☐ CHAPTER 10: LAWS OF MOTION (NEWTON)

WHY? BACKBONE, FOUNDATION,
ABSOLUTE BEDROCK OF ALL OF PHYSICS

WHY NOT "RIGHT" THEORIES?

FIRST UNIVERSAL DESCRIPTION
APPLIES (OR IS MEANT TO) TO EVERYTHING

BREAKS DOWN, FAILS TO WORK
FOR

IDEAS + DETAILS CHANGE – BUT UNDERLYING FOUNDATION IS STILL VALID

VERY SMALL THINGS ~ $\frac{m}{1000000000}$ QUANTUM MECHANICS

VERY FAST THINGS ~ VEL ≈ 186,000 $\frac{\text{MILES}}{\text{SEC}}$ RELATIVITY

VERY BIG, OR VERY MASSIVE ~ BLACK HOLES
NEUTRON STARS
UNIVERSE ITSELF
EINSTEIN'S THEORY OF GRAV.

WORKS FOR CARS, BUILDINGS, PLANETS,
BALLS, COMPUTERS, "EVERYDAY" OBJECTS
~ 300 YEAR OLD IDEAS STILL HOLD BRIDGES UP

OBJECTS IN MOTION

SUPPOSE... STANDARD OBJECT: 

E.G. SOLID BAR OF GOLD, PARTICULAR SHAPE.

MANUFACTURE THEM IN ANY QUANTITY AND ALL ARE EXACTLY THE SAME.

WE DEFINE THE MASS OF OUR OBJECT

$m = 1$ KILOGRAM.

WHAT THE HECK FOR? AREN'T WE JUST GOING AROUND IN CIRCLES? LETS JUST SUPPOSE WE CARRY ON...

1 OBJECT HAS A MASS OF 1 KILOGRAM.

2 OBJECTS HAVE $m = 1\,kg + 1\,kg = 2\,kg$

MASS IS A PROPERTY OF OUR STANDARD OBJECT THAT ADDS. "QUANTITY OF MATTER"

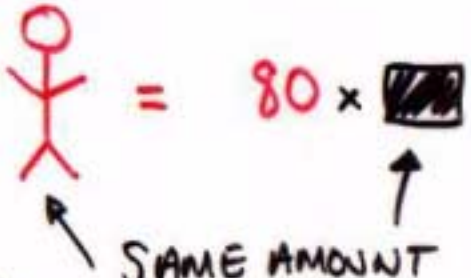
☐ ALL OBJECTS HAVE MASS — NOT JUST OUR STANDARD.

10-5

HOW TO USE THE STANDARD?

THE MASS OF AN OBJECT IS THE "QUANITITY OF MATTER IN IT"

HOW MANY "STANDARD MASSES" DO I HAVE?



TALK ABOUT HOW TO MEASURE IT LATER.

MY MASS IS A PROPERTY OF MY BODY.

DOES NOT DEPEND ON MY

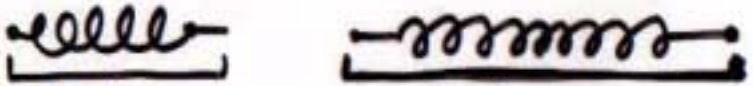
- LOCATION -
- VELOCITY -
- TEMPERATURE -
- ATTITUDE -

so ONLY THE AMOUNT OF "STUFF" IN MY BODY.

STANDARD "FORCE"

SUPPOSE, WE CAN MAKE SPRINGS EXACTLY IDENTICAL IN ANY QUANTITY.

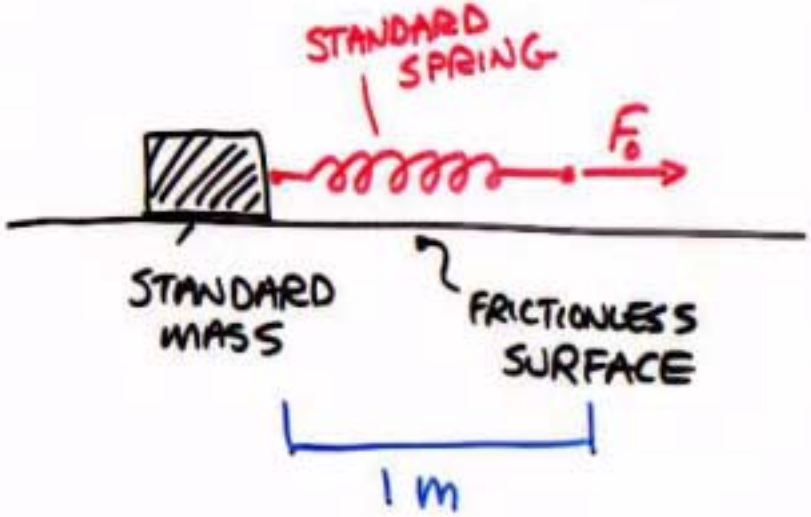
"STRETCHING" A SPRING IS A "FORCE."



SMALL "FORCE"

BIG "FORCE"

LET F_0 ~~BE THAT~~ STAND FOR A SPRING THAT IS STRETCHED OUT BY 1 METER.

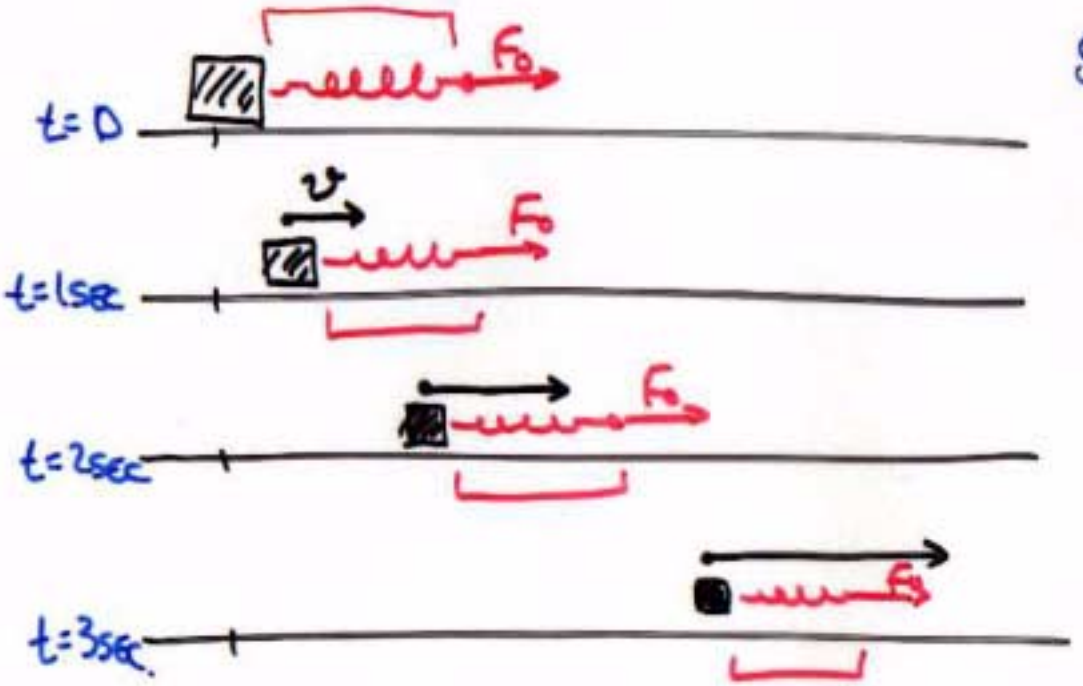


THE OBJECT MUST MOVE.

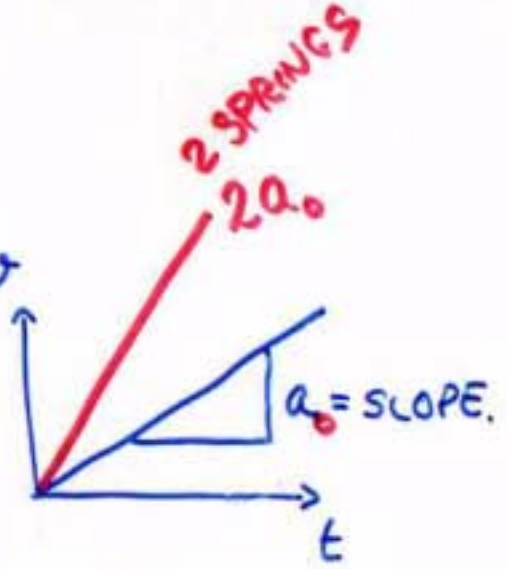
BUT HOW?

KEEP F_0 THE SAME BY KEEPING SPRING STRETCHED 1 m.

☐ THE OBJECT HAS A CONSTANT ACCELERATION.



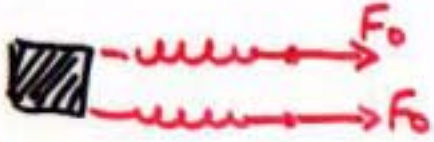
SAME STRETCHING FOR SPRING.



THE ACCELERATION IS CONST:

HOW TO CONTROL THE ACCELERATION?

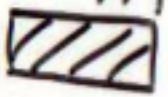
① PULL WITH MORE SPRINGS:

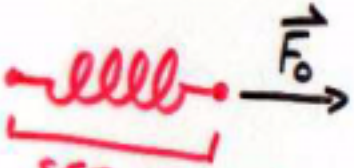


FORCES ADD VECTORS

2 SPRINGS → TWICE AS BIG ACCELERATION.

☐ OPERATIONAL DEFINITION

TAKE STANDARD OBJECT: 

TAKE STANDARD FORCE: 

VECTOR THAT POINTS ALONG SPRING.

HOOK UP THE SPRING TO THE MASS:

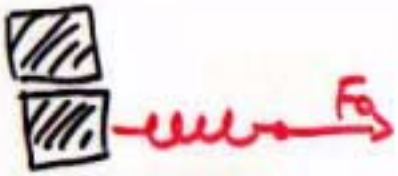
, AND MASS ACCELERATES:

WHEN $\vec{a} = \frac{1 \text{ METER}}{\text{SEC}^2}$, $F_0 = 1$ "NEWTON"

"A FORCE OF 1 NEWTON ACTING ON A BODY OF 1 kg MASS PRODUCES AN ACCELERATION OF 1 M/S^2"

☐ HOW TO CONTROL THE ACCEL?

WHAT HAPPENS IF WE DOUBLE THE MASS



2 STANDARD OBJECTS

1 STANDARD "FORCE"

ACCEL. IS CUT IN HALF.

GUESS THAT a IS PROPORTIONAL TO # OF SPRINGS – "AMOUNT" OF FORCE.

$$a = cF$$

a IS INVERSELY PROPORTIONAL TO "AMOUNT" OF MATTER

$$a = \frac{b}{m}$$

$$a = \frac{F}{m} \rightarrow \boxed{F = ma}$$ DEFINITION OF FORCE,

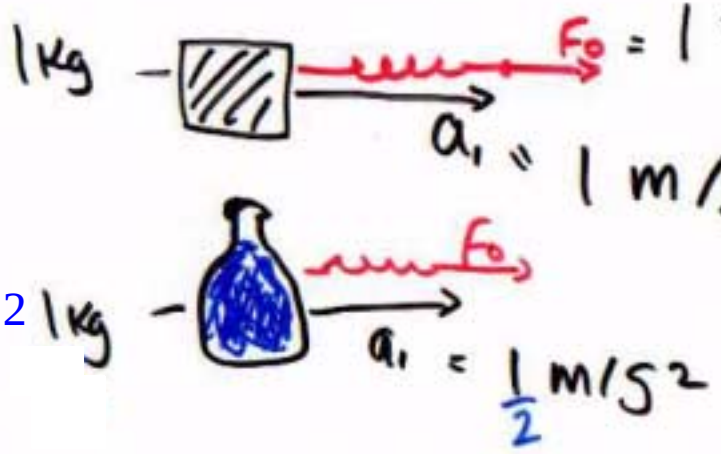
☐ HOW IS THIS A DEFINITION OF MASS?

YOU CAN MEASURE ACCELERATION ... LOOK AT SLOPE OF VELOCITY-VS-TIME GRAPH.

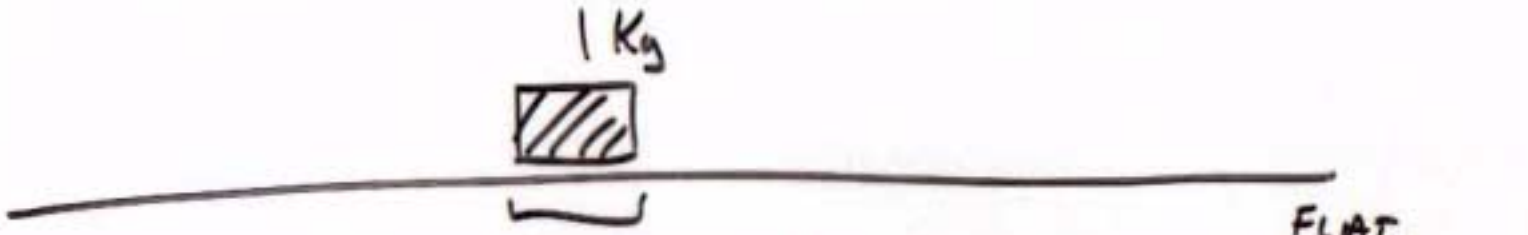
IF 2 OBJECTS ARE "HOOKED UP" TO SAME FORCES,

+ THEIR ACCELERATION IS THE SAME

THEIR MASS IS THE SAME —



So, WHAT IF WE DON'T HOOK UP A FORCE?



FLAT, FRICTIONLESS

NO INFLUENCE FROM OUTSIDE WORLD, AT ALL —

IS THE BODY STOPPED?

MOVING?

"CHANGING" ITS MOTION?

LETS BE EXACT WHEN TALKING ABOUT "MOTION":

"MOTION" OF AN OBJECT.

$\vec{V}$ VELOCITY IS ONE MEASURE - BUT NOT ENOUGH

10 $\frac{\text{MILES}}{\text{HOUR}}$ FREIGHT TRAIN

IS QUITE DIFFERENT FROM

10 $\frac{\text{MILES}}{\text{HOUR}}$ BICYCLE.

(AMOUNT OF MATTER) $\times \vec{V}$ COUNTS MOTION FAIRLY

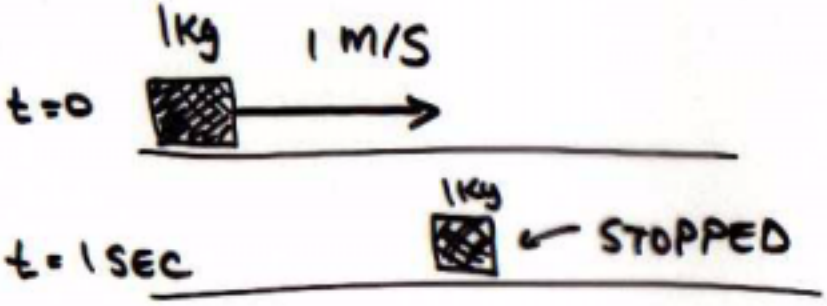
↑ EACH BIT OF THE TRAIN "COUNTS"

THE MORE THERE IS, THE MORE THE VELOCITY COUNTS.

VECTOR MOMENTUM = $m\vec{V}$ - IT IS A VECTOR.

How the "VECTOR MOMENTUM" can change?

ONLY BY INTERACTING WITH SOMETHING ELSE—



SOMETHING INTERACTED TO STOP THE OBJECT.

A "FORCE" ... INFLUENCE FROM SOMETHING

FRICTION IS AN EXAMPLE.

IF $m\vec{v}$ CHANGES, A FORCE MUST HAVE ACTED...

SO, IF NO FORCES ACT... WHAT KIND OF MOTION?

NEWTON'S LAWS: 3 OF THEM

1. WHAT HAPPENS TO AN "ISOLATED" HANDS-OFF OBJECT? "NATURAL" OR "INERTIAL" MOTION!

WITHOUT AN OUTSIDE INFLUENCE —

$m\vec{v}$ = VECTOR MOMENTUM IS CONSTANT. IN TIME, UNCHANGING

IN OTHER WORDS, STRAIGHT-LINE MOTION, CONST. SPEED.

JUST LIKE GALILEO SAID. NEWTON TAKES THIS AS A STARTING POINT.

LAW 1 YOU HAVE TESTED DIRECTLY

LAW 2: WHAT HAPPENS TO AN OBJECT THAT INTERACTS WITH THE WORLD?

AN EXTERNAL INFLUENCE ACTS TO CHANGE THE OBJECT'S MOMENTUM VECTOR.

LET A FORCE, $\vec{F}$ ACT FOR A TIME Δt.

THEN $\underbrace{\Delta(m\vec{v})}_{\text{CHANGE IN THE MOMENTUM}} = \underbrace{\vec{F}\,\Delta t}_{\text{THE STRENGTH OF AN OUTSIDE INFLUENCE.}}$

SUPPOSE THE OBJECT DOESN'T CHANGE ITS MASS...

$$\Delta m\vec{v} = m(\Delta\vec{v}) = \vec{F}\cdot\Delta t$$

OR $m\underbrace{\frac{\Delta\vec{v}}{\Delta t}}_{\text{ACCELERATION.}} = \vec{F}$ — JUST LIKE OUR "OPERATIONAL" DEFINITION.

2ND LAW EXAMPLES.

IF A FORCE OF 1 NEWTON ACTS ON A BODY OF MASS = 1 kg FOR 1 SECOND, AND THE BODY IS INITIALLY AT REST, WHAT IS THE MOMENTUM OF THE BODY BEFORE + AFTER THE FORCE ACTS?

BEFORE: THE BODY IS AT REST, SO $\vec{V}_i = 0$

THEREFORE $m\vec{V}_i = 0$

AND (MOMENTUM-INITIAL) = 0

NOW FORCE ACTS ...

$$\Delta(m\vec{V}) = F\Delta t$$

$$(m\vec{V}_f - m\cdot\vec{V}_i) = 1\ \text{NEWTON}\cdot 1\ \text{SEC}$$

$\vec{V}_i \to 0$

$$\boxed{(m\vec{V}_f) = 1\ \text{NEWTON}\cdot 1\ \text{SEC} = \frac{\text{kg m}}{\text{SEC}}}$$

(FINAL MOMENTUM)

$(mV_f) = \text{kg}\,\frac{m}{s}$

$(1\,\text{kg}\,V_f) = 1\,\text{kg}\,\frac{m}{s}$

$\boxed{V_f = 1\,\frac{m}{s}}$

NEWTON·SEC?

$\text{NEWTON} = \frac{\text{Kg}\cdot m}{s^2}$

$\text{NEWTON}\cdot\text{SEC} = \frac{\text{Kg}\cdot m}{s^2}\cdot s$

$= \frac{\text{Kg}\,m}{s}$

= (MASS)·(VELOCITY)

FORCE = 1 NEWTON, MASS = $\frac{1}{2}$ Kg, Δt = 3 SEC.

INITIAL VELOCITY = $+3\frac{m}{s}$.

INITIAL MOMENTUM = $m \cdot \vec{V}_i = \left(\frac{1}{2}\,Kg\right) \cdot \left(3\frac{m}{s}\right) = \frac{3}{2}\frac{Kg\,m}{s}$

$$\Delta(m\vec{V}) = F \cdot \Delta t$$

$$m \cdot \vec{V}_f - m \cdot \vec{V}_i = 1\,\frac{Kg\,m}{s^2} \cdot 3\,SEC$$

$$\frac{1}{2}Kg\,V_f - \frac{3}{2}\frac{Kg\,m}{s} = 3\frac{Kg\,m}{s}$$

$$\frac{1}{2}Kg\,V_f = 3\frac{Kg\,m}{s} + \frac{3}{2}\frac{Kg\,m}{s} = \left(3+\frac{3}{2}\right)\frac{Kg\,m}{s}$$

$$\left(\frac{1}{2}Kg\right)V_f = \frac{2\cdot 3+3}{2}\frac{Kg\,m}{s} = \frac{9}{2}\frac{Kg\,m}{s} \leftarrow mV_f \text{ FINAL MOMENTUM.}$$

WHAT IS THE FINAL VELOCITY?

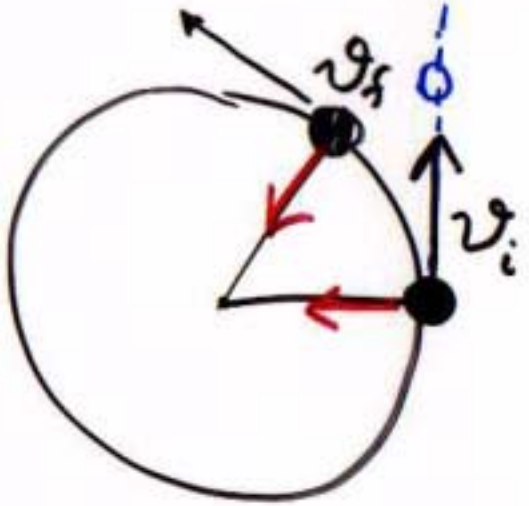
$$\frac{1}{2}Kg\,V_f = \frac{9}{2}\,Kg\frac{m}{s} \rightarrow 1Kg\,V_f = 9\,Kg\frac{m}{s} \qquad \boxed{V_f = 9\frac{m}{s}}$$

☐ 2ND LAW:

IF $(m\vec{v})$ CHANGES - AT ALL -

THERE MUST HAVE BEEN AN

EXTERNAL FORCE - ONLY WAY —



$m\vec{v}$ CHANGES

CONTINUALLY FOR

A BALL GOING-AROUND

A CIRCLE —

FORCE POINTS

ALONG-THE STRING.

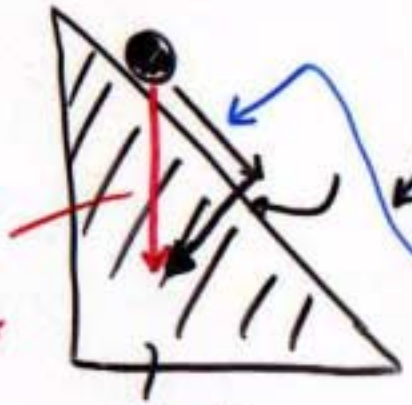
② CONST. ACCEL (CONT.)

FREE-FALL AND ROLLING DOWN RAMPS?

ANY OBJECTS ... SMALL BIG DROP SAME WAY.

$\vec{a} = -10 \frac{m}{s^2}$ (VERTICAL DIRECTION) - BIG ACCEL TO MEASURE.

9-12

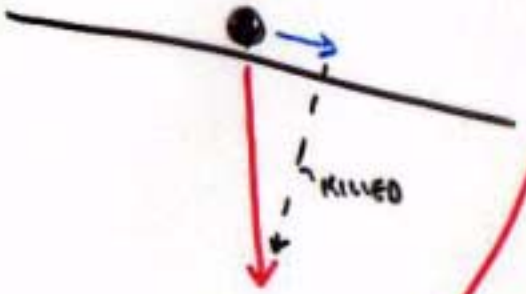


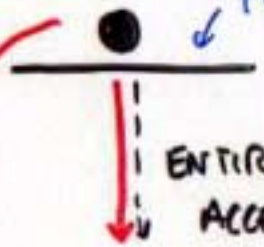
"WANTS" TO KEEP FALLING AT $-10 \frac{m}{s^2}$

BUT IT CAN'T GO THROUGH TRACK!

SOLID RAMP.

COMPONENT OF ACCELERATION GETS "KILLED" BY TRACK LEAVING JUST ALONG TRACK.

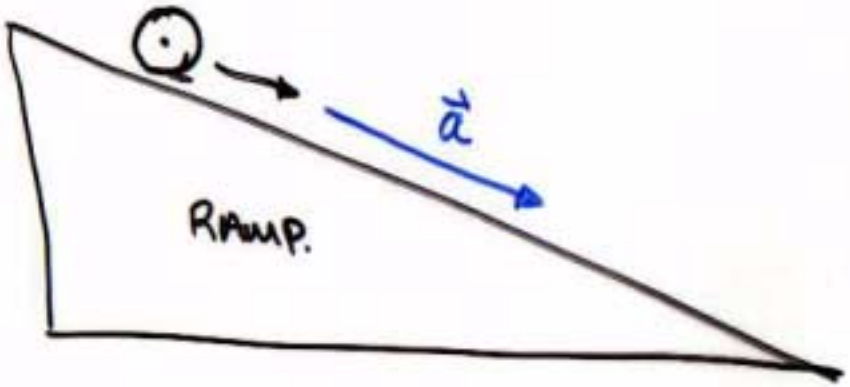




ENTIRE ACCELERATION GETS KILLED..

$\vec{a} = 0$ FOR HORIZONTAL TRACK — CONSTANT VELOCITIES

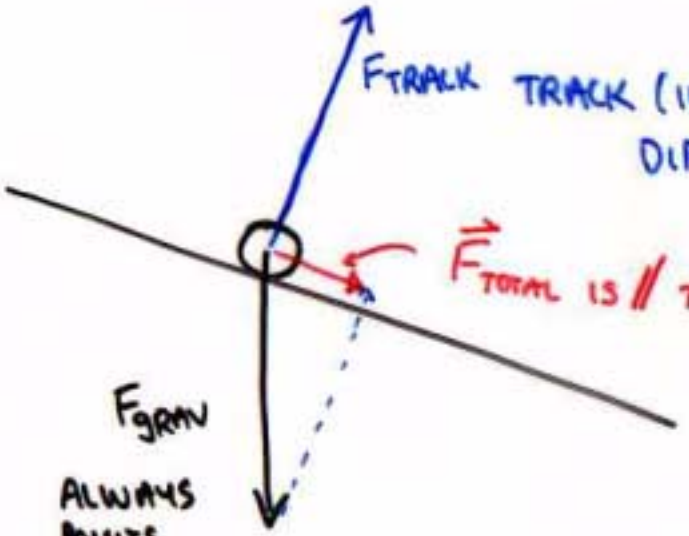
☐ ROLLING DOWN A RAMP.



YOU SHOWED (EXPT. # 4) THAT THE BALL MOVES WITH A CONSTANT ACCELERATION.

WHAT IS THE DIRECTION OF THE ACCELERATION?
ALONG THE TRACK

∴ THE FORCES ACTING ON THE BALL ARE ALONG THE TRACK, TOO.



F_{TRACK} TRACK (IF FRICTIONLESS) CAN ONLY PUSH DIRECTLY AWAY FROM ITSELF!

$\vec{F}_{TOTAL}$ IS MUCH SMALLER THAN $\vec{F}_{GRAV}$ IN LENGTH!

"DILUTE"'S THE ACCELERATION.

☐ 3RD LAW OF NEWTON:

IF OBJECT 1 PUSHES OBJECT 2

OBJECT 2 PUSHES OBJECT 1 BACK JUST AS MUCH —

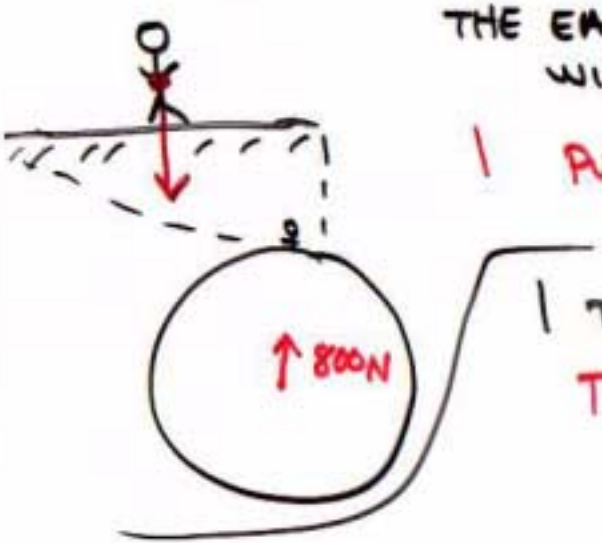
INTERACTIONS ARE ALWAYS 2-WAY —

WHY IS THIS SO IMPORTANT?

O1 PUSHES ON O2 — GIVING IT MOMENTUM.
O2 PUSHES BACK ON O1 - TAKING ITS MOMENTUM BACK.

OVERALL MOMENTUM DOESN'T CHANGE!

☐ ALL FORCES ARE COVERED BY THE 3RD LAW



THE EARTH PULLS ME DOWNWARD WITH A FORCE OF 800 NEWTONS.

I PULL THE EARTH UP AT 800 NEWTONS

I THROW A BALL WITH 500 NEWTONS

THE BALL PUSHES ME BACKWARD W/ 500 NEWTONS.

EVERYTHING "RECOILS."

SUPPOSE YOU STAND ON ICE, + THROW A BOWLING-BALL..

BEFORE

AFTER,

YOU GO BACK, BALL GOES FORWARD -

☐ 3RD LAW + MOMENTUM

$\vec{F}_1 = -\vec{F}_2$ — IS THE 3RD LAW STATEMENT.

2ND LAW FOR 1 SAYS: $\Delta(m_1\vec{v}_1) = \vec{F}_1\Delta t$

2 " : $\Delta(m_2\vec{V}_2) = \vec{F}_2\Delta t = -\vec{F}_1\Delta t$

OR

$$\Delta(m_1\vec{v}_1) = -\Delta(m_2\vec{V}_2)$$

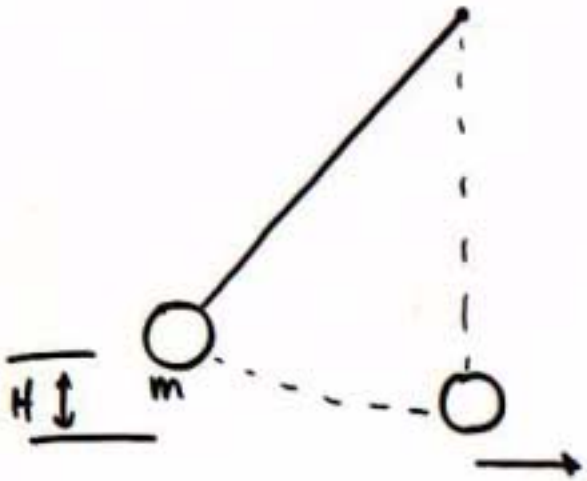
THE MOMENTUM #1 GAINS = THE MOMENTUM #2 LOOSES

OVERALL MOMENTUM DOESN'T CHANGE:

$$\Delta(\underbrace{m_1\vec{V}_1 + m_2\vec{V}_2}_{\text{TOTAL MOMENTUM}}) = 0$$ ← STILL TRUE AS A PHYSICAL LAW!

☐ NEWTON'S REASONING TO GET 3RD LAW:

PENDULUM AGAIN!

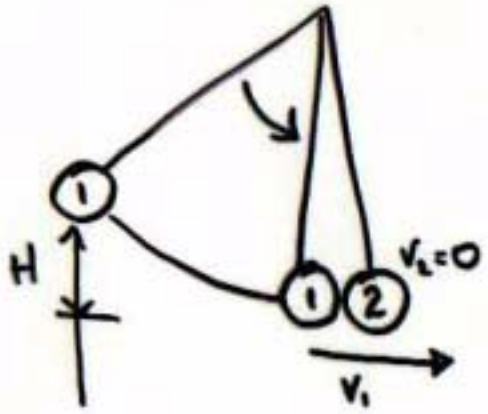


V = "FASTEST" ATTAINED BY MASS m

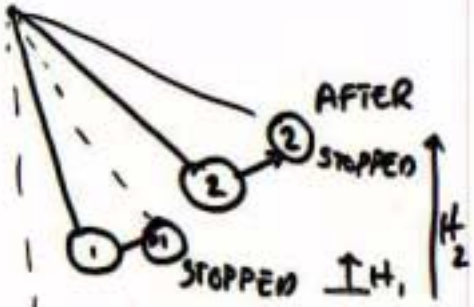
V IS DETERMINED FROM H: HOW FAR THE BALL FELL FROM ITS RELEASE POINT.

"KIND OF LIKE GALILEO?!"

SMACK 2 BALLS TOGETHER!



BEFORE COLLISION

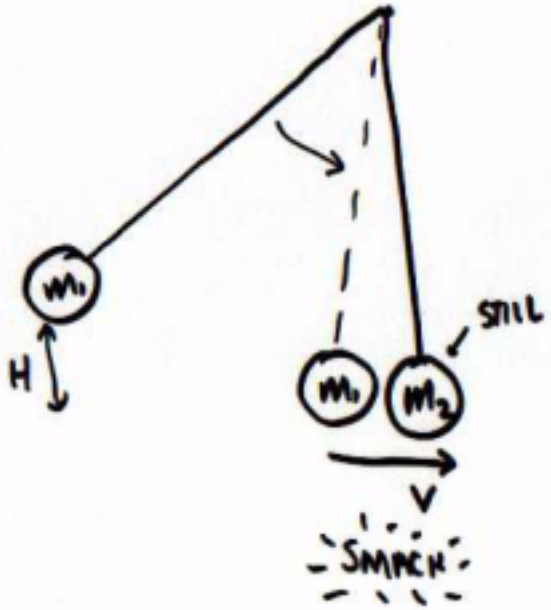


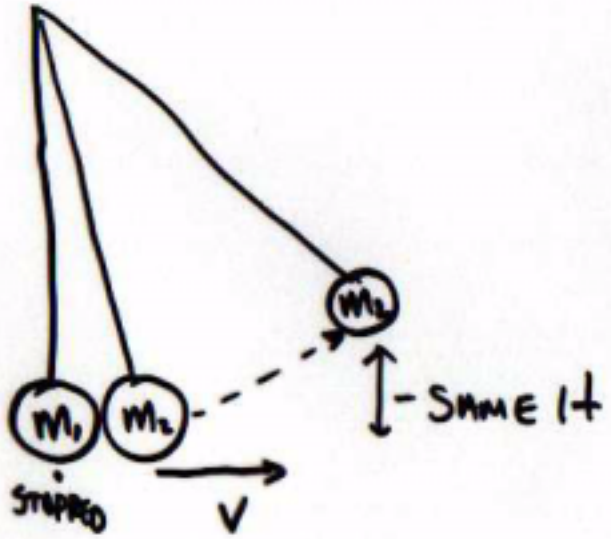
MEASURE H_1, H_2, TELLS YOU HOW FAST #1 AND #2 WERE GOING JUST AFTER COLLISION

H BIG MEANS V BIG.

SO, IF YOU KNOW (m) AND (H) YOU CAN CALCULATE (V) : ($m\vec{V}$) VECTOR MOMENTUM OF BALL 1.

☐ Special Case: $m_1 = m_2$.





MOMENTUM 1 = $m \cdot 10 \frac{cm}{s}$ IN +X DIRECTION

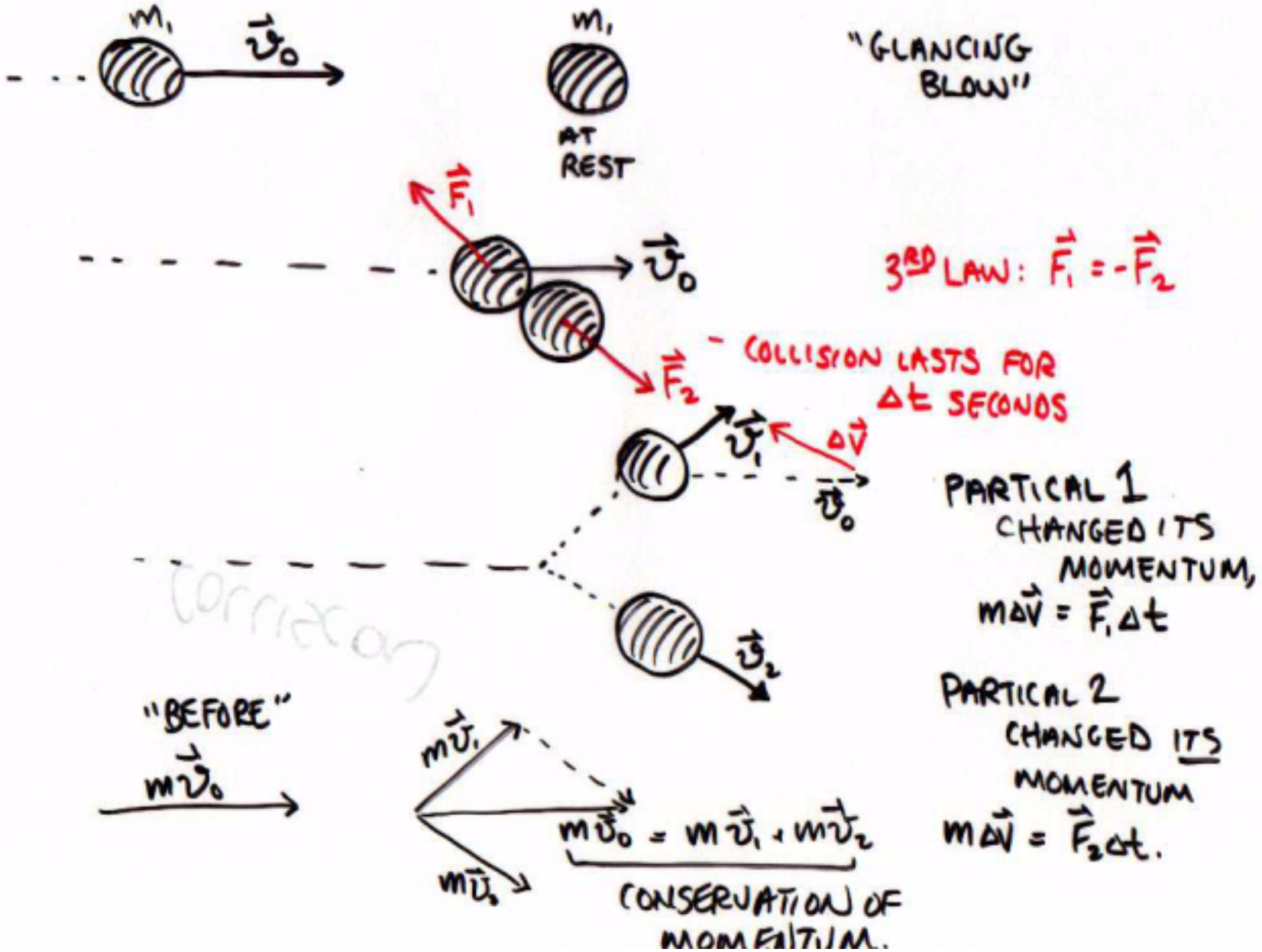
MOMENTUM 2 = $m \cdot 0 \frac{cm}{sec}$

MOMENTUM 1 = $0 \frac{cm}{sec}$

MOMENTUM 2 = $m \cdot 10 \frac{cm}{s}$ IN +X DIRECTION.

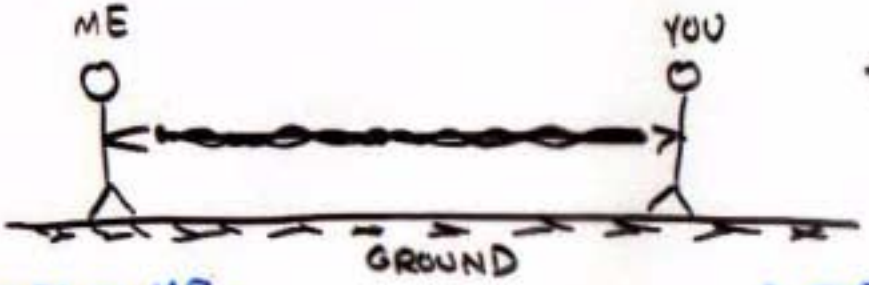
TOTAL MOMENTUM IS THE SAME, BUT IT "CHANGES HANDS" "GETS TRADED" "IS EXCHANGED" ETC.

COLLISION AND THE 3RD LAW:



☐ NEWTON'S THIRD LAW

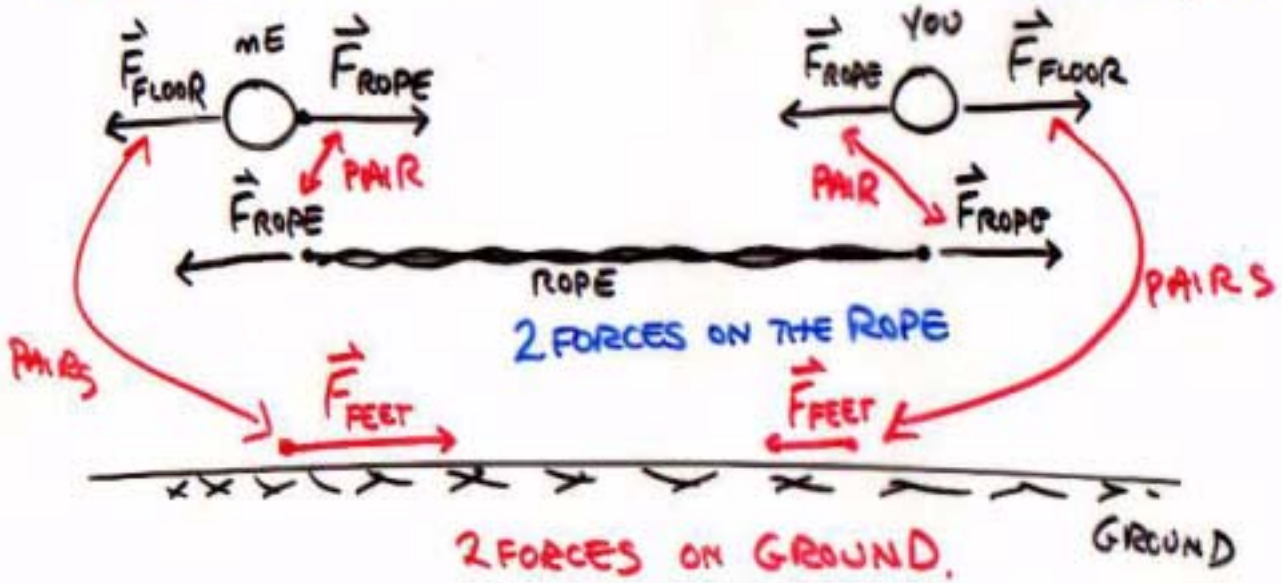
ALL FORCES COME IN PAIRS EQUAL AND OPPOSITE.



TUG-OF-WAR.

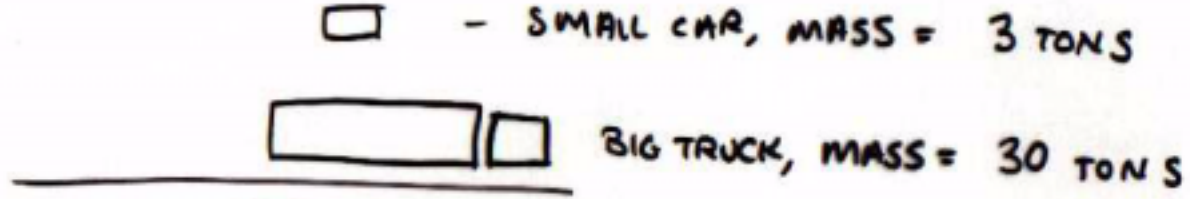
2 FORCES ON ME.

2 FORCES ON YOU



* SOMETIMES NEED TO "SNOOP OUT" ALL OF THE FORCES.

MOMENTUM VS. SPEED:

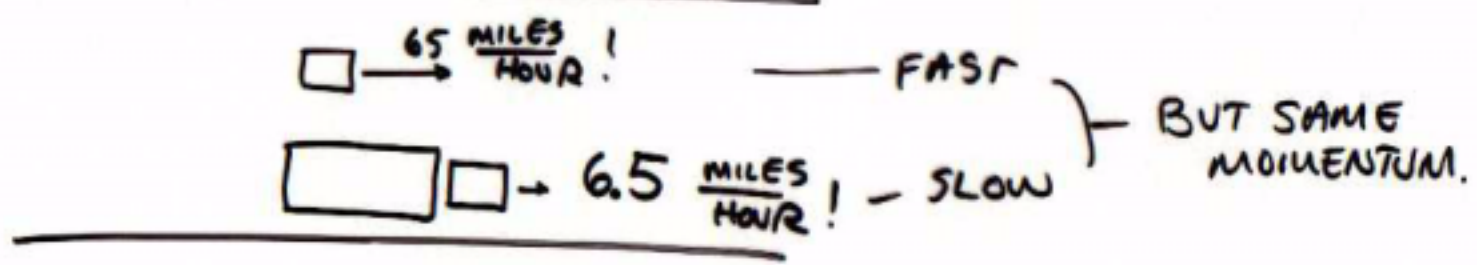


65 MPH LIMIT ON SPEEED

$$\left(\begin{matrix}\text{MOMENTUM}\\ \text{TRUCK}\end{matrix}\right) = 10 \times \left(\begin{matrix}\text{MOMENTUM}\\ \text{CAR}\end{matrix}\right)$$

SUPPOSE INSTEAD OF A SPEED LIMIT, THERE WERE A MOMENTUM LIMIT ON THE HIGHWAY:

MOMENTUM MAX = 3 TONS. 65 $\frac{\text{MILES}}{\text{HOUR}}$.



CHAPTER 10 QUESTIONS:

5:a)

APPLE

1 NEWTON WEIGHT.

$F = ma$

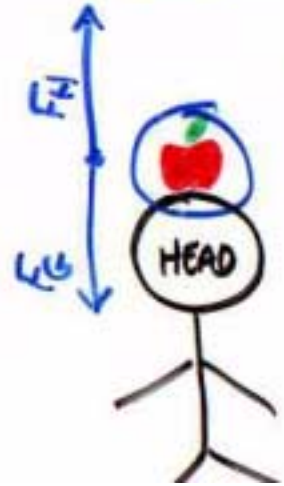
$a = \frac{F}{m} = \frac{1\,N}{1\,kg}$

"FORCE FROM THE EARTH ON THE APPLE"

WHAT IS THE FORCE ON THE EARTH FROM THE APPLE?

- USES 3RD LAW.

b)

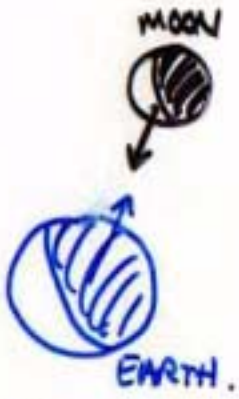


AN APPLE RESTS ON YOUR HEAD.

WHAT IS THE TOTAL FORCE ACTING ON THE APPLE?

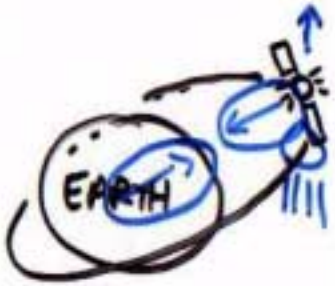
IF NO MOVEMEN (ACCEL!) TOT FORCE = 0

c)



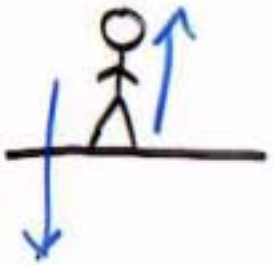
WHICH IS BIGGER... THE FORCE ON THE (SMALL) MOON, OR THE FORCE ON THE (BIG) EARTH?

6) a) IF THE EARTH EXERTS 1000 N FORCE ON THE SATTELITE, WHAT IS THE FORCE THE SATTELITE EXERTS ON THE EARTH?



COMMUNICATION SATTELITE

b)



DOES THE FLOOR EXERT A FORCE ON YOU? UPWARD ON YOUR FEET?

WHY DON'T YOU START MOVING BECAUSE OF THIS FORCE?