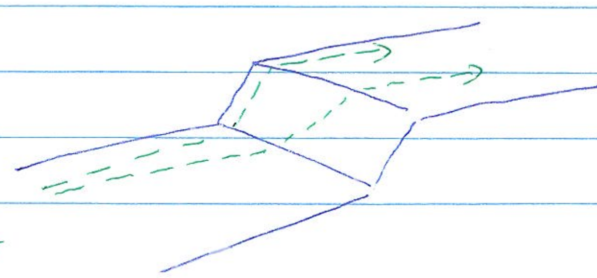


When $v = v_{esc}$, $E_{tot} = KE + PE = 0 + 0 = 0$
$r = R$

$r \to \infty$
$v \to 0$

When $v < v_{esc}$, $E_{tot} < 0$

When $v > v_{esc}$, $E_{tot} > 0$



(G-13)

(G-20) $KE_i + PE_i = KE_f + PE_f$

Air track + 2 glider
Wax cup + pin
Happy/sad balls ①
Happy/sad foam pads

Mon Oct 22

READ Ch 9

Exam 2 (Ch. 2-8) Thurs 7:30 - 9pm

Locations on Web

Early Exam sign up in lecture (CU Conflict or Disability Letter)

CAPA Tues 10pm, Tut HW recitation

SmartPhysics Fri 8am

(P-1) Which has larger momentum?

Def'n: (linear) momentum of an object $\overset{m}{O} \longrightarrow V$

$$\vec{p} = m\vec{v}$$

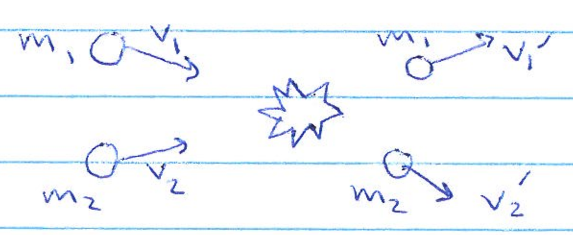
Def'n: Momentum of system of objects

$$\vec{p}_{tot} = \sum_i \vec{p}_i = \sum_i m_i \vec{v}_i$$ (Maybe repeat P-1)

units $[p] = kg \cdot \frac{m}{s}$ (no special name)

Claim: Momentum is conserved

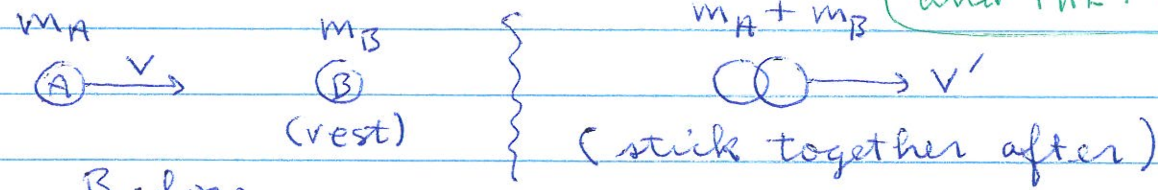
$\Rightarrow$ For <u>isolated</u> system $\vec{p}_{tot} = \text{const}$



$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_1' + m_2\vec{v}_2'$$

(P-2) Earth-car

Example: 1D Collision (Demo w/ air track and PhET sim) ②



Before

$$p_{tot,\,Before} = m_A v = p_{tot,\,after} = (m_A + m_B)\,v'$$

$$v' = \left(\frac{m_A}{m_A + m_B}\right) v \qquad (v' < v)$$

Collision Types

- elastic: KE conserved $\Leftrightarrow$ No KE ~~conserve~~ converted to PE or E_{therm}
- inelastic: some KE lost to E_{therm} or PE
- perfectly inelastic: objects collide and stick together

(Happy / Sad Balls) (P4) (a) (b) KE $\rightarrow E_{therm}$

(Demo P4 w/ air track)

(P5) (a) (b) (c) Masses/springs

Story of Newton, never once wrote $\vec{F} = m\vec{a}$

Impulse NII: $\vec{F}_{net} = m\vec{a} \Rightarrow \boxed{\vec{F}_{net} = \frac{d\vec{p}}{dt}}$

$$\frac{d\vec{p}}{dt} = \frac{d(m\vec{v})}{dt} \underset{(m\ \text{const})}{=} m\frac{d\vec{v}}{dt} = m\vec{a}$$

$$\vec{F}_{net} = \frac{\Delta\vec{p}}{\Delta t} \Rightarrow \boxed{\Delta\vec{p} = \vec{F}_{net} \cdot \Delta t}$$ True if $\vec{F}_{net}$ const during Δt

$$\left(\Delta\vec{p} = \vec{F}_{net,avg} \cdot \Delta t = \int \vec{F}_{net}\, dt\right)$$ ← True always

Def'n: Impulse $\vec{J} = \vec{F}_{net} \cdot \Delta t$

NII: $\vec{J} = \Delta\vec{p}$ To change $\vec{p}$, must apply $\vec{F}_{net}$ for Δt

(P6)

$$\vec{p}_1 + \Delta\vec{p} = \vec{p}_2$$

Physicist skateboard +
Medicine balls +
fire extinguisher

Fri Oct 26

- For Mon READ Ch. 10 Rotations
- SmartPhysics Mon 8am
- CAPA Tues 10 pm

P-1 Which has larger $\vec{p}_{tot}$? (Review, was asked before.)

$\vec{p} = m\vec{v}$, $\vec{p}_{tot} = \sum_i \vec{p}_i$

Conservation of Momentum:

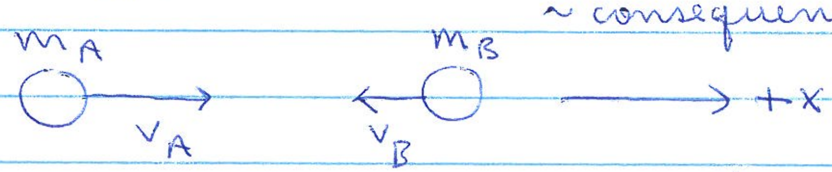
$$\vec{p}_{tot} = \sum_i \vec{p}_i = \text{constant for } \underline{\text{isolated}} \text{ system}$$

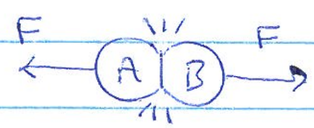
N II: $\vec{F}_{net} = m\vec{a} = \frac{d\vec{p}}{dt} \Rightarrow \Delta\vec{p} = \vec{F}_{net\ avg} \cdot \Delta t$

P-8 Bowling ball / tennis ball

Same $\vec{p}$, same $\vec{F}$, same Δt

Why $\vec{p}_{tot}$ = const ? Why is momentum conserved?
~ consequence of N III





Same $|\vec{F}|$ by N III
Same Δt

So, SAME $|\Delta\vec{p}| = |\vec{F}|\Delta t$

$\Delta p_A = -|F| \cdot \Delta t$, $\Delta p_B = +|F| \cdot \Delta t$

$\Delta\vec{p}_A = -\Delta\vec{p}_B \Rightarrow \Delta\vec{p}_{tot} = \Delta\vec{p}_A + \Delta\vec{p}_B = 0$

$\Rightarrow \vec{p}_{tot} = \vec{p}_A + \vec{p}_B = \text{const}$

P-10 Cons of E vs conservation of $\vec{p}$

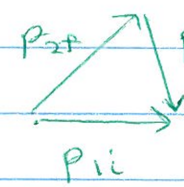
P-11 $\vec{p}_{tot}$ $\cancel{\Delta}$ in 1D

2D $\vec{p}_{tot} = \text{const} = \sum_i \vec{p}_i$

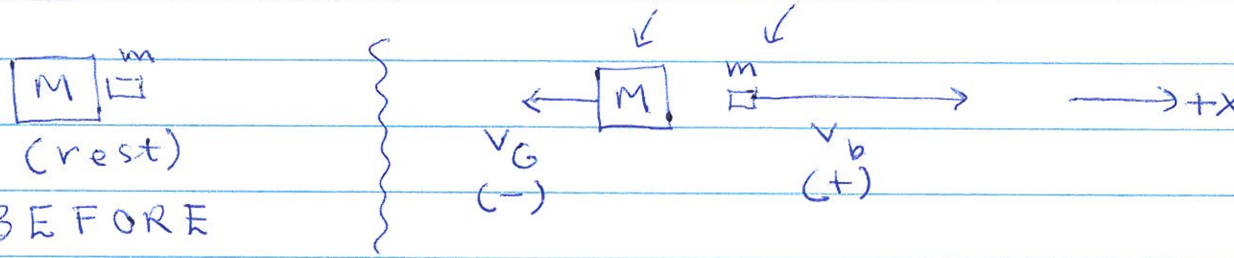
$$\Rightarrow \quad p_{tot,x} = \sum_i p_{ix} = \text{const}$$

$$p_{tot,y} = \sum_i p_{iy} = \text{const}$$

(P-12) 2D $\vec{p}_{tot} = \vec{p}_{1i} = \vec{p}_{1f} + \vec{p}_{2f}$



Rockets and Guns



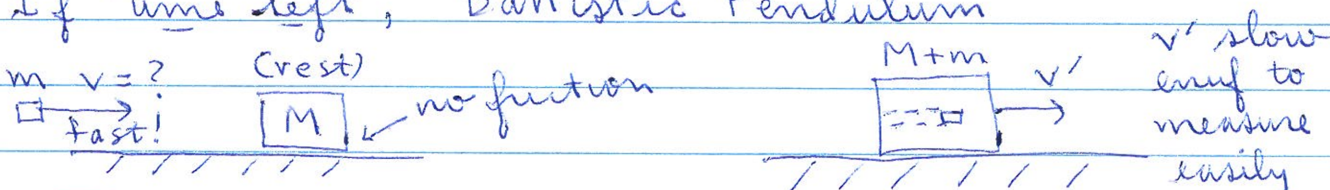
$$p_{tot} = 0 = \underbrace{M v_G}_{(-)} + \underbrace{m v_b}_{(+)}$$

$$V_G = -\frac{m}{M} v_b = -\frac{0.01\,kg}{3\,kg} \cdot 500\,m/s = -1.7\,\frac{m}{s}$$

Demos: Throw medecine balls from rolling platform (quite a kick!)

Then fire extinguisher while sitting on platform (ear protection). Comment about StarTrek warp drive.

If time left, Ballistic Pendulum



(P-14) (a) (b) (c)

$$mv = (M+m)v' \qquad v = \left(\frac{M+m}{m}\right) v'$$

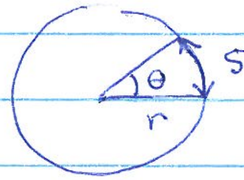
Bike wheel w/ fixed axis
Fan belt  (1)
String 1 radius long

Mon, Oct 29

- READ Ch. 10 Rotations
- SmartPhysics Weds 8am
- CAPA Tues 10pm / Tut HW in recitation

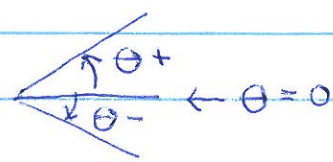
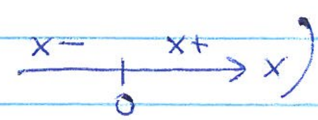
CTR-1 How many degrees in radian?

Rotation about fixed axis (like motion along x-axis)

angle in radians  $\theta = \frac{s}{r}$ (rads) (dimensionless)

$180° = ?$ rads

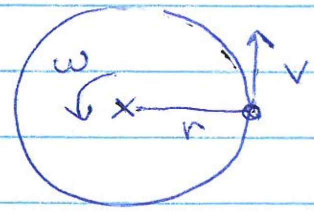
 $\theta = \frac{s}{r} = \frac{\pi \cancel{r}}{\cancel{r}} = \pi$ rads

angular position θ  (like x )

angular velocity $\boxed{\omega = \frac{d\theta}{dt}}$ (like $v = \frac{dx}{dt}$)

$[\omega] = $ rad/s

$(+\omega)$ $(-\omega)$ (like $\xrightarrow{} +v$, $-v \xleftarrow{}$)



$\boxed{v = \omega r}$ $v = \frac{\Delta s}{\Delta t} = r\frac{\Delta\theta}{\Delta t} = r\omega$ ✓

$\left(\Delta\theta = \frac{\Delta s}{r},\ \Delta s = r\,\Delta\theta\right)$

Rot (2a) (2b) Big Ben

Rot (3a) (3b) 

Angular acceleration $\boxed{\alpha = \frac{d\omega}{dt}}$ (like $a = \frac{dv}{dt}$)

$[\alpha] = $ rad/s^2

$\omega = \text{const} \iff \alpha = 0$, $\omega \nearrow \iff \alpha > 0$, $\omega \searrow \iff \alpha < 0$

Recall Ch. 2 : $v = dx/dt$, $a = dv/dt$

$$a = \text{const} \Rightarrow \begin{cases} v = v_0 + at \\ x = x_0 + v_0 t + \frac{1}{2} a t^2 \\ v^2 = v_0^2 + 2a(x - x_0) \end{cases}$$

Now Ch 10 : $\omega = d\theta/dt$, $\alpha = d\omega/dt$

$$\alpha = \text{const} \Rightarrow \begin{cases} \omega = \omega_0 + \alpha t \\ \theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2 \\ \omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0) \end{cases}$$

Feynman: "Same eq'ns have same solutions."

Rot 4 Which equation to use?

$\omega = \frac{\#\text{ rads}}{s}$, frequency $f = \frac{\#\text{ rev's}}{s}$ (1 rev $= 2\pi$ rad)

$\omega = \frac{2\pi \text{ rad}}{T}$, $f = \frac{1 \text{ rev}}{T}$

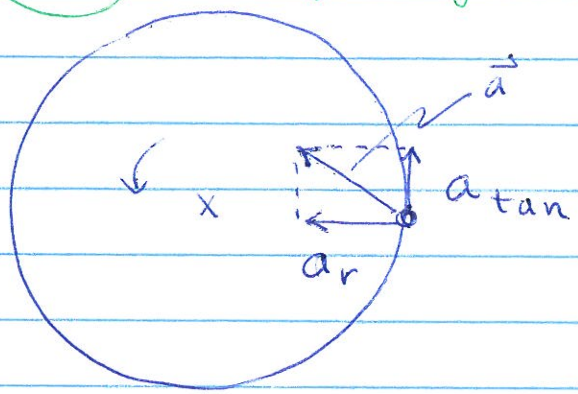
period $\rightarrow$

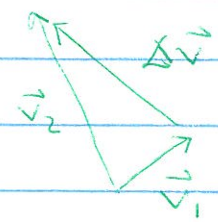
$\omega = 2\pi f$, ~~$2\pi \frac{rad}{rev}$~~ $\omega\left(\frac{rad}{s}\right) = 2\pi\left(\frac{rad}{rev}\right) f\left(\frac{rev}{s}\right)$

2π rad/rev

R-5 rev/min^2 or rad/min^2

R-6 Lady bug on rim, speeding up





$(v = \omega r)$

radial acceleration $a_r = \frac{v^2}{r} = \omega^2 r$

tangential acceleration $a_t = \frac{dv}{dt} = r\frac{d\omega}{dt} = r\alpha$

$\boxed{a_{tan} = r\alpha}$ $\qquad (v = \omega r)$

1D	Trans	Rot
	x	θ
	$v = dx/dt$	$\omega = d\theta/dt$
	$a = dv/dt$	$\alpha = d\omega/dt$
	F	?
	M	?
	$F_{net} = Ma$	$? = ?\,\alpha$
	$KE = \frac{1}{2}Mv^2$	$KE = \frac{1}{2}\,?\,\omega^2$

start Weds lecture?

Weds, Oct 31

Meter sticks + weights
C-clamps (1)
Bicycle wheel fixed axis
Yellow handle hammer
tiny/giant crescent wrenches

- READ Ch. 10
- Tut 8 HW in recitation
- ~~CAP~~ SmartPhysics

(R-7) PhET spinning wheel $\alpha = 0$ $\omega = \text{const}$

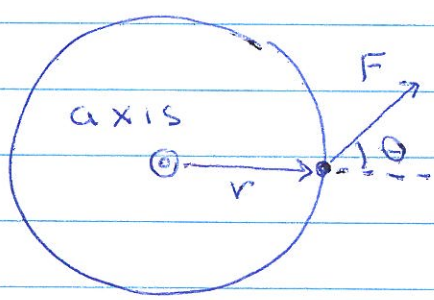
$\omega = d\theta/dt$ (like $v = dx/dt$)

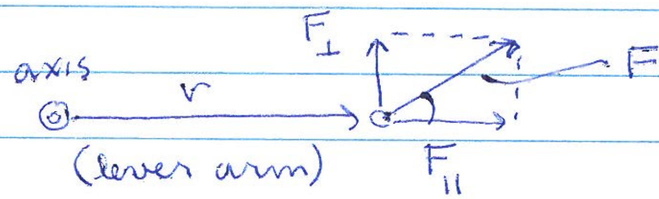
$\alpha = d\omega/dt$ (like $a = dv/dt$)

(?) causes α (like F_{net} causes a)

torque $|\tau| = r \cdot F_{\perp} = r F \sin\theta$

$\theta = \measuredangle \vec{r}, \vec{F}$ (Not θ in $\omega = d\theta/dt$!)





(R-8) Largest τ?

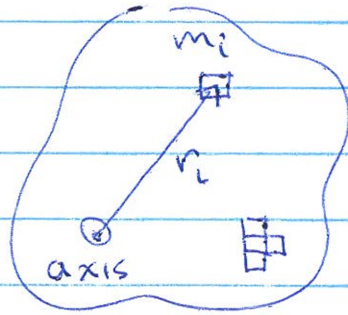
sign convention $(+\tau)$ $(-\tau)$ (like $\longrightarrow F+$ $F- \longleftarrow$)

$\tau_{net} = \sum_i \tau_i$ (R-9) $\tau_{net} = ?$

τ_{net} causes α (like F_{net} causes a)

$\tau_{net} = I \cdot \alpha$ (like $F_{net} = Ma$)

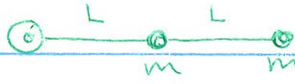
I = rotational mass = "moment of inertia"



$$I = \sum_i m_i r_i^2$$

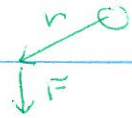
r_i = distance to axis

Demo: meter sticks + weights
large and small I

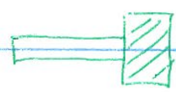
R-11 (a) 

$I = 5mL^2$

(b) $\tau = 3mgL$ (c) $\alpha = \frac{\tau}{I} = \frac{3\cancel{m}gL}{5\cancel{m}L^{2}} = \frac{3}{5}\frac{g}{L}$

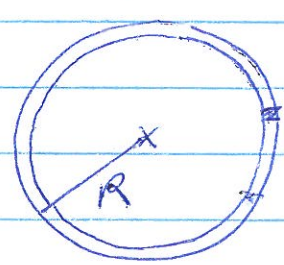
R-10 (a) (b) 

$\tau \searrow$, $\alpha \searrow$

R-12  I_{max}

R-13 I_{hoop} vs I_{DISC}

Hoop
M, R



$$I = \sum_i m_i \underset{R}{r_i^2} = R^2 \underbrace{\sum_i m_i}_{M}$$

$$= MR^2$$

Solid Disk
M, R

$$I = \tfrac{1}{2} MR^2$$

R- 14 a 14 b ~~B~~ Pulley CT's (if time)

No time for R-14

- Fixed axis bicycle wheel
- Rolling tan spokes wheel
- 2 kg mass clamped to 2-meter stick
- ramp w/ rolling masses

Fri Nov 2

- For Mon, Read Ch. 11
- Smart Physics
- CAPA Tues 10 pm

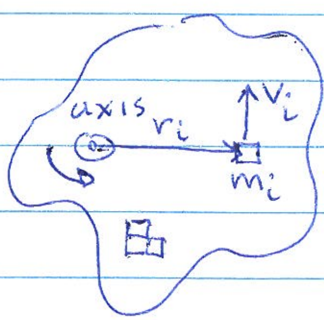
R-14 (a) (b) $\quad mg > F_T \quad , \quad \tau = R F_T \; \cancel{\gtrless} \; R\,mg$

$\omega = d\theta/dt \qquad \alpha = d\omega/dt \qquad |\tau| = r F_\perp$

$I = \sum_i m_i r_i^2 \qquad \tau_{net} = I\alpha$ (like $F_{net} = ma$)

~~BW~~ PhET sim torque and rotation, Sim name is Torque

Rotational KE: $KE_{rot} = \frac{1}{2} I \omega^2$ (like $KE_{trans} = \frac{1}{2} m v^2$)

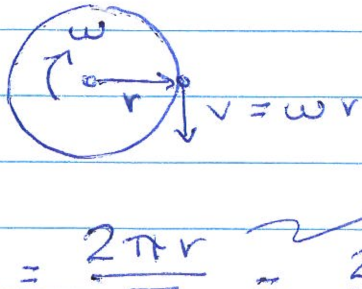


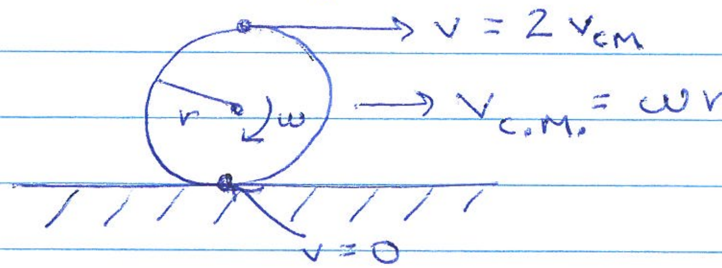
$$KE_{tot} = \sum_i \tfrac{1}{2} m_i v_i^2 = \tfrac{1}{2} \underbrace{\sum_i m_i r_i^2}_{I} \cdot \omega^2$$

$(v_i = \omega r_i)$

Fixed axis vs Rolling Wheel

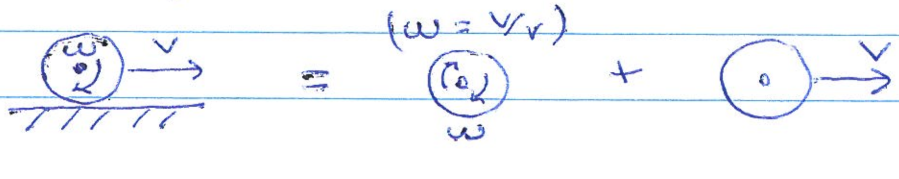
c.M. = center of mass





$$v_{CM} = \frac{2\pi r}{T} = \frac{2\pi}{T} \cdot r = \omega r$$

~~KE~~ rolling: wheel motion



$$KE_{rolling} = KE_{trans} + KE_{rot}$$

$$= \frac{1}{2} M v_{CM}^2 + \frac{1}{2} I_{CM} \omega^2 \qquad (v_{CM} = \omega r)$$

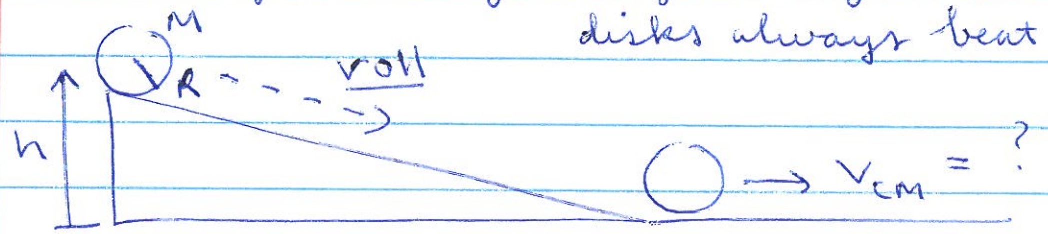
R-15 $\bigcirc \rightarrow$ $\bigcirc \rightarrow$ largest KE ?

Rolling Demo Hoop vs Disk? Hoop vs hoop?

Ask for show of hands: who wins?

Must explain why: hoops always tie, disks always tie

disks always beat hoops



$$KE_i + PE_i = KE_f + PE_f$$

$$0 + Mgh = \left(\frac{1}{2} M v^2 + \frac{1}{2} I \omega^2\right) + 0$$

$I = \beta M R^2$, $\beta = 1$ (hoop) or $\frac{1}{2}$ (disk) or $\frac{2}{5}$ etc (sphere)

$$\frac{1}{2} I \omega^2 = \frac{1}{2} \beta M \cancel{R^2} \left(\frac{v}{\cancel{R}}\right)^2 = \frac{1}{2} \beta M v^2$$

$$\Rightarrow \cancel{M} g h = \frac{1}{2} (\beta + 1) \cancel{M} v^2$$

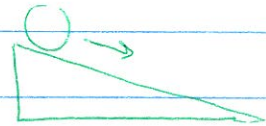
$$v = \sqrt{\frac{2gh}{(1+\beta)}}$$ (No R, No M in formula)

Big $\beta \rightarrow$ small v, Why??,

$Mgh = KE_{rot} + KE_{trans}$ = fixed total (Mgh)

Big $\beta \rightarrow$ Big $KE_{rot} \rightarrow$ less $KE_{trans} \rightarrow$ smaller v

R-17

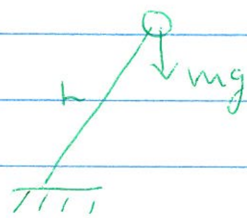


Which has largest KE_{tot}?
(same!)

R-18

greatest h_f?
(Hoops)

R-26



$$\alpha = \frac{\tau}{I} = \frac{mgL\sin\theta}{mL^2} \propto \frac{1}{L}$$

Larger L <u>easier</u> to balance.

Demo balance weight on 2-m stick

<u>If time</u>

R-23 (a) (b) (c)

$$\alpha = \frac{\tau}{I} = \frac{\cancel{m}g\cancel{L}\sin\theta}{\cancel{m}L^{\cancel{2}}} = \frac{g\sin\theta}{L}$$

Bicycle wheel / glove / rotating platform / hand weights (1)

Mon Nov 5

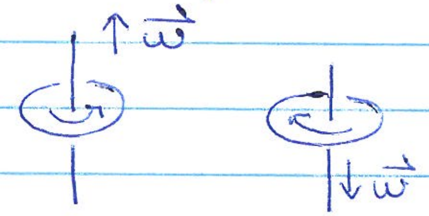
- Read Ch. 11 (for Fri, Ch. 12)
- Smart Physics
- CAPA Tues 10pm / Tut HW in recitation

(ANG-0) Have you studied cross-product before

Angular Momentum $L = I\omega$ (like $p = mv$)

angular velocity $\omega = \frac{d\theta}{dt}$ (+) (−) fixed axis

Axis not fixed: angular velocity vector $\vec{\omega} \parallel$ axis



$|\vec{\omega}| = |d\theta/dt|$

$\Leftarrow$ "right-hand rule"

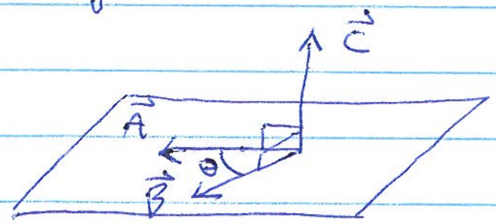
angular acceleration vector $\vec{\alpha} = \frac{d\vec{\omega}}{dt} \approx \frac{\Delta\vec{\omega}}{\Delta t} = \frac{\vec{\omega}_2 - \vec{\omega}_1}{\Delta t}$

(ANG-1) $\vec{\alpha} \parallel \Delta\vec{\omega}$

$\vec{\omega}_1$ $\vec{\omega}_2$ $\Delta\omega$ $\qquad \vec{\omega}_1 + \Delta\vec{\omega} = \vec{\omega}_2$

torque vector $\vec{\tau} = \vec{r} \times \vec{F}$ $\quad (|\vec{\tau}| = |r F_\perp|)$

cross product $\vec{A} \times \vec{B} = \vec{C}$

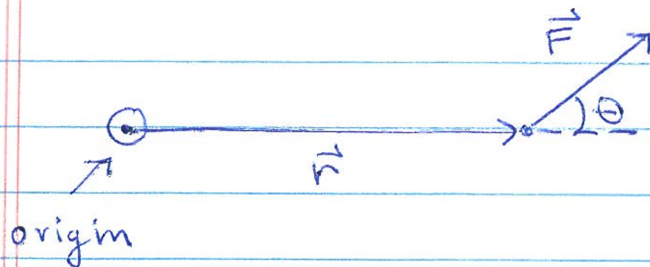


right-hand rule

$|\vec{C}| = |\vec{A} \times \vec{B}| = AB\sin\theta = AB_\perp$

$B\sin\theta = B_\perp$

(Ang 2) $\hat{j} \times \hat{i} + \hat{k} = ?$



$\vec{\tau} = \vec{r} \times \vec{F}$ $\quad \overset{\vec{\tau}}{\odot}$ (out)

depends on origin

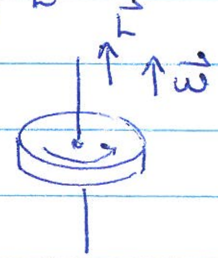
fixed axis: $\tau_{net} = I\alpha$

any axis: $\vec{\tau}_{net} = I\vec{\alpha} = I\frac{d\vec{\omega}}{dt}$ (like $\vec{F}_{net} = m\vec{a} = m\, d\vec{v}/dt$)

Ang 3) $\vec{\tau}_{\substack{earth\\sun}} = 0$

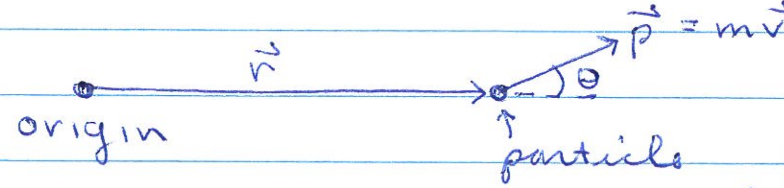
Angular Momentum $\vec{L}$ of spinning object

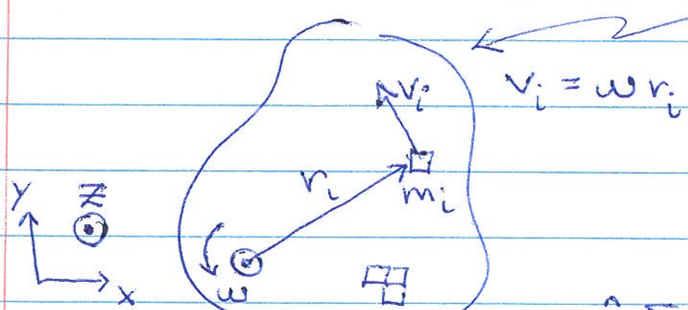
$\underbrace{\vec{L} = I\vec{\omega}}_{\text{not def'n of } \vec{L}}$ (like $\underbrace{\vec{p} = m\vec{v}}_{\text{def'n of } \vec{p}}$)



Def'n of angular momentum of particle = $\vec{L}_{part} \equiv \vec{r} \times \vec{p}$

(depends on origin)





$v_i = \omega r_i$

$\vec{L}_{tot} = \sum_i \vec{L}_i =$

$\sum_i \vec{r}_i \times m_i \vec{v}_i =$

$\hat{z} \sum_i r_i m_i \underbrace{v_i}_{r_i \omega} =$

$= \hat{z} \sum_i m_i r_i^2 \omega = \hat{z} I \omega = I\vec{\omega}$ ✓

Conservation of Angular Momentum

If $\vec{\tau}_{net} = 0$, $\vec{L}_{tot} = \text{const}$

(like if $\vec{F}_{net} = 0$, $\vec{p}_{tot} = \text{const}$)

Claim: $\vec{\tau}_{net} = \frac{d\vec{L}}{dt}$ (like $\vec{F}_{net} = d\vec{p}/dt$)

(Proof in notes)

$$\Rightarrow \vec{\tau}_{net} = 0 \Longleftrightarrow \frac{d\vec{L}}{dt} = 0 \Rightarrow \vec{L} = \text{const}$$

$$\vec{L} = I\vec{\omega} = \text{const} \Rightarrow I \downarrow \quad \omega \nearrow$$

Ang Mom 4 $\quad L_{planet} = \text{const}$

Wheel + handweights demo (if time)

①

Weds Nov 7

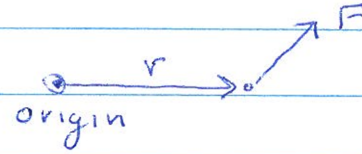
- Hobermann sphere
- rotating platform/ cluthwheel/glove
- bicycle wheel clamped to stand
- flashlight

- Read Ch. 11
- Tut HW in recitation
- SmartPhysics Fri 8am

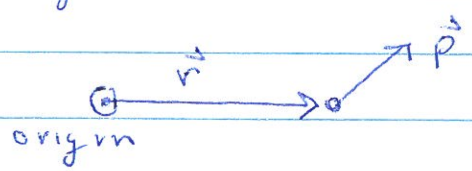
CT-5 $\quad \vec{L}\uparrow \quad \vec{L}\uparrow \quad \vec{L}\downarrow \qquad \vec{L}_{tot} = \vec{L}$

$\uparrow\vec{\omega} \quad |\vec{\omega}| = |d\theta/dt| \quad , \quad \vec{\alpha} = d\vec{\omega}/dt \; ,$

$\vec{\tau} = \vec{r} \times \vec{F}$



Angular Momentum



$\vec{L}_{particle} = \vec{r} \times \vec{p}$

(depends on origin)

$\Rightarrow \vec{L}_{object} = I\vec{\omega}$ ⟵ does not depend on origin

spinning about stationary axis

$\vec{\tau}_{net} = I\alpha$ (if I const) $\qquad$ (like $\vec{F}_{net} = m\vec{a}$ if m const)

$$\boxed{\vec{\tau}_{net} = \frac{d\vec{L}}{dt}} \qquad \left(\text{like } \vec{F}_{net} = \cancel{m}\frac{d\vec{p}}{dt}\right)$$

Conservation of Angular Momentum

$\vec{\tau}_{net} = 0 \Rightarrow \vec{L} = \text{const}$

$L = I\omega = \text{const} \Rightarrow I \searrow$ as $\omega \nearrow$

Wheel + platform demo $\qquad$ NIII discussion

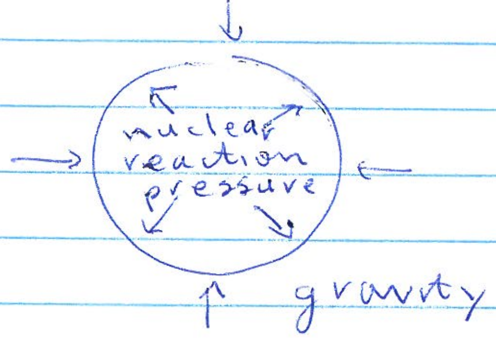
AngMom 6 (a) (b) (c) ~~KE~~ =

$$KE_{rot} = \frac{1}{2} I \omega^2 = \frac{1}{2} \frac{(I\omega)^2}{I} = \frac{1}{2} \frac{L^2}{I}$$

AngMom 8 Flip Wheel

Bicycle Wheel Gyro Demo

Stellar Evolution



Fusion reaction

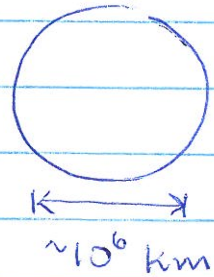
light/heat

$4H \rightarrow 1He + \gamma's + 2\nu + 2e^+$

$H \rightarrow He$ runs out in 10 billion years $\Rightarrow$ then Sun will shrink

Star

$M_\odot$ = 1 solar mass



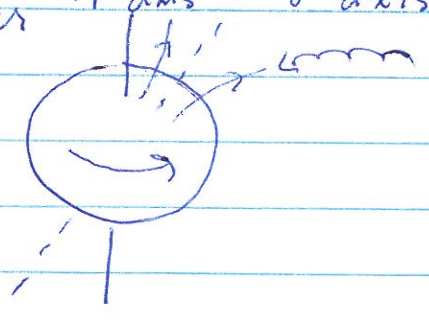
$M < 1.4 M_\odot$ → 10^4 km white dwarf

$1.4 M_\odot < M < 3 M_\odot$ → 10 km neutron star $v_{esc} \simeq 0.8c$

$M > 3M_\odot$ → <10 km black hole $v_{esc} > c$

Hobermann Sphere

Pulsar



Flashlight

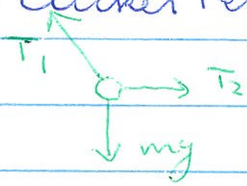
Pulsar Sounds

~~Short ladder~~
board w/ Pb brick

Fri Nov 9

- READ Ch. 12, 13 (For Mon/Weds Ch. 13)
- CAPA Tues 10 pm
- SmartPhysics Mon 8am
- Sign ups for Clicker Team on Website

SE-9



$T_2 \gtreqless T_1$

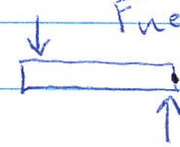
Static Equilibrium of an object assured if

(1) object NOT translating $\leftrightarrow$ $\updownarrow$

(2) object NOT rotating

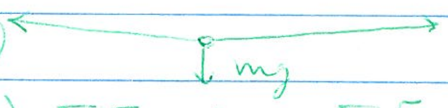
(1) $\Rightarrow \vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \ldots = \sum_i \vec{F}_i = 0$

$\Rightarrow \boxed{\sum F_x = 0 \quad , \quad \sum F_y = 0}$



(2) $\tau_{net} = \sum \tau_i = 0$ $\tau +$ $\tau -$ about any axis

SE1



SE2 $\sum F_x = 0 , \quad \sum F_y = 0$

SE3 $\tau +$

SE4 $\sum \tau = 0$ about any axis

SE5 (a) $F_R \frac{L}{3} = F_L 2 \frac{L}{3}$ $\quad F_R / F_L = 2$

(b) Ask (b), then ask (c), then back to (b)

(c) Where to put origin?

Short Ladder ①

Mon Nov 12

- READ Ch. 12 (For Weds ~~&~~, Ch 13)
- CAPA Tues 10 pm / Tut HW in recitation
- SmartPhysics Weds 8am

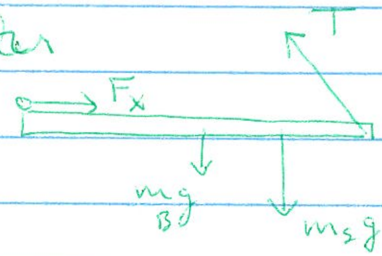
Static Equilibrium if

(1) $\Sigma F_x = 0$; $\Sigma F_y = 0$

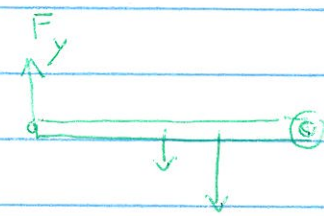
(2) $\sum_i \tau_i = 0$ about *any* axis

~~SE6 Ladder~~

SE7 (a)

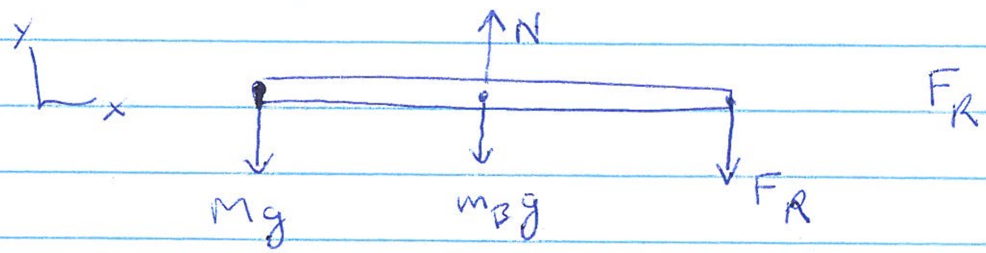


(b)



SE6 Ladder (a) (b) (c) (d) Ladder demo

SE8 Draw extended FBD. Have audience throw paper it



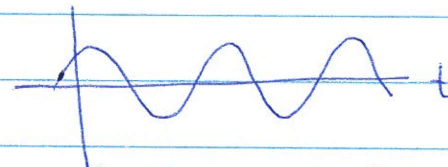
$F_R = ?$ $\cancel{R}\, F_R = - \cancel{R}\, Mg$

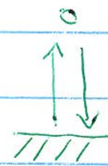
If time:

Simple Harmonic Motion

- restoring force ∝ displacement for Equilibrium (like $F_{spr} = -kx$)
- $PE \propto x^2$ (like $\cancel{P} PE_{elastic} = \frac{1}{2} k x^2$)

- period T independent of amplide A of motion

- x, v, a all sinusoidal 

SHM-1  Is bouncing ball SHM?

~~kyfed382 = Kyle ferguson~~

Demos: ①
Superball
Vertical mass on spring
horiz mass/cart on spring

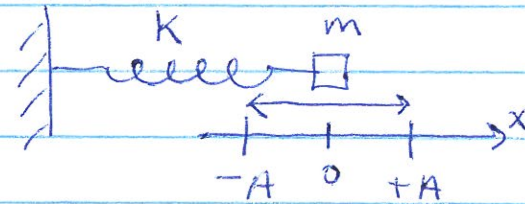
Weds Nov 14

- READ Ch. 13
- Tut HW in recitation / next CAPA due after Fall break
- Exam 3 is Thu Nov 29
- Smart Physics

SHM-1 Bouncing ball $\neq$ SHM

Simple Harmonic Motion (SHM) when
- $F_{restore} \propto x$
- $PE \propto x^2$
- T ind of amplitude A — PhET sim Masses and Springs
- x, v, a vs. t all sinusoidal

Differential Eq'n for SHM



$$\underbrace{F_{net}}_{-k\cdot x} = ma \Rightarrow a = -\frac{k}{m}\cdot x$$

$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2} = -\frac{k}{m}\cdot x \, ;$$

Notation: $\underbrace{\omega^2}_{(+)} = \frac{k}{m}$

$$\boxed{\frac{d^2x}{dt^3} = -\omega^2 x}$$ ⇐ diff. eq'n for $x = x(t)$

SHM5 Differential Eq'n

Solution $x = x(t)$? Guess answer!

$x(t) = A\cos(\omega t + \varphi)$; A, φ constants

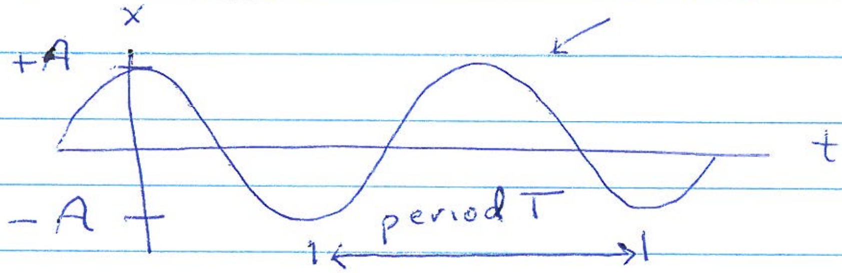
Chain rule

Check: $\frac{dx}{dt} = -A\sin(\omega t + \varphi) \cdot \omega = v$

$\frac{d^2x}{dt^2} = -\cancel{A}\,\omega^2 \underbrace{A\cos(\omega t + \varphi)}_{x} = -\omega^2 x$ ✓ Works!

$\boxed{\omega = \sqrt{\frac{K}{m}}}$

$x(t) = A\cos(\omega t + \varphi)$



Claim: $\omega = \frac{2\pi}{T}$ SHM 7 $\Delta\theta = 2\pi$ for 1 period

$\theta = \omega t + \varphi \Rightarrow \Delta\theta = \omega \cdot \Delta t \quad (\varphi = \text{const})$

$\Rightarrow 2\pi = \omega \cdot T \Rightarrow \omega = 2\pi/T$

$\boxed{\omega = \sqrt{\frac{K}{m}} = \frac{2\pi}{T}}$ SHM 8 $T = 2\pi\sqrt{\frac{m}{K}}$ m, K, A 1/2x ~~A~~ T → const

$T = 2\pi\sqrt{\frac{m}{K}}$ independent of A

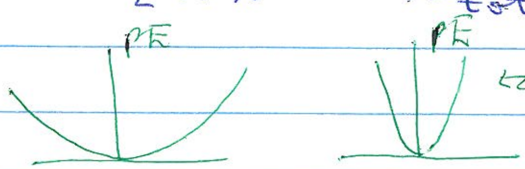
Conservation of Energy for SHM mass/spring

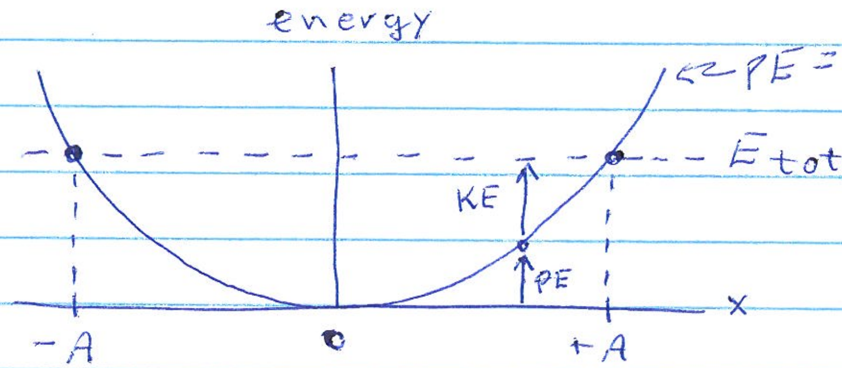
PhET sim Masses/Springs

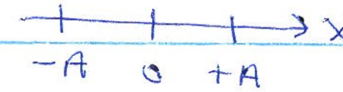
KE + PE = const (if no friction)

$\frac{1}{2}mv^2 + \frac{1}{2}Kx^2 = E_{tot} = \text{const}$

3a







3b 3c

$x = 0$: $PE = 0$, $KE_{MAX} = E_{tot}$, $v = v_{MAX}$

$x = \pm A$: $v = 0$, $PE_{Max} = E_{tot}$

$$KE_{Max} = \frac{1}{2} m v_{MAX}^2 = PE_{Max} = \frac{1}{2} k A^2 = E_{tot}$$

$$v_{MAX} = \sqrt{\frac{k}{m}}\, A = \omega A$$

3d $k \nearrow$, $E_{tot} \rightarrow$, $A \downarrow$

If time

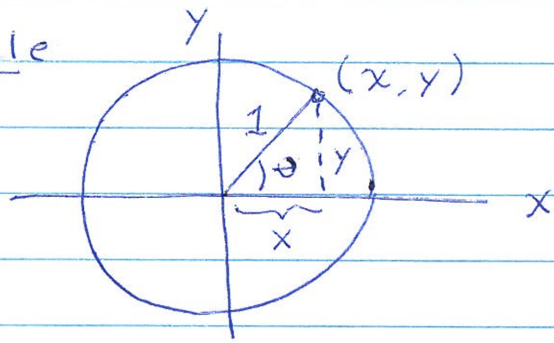
Pendulum ①
styrofoam rock
Vortex + smoke
Magnet drops

Fri Nov 16 (before Fall break)

READ Ch. 14 (Mon after break)
CAPA Tues 10pm (after break)
Exam 3 Thurs Nov 29, 7:30-9pm
SmartPhysics Mon after Fall break   SHM2(a)(b)(c)

SHM (9a) $\sin\theta = (+)$ or $(-)$

Unit Circle



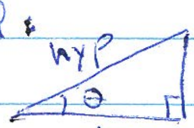
College

$\cos\theta = \frac{X}{1} = x$

$\sin\theta = \frac{Y}{1} = y$

$\tan\theta = y/x$

High School:



$\cos\theta = $ adj / hyp

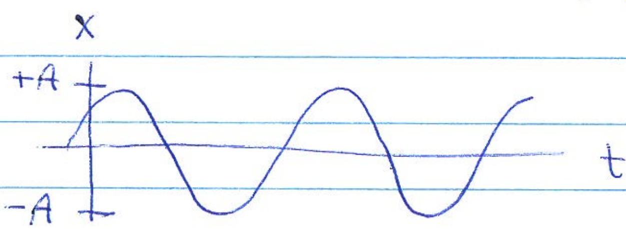
$\sin\theta = $ opp / hyp

$\tan\theta = $ opp / adj

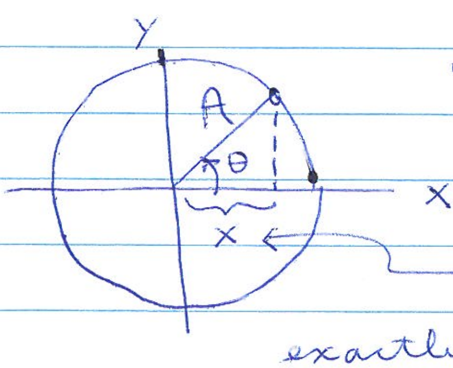
(9b) $\cos(270°) = ?$

Circular Motion and SHM

SHM: $x = A\cos(\omega t + \varphi) = A\cos\theta$



$\omega = \sqrt{\frac{k}{m}} = \frac{2\pi}{T}$



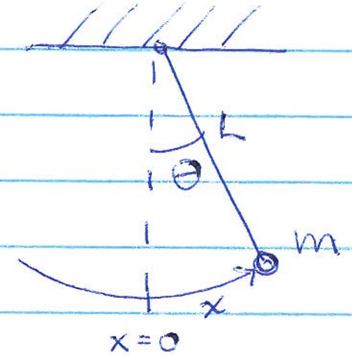
$\theta = \omega \cdot t + \varphi$, $\omega = \frac{d\theta}{dt} = \Delta\theta/\Delta t$

$\Delta\theta = \omega \cdot \Delta t$

$x = A\cos\theta = A\cos(\omega t + \varphi)$

exactly same formula in both cases

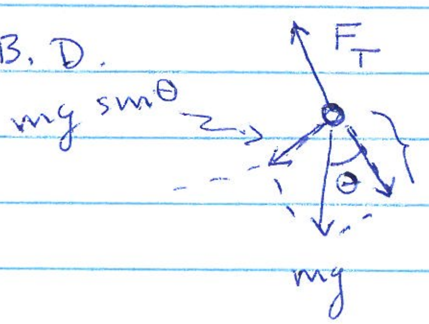
Simple Pendulum



$\theta \text{ (rads)} = \dfrac{x}{L}$

⇐ curved x-axis

F. B. D.



$|F_{restore}| = mg\sin\theta$

$F_{restore} = -mg\sin\theta$

$F_{restore} \simeq -\left(\dfrac{mg}{L}\right)\cdot x \qquad \underset{(\text{small }\theta)}{\simeq} -mg\cdot\theta$

Exactly like $F_{restore} = -kx$ (replace k w/ $\frac{mg}{L}$).

$\omega = \dfrac{2\pi}{T} = \sqrt{\dfrac{k}{m}} \xrightarrow[k \to \frac{mg}{L}]{} \dfrac{2\pi}{T} = \sqrt{\dfrac{g}{L}}$

$T = 2\pi\sqrt{\dfrac{L}{g}}$ ~~SH~~ SHM 10 T ind of m

SHM 11 T depends on ~~x~~ g

PhET pendulum sim $T = T(A)$

Ch. 14 Fluids (Liquid or Gas)

pressure $= \dfrac{\text{force}}{\text{area}}$, $p = \dfrac{F_\perp}{A}$

$[p] = \dfrac{N}{m^2}$ = pascal (Pa)

"rho"

density $= \dfrac{\text{mass}}{\text{volume}}$, $\rho = \dfrac{m}{V}$, $[\rho] = \dfrac{kg}{m^3}$ or g/cm^3

$\rho_{water} = 1 \dfrac{g}{cm^3} = 1000\ kg/m^3$

$\rho_{iron} = 7.9\ g/cm^3$, $\rho_{air} \simeq 1.5\ kg/m^3$

F1 density   F2 pressure on window
F3 Big rock mass = ?

If time, vortex machine, magnet drops

Magdeburg spheres
glass containers w/ red dye
Floating bowling ball (1)
diet/regular coke

Mon Nov. 26

CAPA Tues 10 pm / Tut HW Thurs

READ Ch. 15 Fluids, then Ch. 14 Waves/Sound

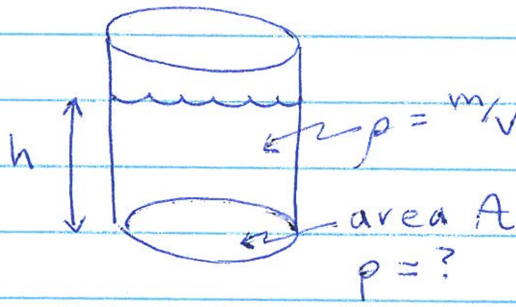
Next SmartPhysics next week / Exam 3 / Early exam signup

Fluids 2 pressure

pressure $p = F_\perp / A$ $\quad (N/m^2 = Pa)$

density $\rho = \frac{M}{V}$ $\quad (kg/m^3)$ $\Rightarrow m = \rho \cdot V$

pressure due to weight of fluid above:



$$p = \frac{F}{A} = \frac{mg}{A} = \frac{\rho V g}{A}$$

$(V = A \cdot h)$

$$p = \frac{\rho \cancel{A} h g}{\cancel{A}} =$$

$$\boxed{p = \rho g h}$$ ⇐ assumes ρ = const

$\Delta p = \rho g \Delta h$

p is same in every direction

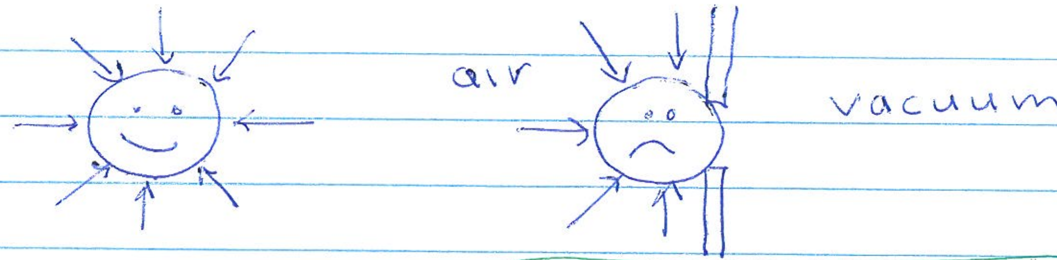
E4 equal levels

Demo w/ water glass containers

$p_{atm} = 1.01 \times 10^5$ Pa $\simeq 15$ lb/in^2

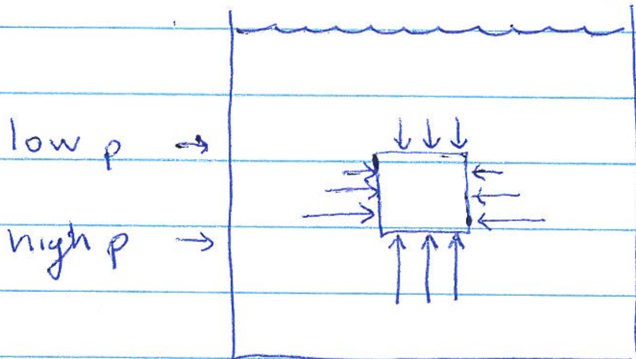
PhET sim ideal gas

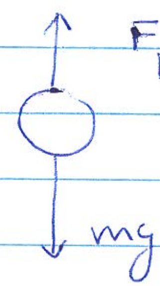
Magdeburg sphere demo



Buoyant Force

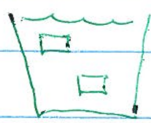
Floating Bowling Ball





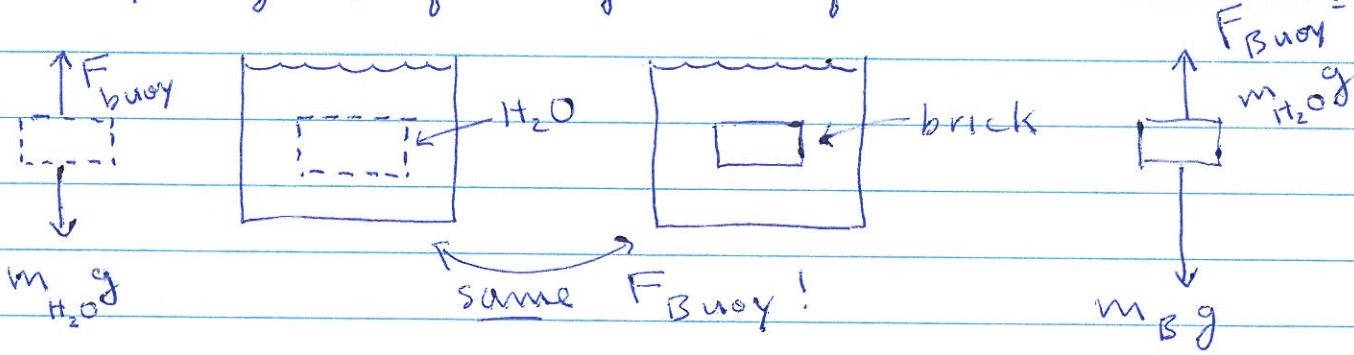
F_{buoy} = <u>net</u> force due to pressure from <u>all</u> sides

F5



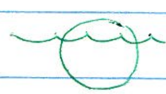
Archimedes Principle (Greek 287 - 212 B.C.)

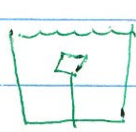
The upward buoyant force on submerged object = |weight| of displaced fluid



$F_{Buoy} < mg$, m <u>sinks</u> , $F_{Buoy} > mg$, m <u>rises</u>

Diet / Regular Coke

F6  $F_B = mg$

F7  $F_B = \rho_w V g$

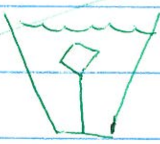
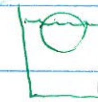
Weds, Nov 28

Exam 3 Review

Crown of Archimedes
Lead brick

Fri Nov 30

- Today Ch. 15 Fluids
- READ Ch. 14 Wave Motion for Mon
- CAPA Tues / 10 pm
- ~~Ex~~ SmartPhysics next Weds

~~Fluids 7~~  F-6 (again) 

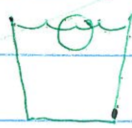
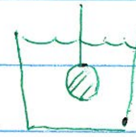
Archimedes' Principle

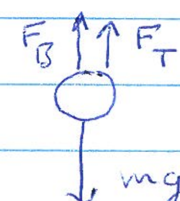
|Buoyant force| = |weight of displaced fluid|

story of Au/Pb Movie 3 Kings

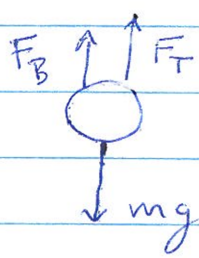
$\rho = \frac{m}{V}$, $m = \rho V$, weight $= mg = \rho V \cdot g$

$F_{Buoy} = m_{fluid}\, g = \rho_{fluid} V g$

~~F-8~~  $F_B = ?$ start w/ $\Rightarrow$ F-9 



Crown of Archimedes Demo Gold or Lead?
Au/Pb story



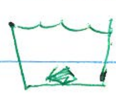
$\Sigma F_y = 0 \qquad F_B + F_T - mg = 0$

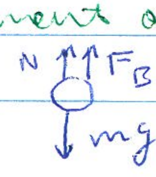
$F_B = mg - F_T$

$\rho_{water} \cdot V_{crown} \cdot g = mg - F_T$

$\Rightarrow$ can solve for $V_{crown} \Rightarrow \rho_{crown} = \frac{M}{V_{crown}}$

F-11 ice cube Comment on Global Warming

F-12 (if time) 



Mon Dec 3

- READ Ch. 14
- Smart Physics Weds 8am
- CAPA Tues 10pm
- Final exam <u>in</u> <u>Coors</u>

W-1 Drumhead = transverse wave

- ~~Transverse~~

Wave = self-propagating disturbance in a <u>medium</u>

<u>air</u>, <u>water</u>, <u>string</u>, <u>people</u>

- transverse $\updownarrow$ medium $\xrightarrow{\text{wave}}$ vs |
- longitudinal $\overset{\longleftrightarrow}{\text{medium}}$ $\xrightarrow{\text{wave}}$
- impulse vs sinusoidal

Sinusoidal traveling wave PhET sim wave on string

$\xrightarrow{v}$ λ = wavelength

T = period = time for 1 cycle to pass by

$$v = \frac{\text{dist}}{\text{time}} = \frac{\lambda}{T} = \lambda \cdot f \quad , \quad f = \frac{\#\text{ cycles}}{\text{time}} = \frac{1}{T}$$

$\boxed{v = \lambda \cdot f}$ W3a $\xrightarrow{v}$ v 3b $a = ?$

Usually v_{wave} depends on properties of <u>medium</u> not on λ or f of wave

$v_{sound} \simeq 340\ \frac{m}{s} \quad \propto \sqrt{\frac{T}{m}}$ ← temperature (K) ← mass of molecule

$v_{\text{wave on string}} = \sqrt{\frac{F_T}{\mu}}$ ← tension ← mass/length

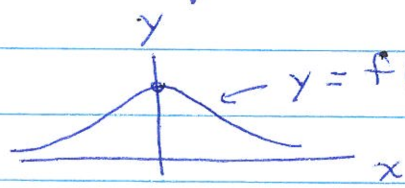
W4a $v = \text{const}$

W4b highest f? $f = v/\lambda$ (shortest λ)

$v = \lambda \cdot f = \text{const} \Rightarrow \lambda \searrow,\ f \nearrow$

W5 $x - v\cdot t = \text{const}\ \Theta \Rightarrow x = v\cdot t + \Theta$

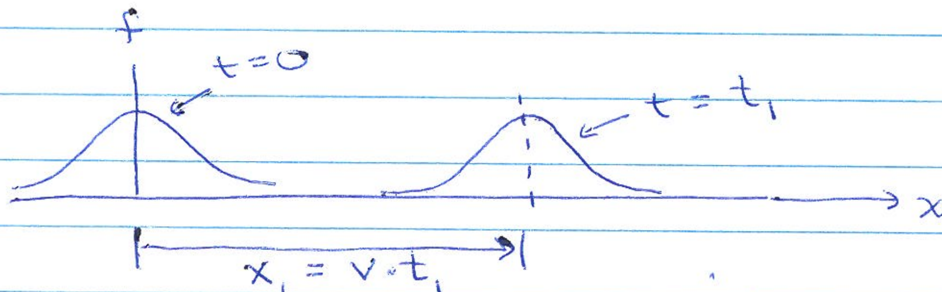
Math of 1D traveling wave $y = y(x,t)$



← $y = f(x) = e^{-x^2}$, $y = y_{Max}$ at $x = 0 \Rightarrow y_{Max} = f(0)$

$$y = f(x - v\cdot t) = e^{-(x - v\cdot t)^2}$$

$y = y_{Max} = f(0)$ when $x - v\cdot t = 0$, $x = v\cdot t$

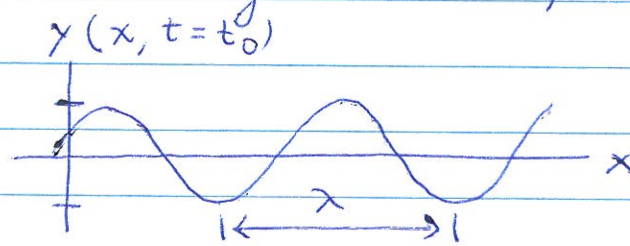


$$y = f(x \mp v\cdot t)$$

rt-going ($-$), left-going ($+$)

Sinusoidal traveling wave $y = y(x,t)$

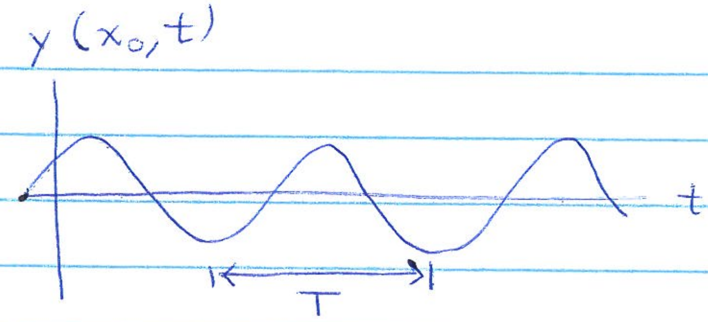
freeze t:



$y(x, t=0) = A\sin\left(2\pi \frac{x}{\lambda}\right) = A\sin(kx)$

$k = \frac{2\pi}{\lambda}$ = wave number

Pick an x



$\omega = \frac{2\pi}{T}$, $\quad y(x_0, t) = A \sin\left(2\pi \frac{t}{T}\right) = A \sin(\omega t)$

Wave traveling to the right

$$y(x,t) = A \sin(kx - \omega t) = A \sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]$$

$$\stackrel{?}{=} f(x - v \cdot t)$$

$$y(x,t) = A \sin\left[2\pi k\left(x - \underbrace{\frac{\omega}{k}}_{v} \cdot t\right)\right]$$

$$\frac{\omega}{k} = \frac{2\cancel{\pi}}{T} \cdot \frac{\cancel{\lambda}\lambda}{2\cancel{\pi}} = \frac{\lambda}{T} = v \qquad \text{(check!)}$$

W6a 6b 6c

W7 $\frac{\partial y}{\partial t} \stackrel{?}{=} v$ No!

①

speaker + tone generator
2-tone xylophone

Weds Dec 5

- READ Ch. 14
- Last CAPA next tues 10pm
- Last Smart Physics Fri 8am
- Tut HW in recitation

W-7 $\partial y / \partial t = ?$

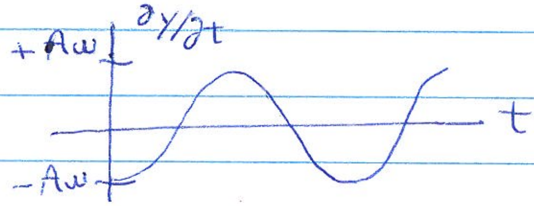
Any traveling wave $y(x,t) = f(x \pm v \cdot t)$ left-going / rt-going

Sinusoidal traveling wave:

$$y = A \sin(kx - \omega t) = A \sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]$$
$$= A \sin\left[\frac{2\pi}{\lambda}\left(x - \underbrace{\left(\frac{\lambda}{T}\right)}_{v} \cdot t\right)\right] = f(x - v \cdot t)$$

$$\left.\frac{\partial y}{\partial t}\right|_x = \frac{dy}{dt}, \text{ hold } x \text{ const} = -A\omega \cos(kx - \omega t)$$

= up-down velocity of point x



Interference of waves

Waves add linearly: $Y_{tot}(x,y) = y_1(x,t) + y_2(x,t)$

Interference Movie   Where is energy?

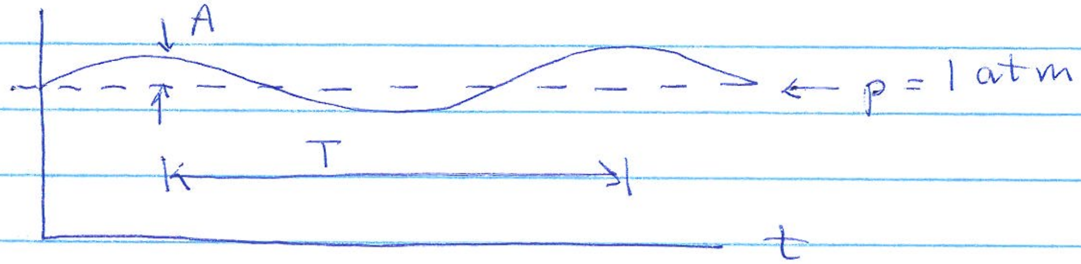
W-8 Interference → PhET Demo

2-tone xylophone + CT Hearing Test

Beats Graphics

Sound = pressure wave in air

p at my ear



frequency $f = 1/T$ = pitch

amplitude A = loudness

(W-11) 3 pressure waves, highest f

(PhET Sim speaker)

(W-9) ~~Loux~~ Loudness / f of sound

human hearing range $f = 20\,Hz \rightarrow 20\,kHz$

(Hearing test) w/ tone generator:

Start at $f = 21\,kHz$ (ultrasonic)

Lower f, 1 kHz steps, students raise hands when they hear tone

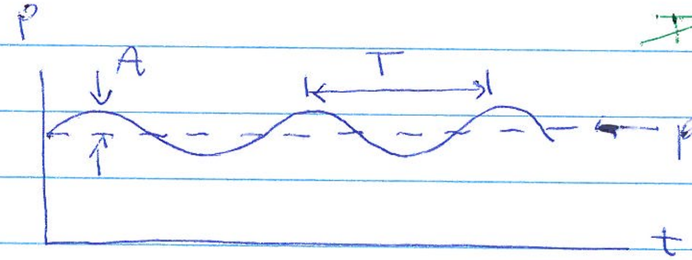
Fri Dec 7

- READ On line lec. notes, "A Little Heat"
- CAPA next Tues 10pm
- Final Exam in Coors

W-9 Loudness of sound/speaker cone

Music overheads Tone vs f vs note

~~Theremin D.~~



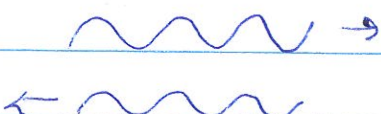
paddle-wheel piano

freq $f = 1/T$ = pitch
amplitude A = loudness

Classification of musical instruments?

Theremin   Sci-Fi Best

Standing Wave = 2 sinusoidal traveling waves
same λ, opposite directions



Movie

PhET sim $A = 6,\ f = 25,\ D = 0$

W10a 10b Standing Waves

Musical tone = mixture of f's

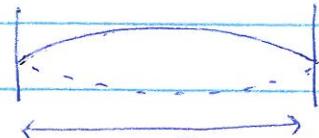
f_1 = fundamental = 1st harmonic

$f_2 = 2 \cdot f_1$ = 2nd harmonic

$f_3 = 3 \cdot f_1$ = 3rd harmonic

Harmonic

1



$L = \lambda/2, \ \lambda = 2L$

$v = \lambda \cdot f, \ f = v/\lambda$

$f_1 = \frac{v}{\lambda_1} = \frac{v}{2L}$

2

$L = \lambda, \ f_2 = \frac{v}{\lambda_2} = \frac{v}{L} = 2 f_1$

3

$L = \frac{3}{2}\lambda, \ f_3 = \frac{v}{\lambda_3} = 3 \frac{v}{2L} = 3 f_1$

$\lambda = \frac{2}{3} L$

Tygon tube Standing Waves

dB scale

W-14 Waves Jet / sonic boom CT

Bull whip + Black Hat

Strobe + Fan + tuning fork

Breath He

Just for fun Vortex Box

Forbidden Planet DVD

Mon Dec 10

Last CAPA due Weds 10pm

Last Tut HW due in recitation

Final Exam in Coors, Sat 10:30 am

Heat + Temperature

temperature = measure of energy per atom.

PhET sim friction

Kelvin scale $\Delta T = 1°C = 1K$ $T_K = T_C + 273.15$

absolute zero = no energy per atom

= 0 K = −273 °F = −459 °F

heat Q = thermal energy transferred to a body by a temperature diff

1 calorie = 4.184 J = energy to raise T of 1 gram of water by $\Delta T = 1°C$

1 kcal = 1 Cal = 4184 J = food calorie

$$\text{heat capacity} = \frac{\text{heat added}}{\text{temp. rise}} = \frac{\Delta Q}{\Delta T}$$

$$\text{specific heat} = c = \frac{\Delta Q}{m \cdot \Delta T} = \frac{\text{heat capacity}}{\text{mass}}$$

$$\boxed{\Delta Q = m \cdot c \cdot \Delta T} \qquad c_{water} = \frac{1\ \text{cal}}{g \cdot °C}$$

Example: heat mug coffee $m = 200g$, $T = 20°C \rightarrow 90°C$

$\Delta T = 70°C$, $\Delta Q = 200\,g \cdot \dfrac{1\ \text{cal}}{g \cdot °C} \cdot 70°C = 14{,}000$ cal $= 14$ Cal

(Hot has more calories than cold.)

Thermal 1 Heat coffee

$$P = \frac{\Delta Q}{\Delta t} = mc\frac{\Delta T}{\Delta t}, \quad \Delta t = \frac{mc\,\Delta T}{P} = \frac{240(1)(1)}{24} = 10\,s$$

Krell Movie Clip

T-2 c of Krell metal

In thermal equilibrium, all objects have the same temperature.

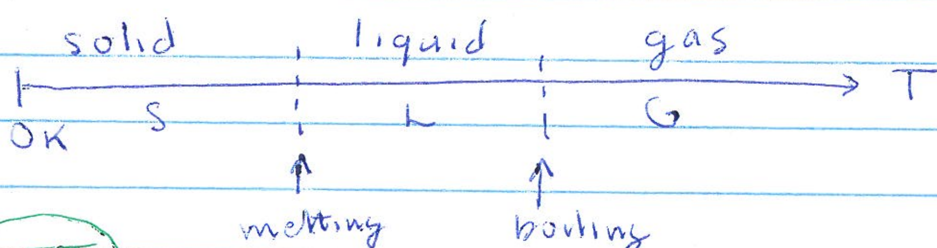
T-3 A + B

$$|\Delta Q_A| = |\Delta Q_B|$$

$$\cancel{m}\, c_A \underbrace{|\Delta T_A|}_{80} = \cancel{m}\, c_B \underbrace{|\Delta T_B|}_{20}$$

$$\frac{c_B}{c_A} = \left|\frac{\Delta T_A}{\Delta T_B}\right| = 4$$

$\Delta Q = m \cdot c \cdot \Delta T$ <u>if</u> no phase change



PhET SIM States of Matter

~~Weds Apr27~~ Pentultimate Lecture

Forbidden Planet Clip
IR Camera
BB PhET Sim
Big Lava Lamp
Copper pipe

- Final Exam is Tues May 3
  10:30 am in Coors Event Cntr
  Bring Photo ID to Coors. Assigned Seating
- Last Tut HW tomorrow in recitation
- Last ~~Tut~~ CAPA due Fri 10pm

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specific heat capacity c : $\Delta Q = m \cdot c \cdot \Delta T$ if no phase change

$$c_{water} = 1 \frac{cal}{g \cdot {}^\circ C}$$

$$c_{ice} = 0.50 \frac{cal}{g \cdot {}^\circ C}$$

Latent heat $L = \frac{\text{energy}}{\text{mass}} = \frac{\Delta Q}{m}$ for phase change

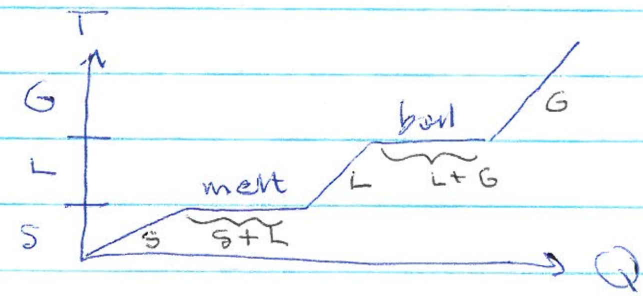
$$\underset{\text{phase change}}{\Delta Q} = m \cdot L$$

Solid | melt | Liquid | boil | Gas $\rightarrow T$

Water: $L_{SL} = 80 \text{ cal/g}$, $L_{LG} = 539 \text{ cal/g}$

T-4 ice / water

Tiger Vaporize Clip



m = 1 gram of H_2O

$$\Delta Q = \underbrace{m \cdot c \cdot \Delta T} + \underbrace{m \cdot L}$$

$T_i = 20°C \rightarrow$ $T_f = 100°C$ (water)

$T_i = 100°C$ (water) $\rightarrow$ $T_f = 100°C$ (steam)

ΔQ of 1 gram H_2O = $(1)(1)(80)\cancel{cal} + 1(539)$
$\cong 620$ cal

Tiger: $\Delta Q \simeq 250\,kg \times \frac{1000g}{kg} \times \frac{620\,cal}{g} \times \frac{4\,J}{cal}$
$= 6 \times 10^8\,J$ = 5 gal gas =
300 sticks dynamite

T-5

Heat transfer Mechanisms

1) Conduction: heat transfer by direct
copper bar — touching of atoms (slow)

2) Convection: heat tranfer by bulk
Lava Lamp — movement of hot matter

3) Radiation: heat transfer by light
IR camera — (EM radiation)

BB PHET sim

T-6 Heat
house by convection