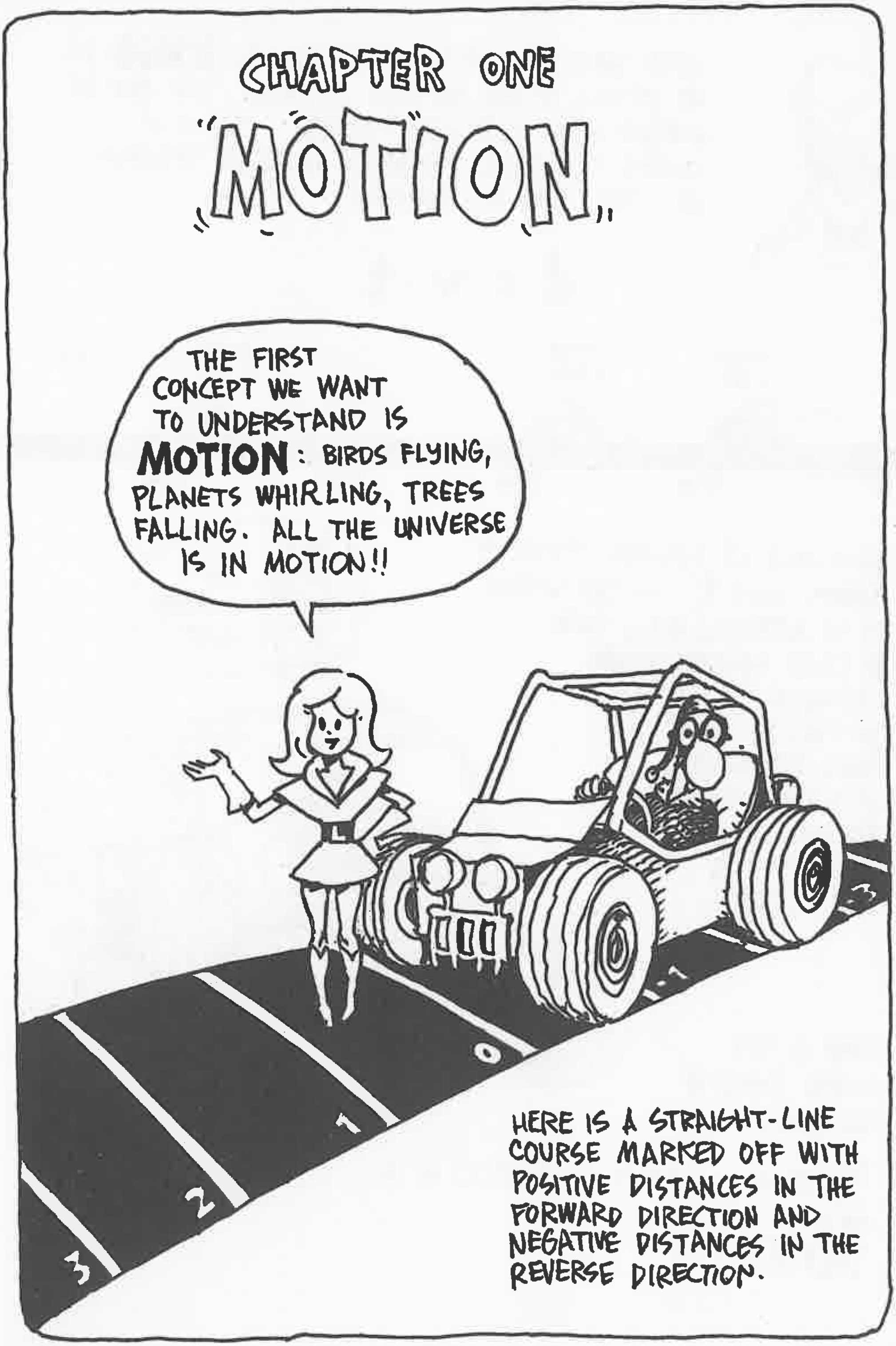
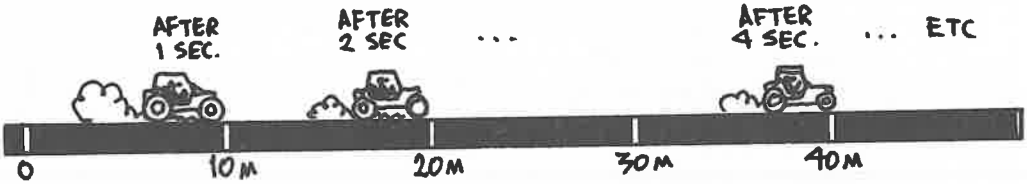
• PART ONE •
MECHANICS


CHAPTER ONE
MOTION
THE FIRST CONCEPT WE WANT TO UNDERSTAND IS MOTION: BIRDS FLYING, PLANETS WHIRLING, TREES FALLING. ALL THE UNIVERSE IS IN MOTION!!
3
2
1
0
-1
-3
HERE IS A STRAIGHT-LINE COURSE MARKED OFF WITH POSITIVE DISTANCES IN THE FORWARD DIRECTION AND NEGATIVE DISTANCES IN THE REVERSE DIRECTION.

LET'S WATCH MY FELLOW ASTRONAUT **RINGO** AS HE DRIVES A CAR ON THIS COURSE. THE CAR IS MOVING WITH CONSTANT SPEED. THEN IT COVERS THE SAME DISTANCE IN EACH INTERVAL OF TIME, AND WE WRITE:

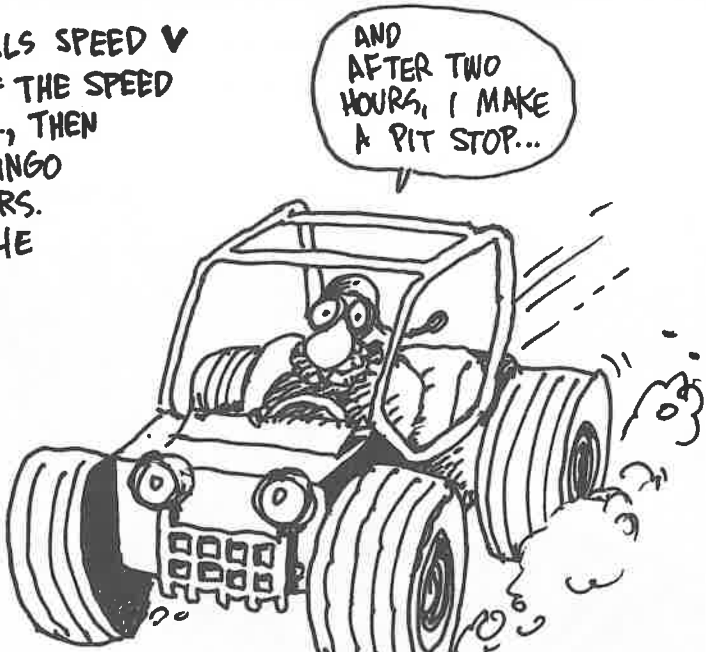
$$d = v \cdot t$$



DISTANCE **d** EQUALS SPEED **v** TIMES TIME **t**. IF THE SPEED IS 10 METERS/SEC., THEN IN EACH SECOND RINGO TRAVELS 10 METERS. IN TWO SECONDS HE GOES 20 METERS, IN THREE SECONDS 30 METERS, IN ONE MINUTE 600 METERS

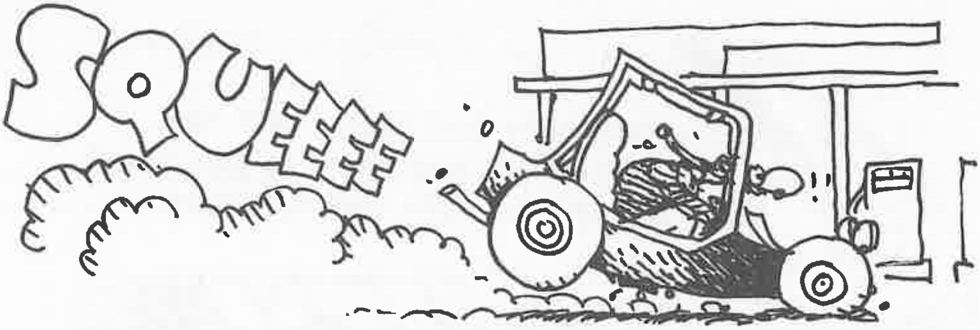
⋮

AND IN ONE HOUR (3600 s) HE GOES



$$3600 \text{ s} \times 10 \text{ m/s} = 36{,}000 \text{ m} =$$

36 KM.

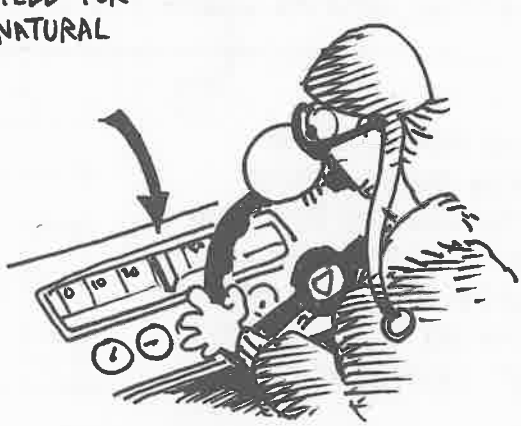


IN AN ORDINARY TRIP, YOU ARE ALWAYS SPEEDING UP AND SLOWING DOWN: YOUR SPEED IS NOT CONSTANT. THEN WHAT HAPPENS TO THE EQUATION $d = v \cdot t$? IF v IS CHANGING, WHICH VALUE OF v DO YOU USE?

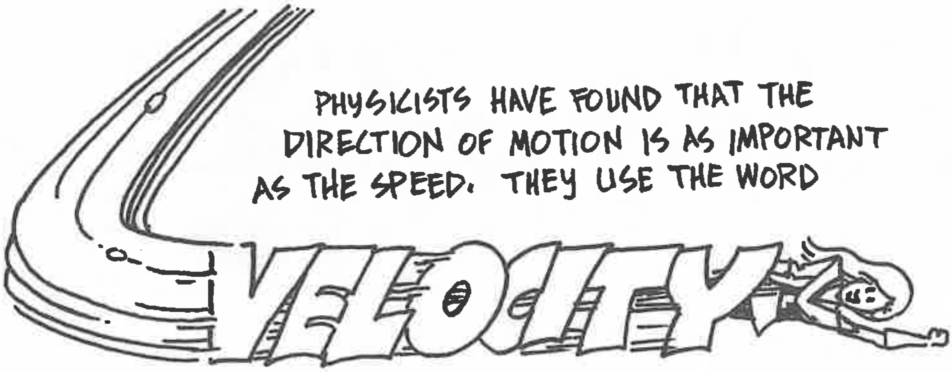
YOU COULD SOLVE THE EQUATION FOR v TO GET $v = d/t$, SO

$$v = \frac{\text{FINAL ODOMETER READING} - \text{INITIAL ODOMETER READING}}{\text{ELAPSED TIME}}$$

THIS GIVES THE **AVERAGE** SPEED FOR THE TRIP. IT TOOK THE OLD NATURAL PHILOSOPHERS A LONG TIME TO REALIZE THAT AN OBJECT ALSO HAS AN **INSTANTANEOUS** SPEED, A SPEED AT EACH MOMENT. THAT IS THE NUMBER YOUR SPEEDOMETER MEASURES.

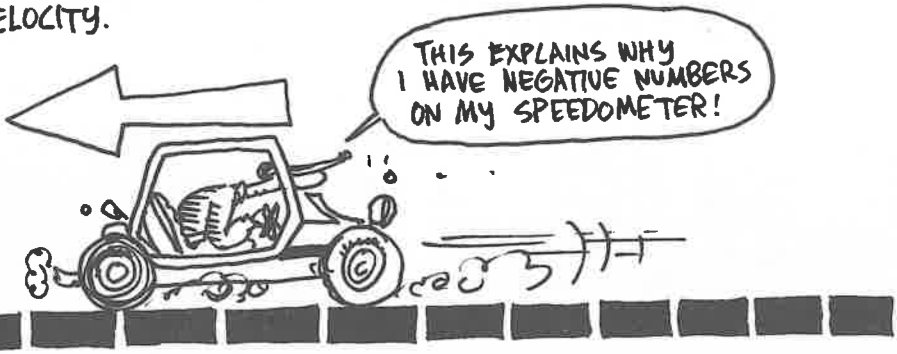


PHYSICISTS HAVE FOUND THAT THE DIRECTION OF MOTION IS AS IMPORTANT AS THE SPEED. THEY USE THE WORD



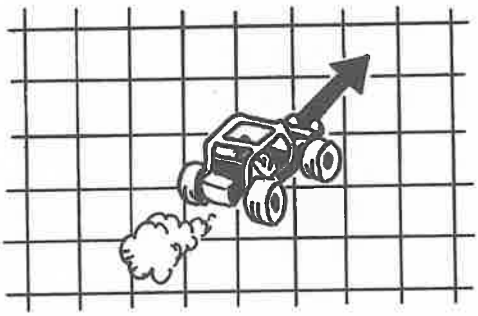
TO REPRESENT BOTH SPEED AND DIRECTION.

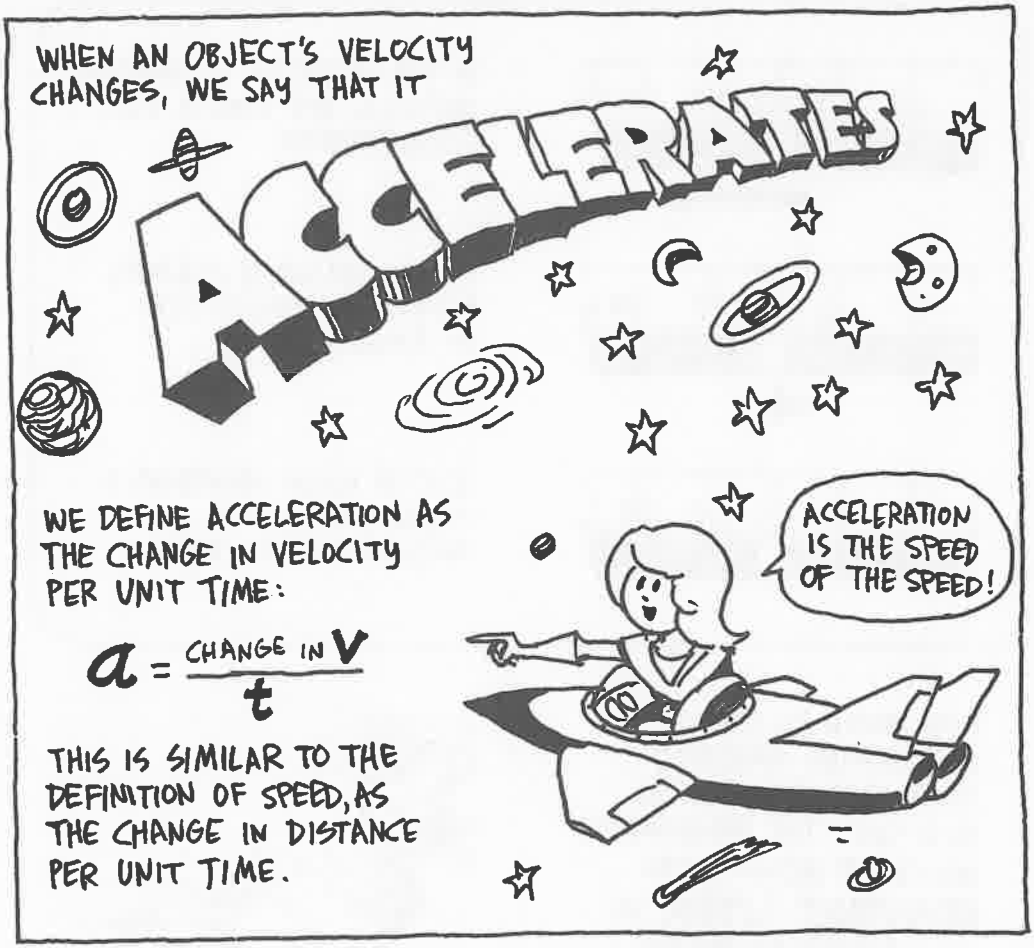
IF RINGO TRAVELS IN THE NEGATIVE DIRECTION, BY BACKING UP OR TURNING AROUND, WE SAY THAT HE HAS **NEGATIVE** VELOCITY.



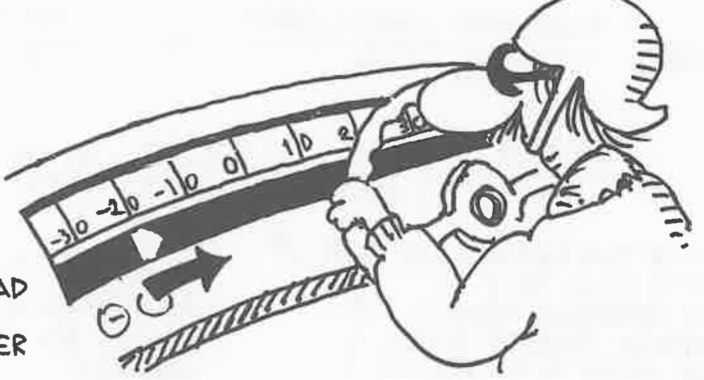
YOU CAN THINK OF VELOCITY AS AN ARROW POINTING IN THE DIRECTION OF MOTION, WITH ITS LENGTH PROPORTIONAL TO THE SPEED.

MORE GENERALLY, IF RINGO DRIVES IN ANY DIRECTION, WE REPRESENT HIS VELOCITY BY AN ARROW — FOR EXAMPLE, **V** = 32 m/sec AT 28° EAST OF NORTH.

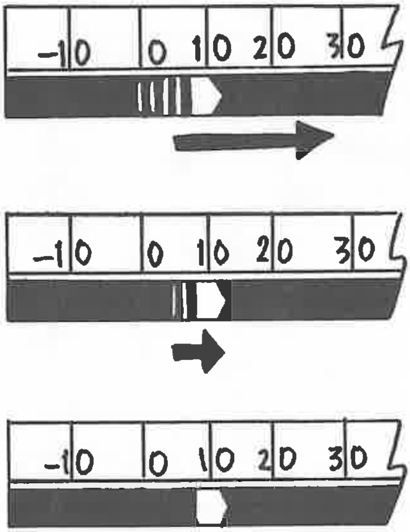




LET'S RIDE WITH RINGO AGAIN. HIS CAR HAS A LINEAR SPEEDOMETER, WITH NEGATIVE READINGS FOR BACKING UP— A "VELOCITOMETER." THEN ACCELERATION IS NOTHING BUT THE VELOCITY OF THE INDICATOR NEEDLE!*



*USING THE UNITS OF VELOCITY READ OFF THE VELOCITOMETER

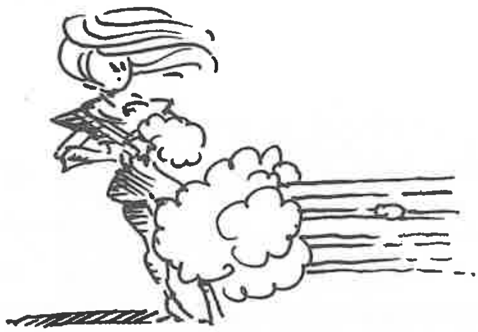


IF THE VELOCITY IS CHANGING RAPIDLY, WE HAVE A BIG ACCELERATION.

IF THE VELOCITY CHANGES SLOWLY, ACCELERATION IS SMALL.

AND IF RINGO MAINTAINS A STEADY SPEED, HIS ACCELERATION IS ZERO.

NOW WATCH AS RINGO ACCELERATES SMOOTHLY FROM 0 TO 50 km/hr. IN 5 SEC. THE SPEEDOMETER INDICATOR MOVES WITH **CONSTANT SPEED,** SO HERE **ACCELERATION IS A CONSTANT,** AND WE CALCULATE:

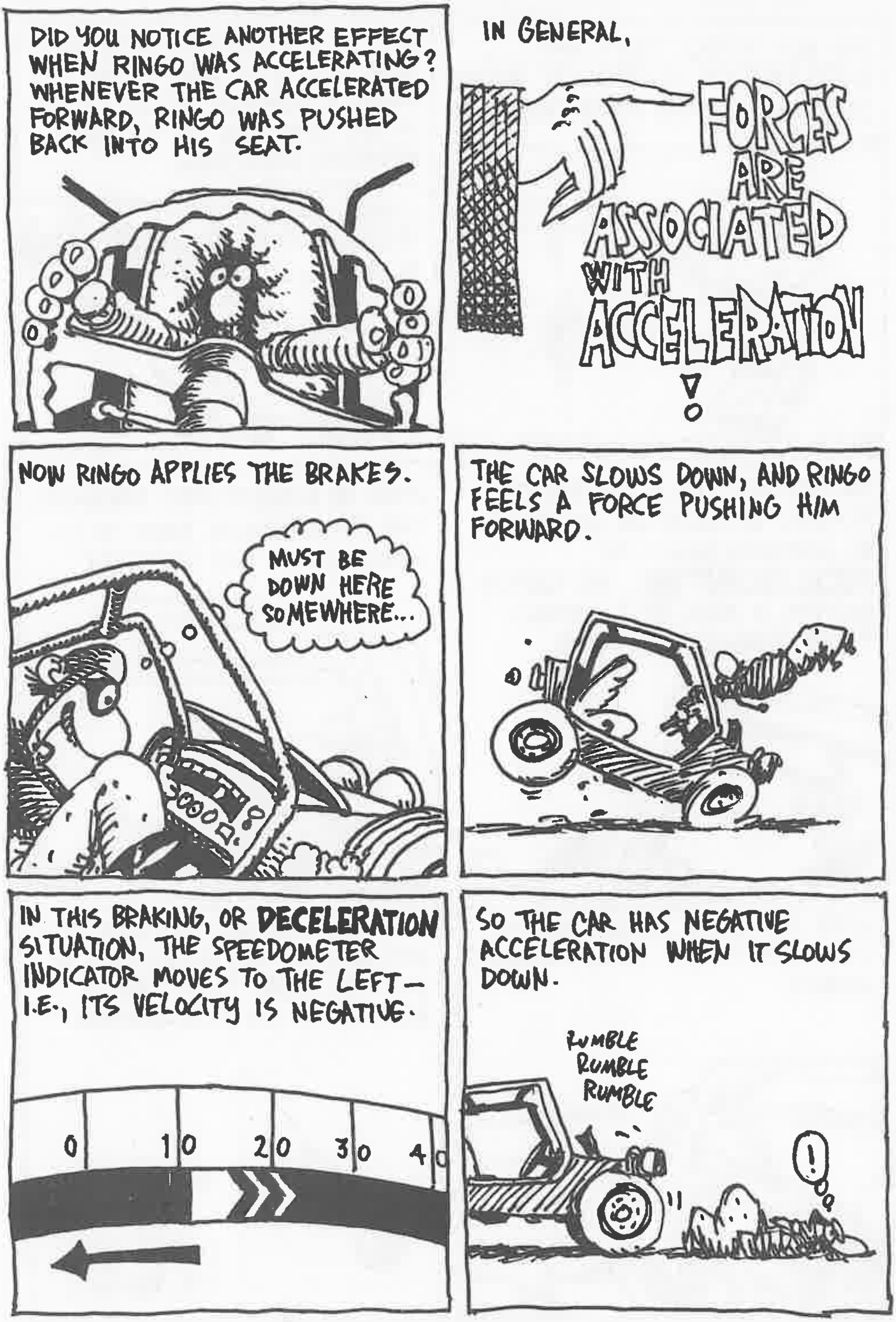


$$a = \frac{\text{FINAL SPEED} - \text{INITIAL SPEED}}{\text{ELAPSED TIME}} = \frac{50\ \text{KM/H}}{5\ \text{S}}$$

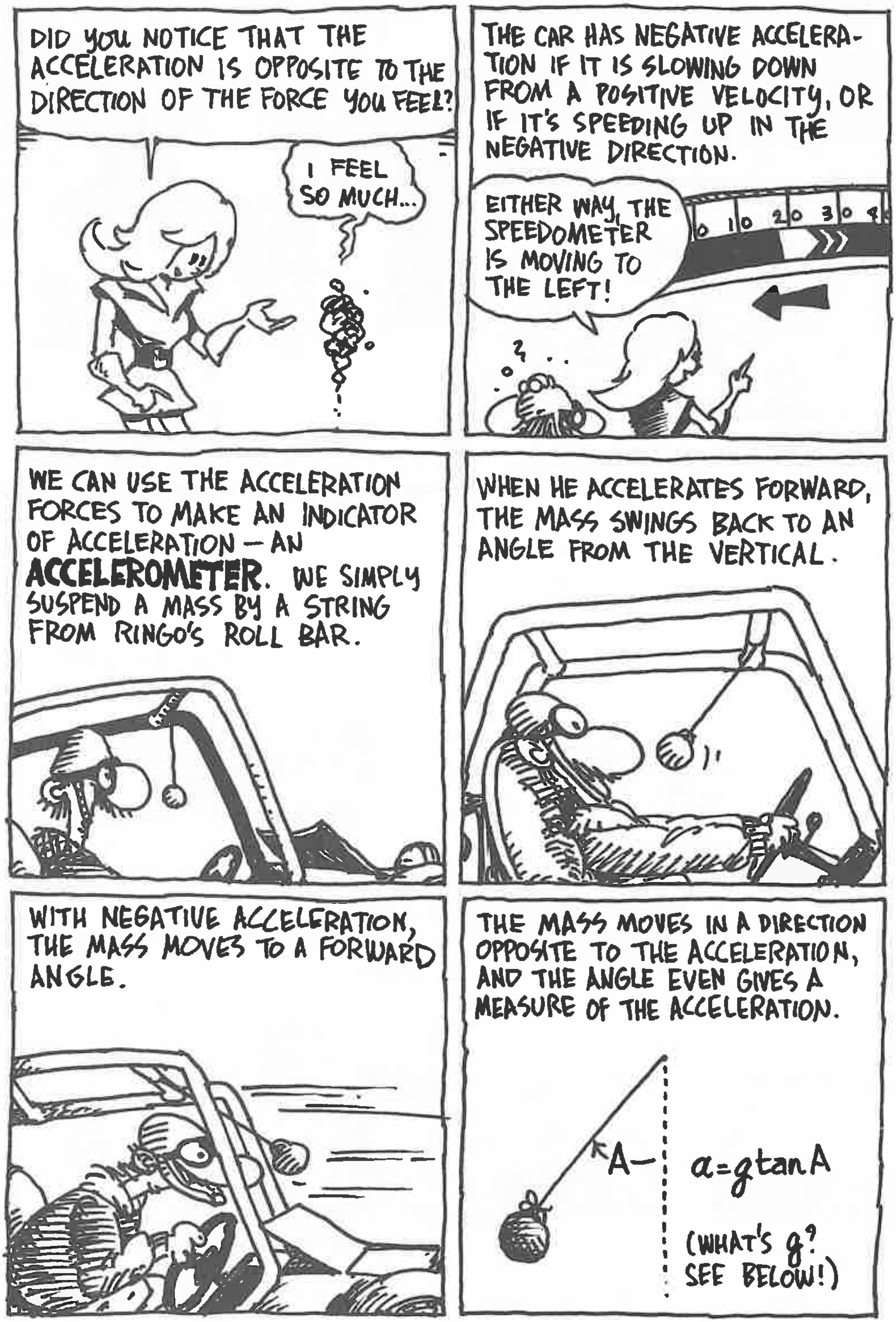
$$= \frac{50\ \text{KM/H}}{5\ \text{S}} \times \left(\frac{1\ \text{H}}{3600\ \text{S}}\right)\left(\frac{1000\ \text{M}}{1\ \text{KM}}\right) = 2.78\ \text{M/S}^2$$

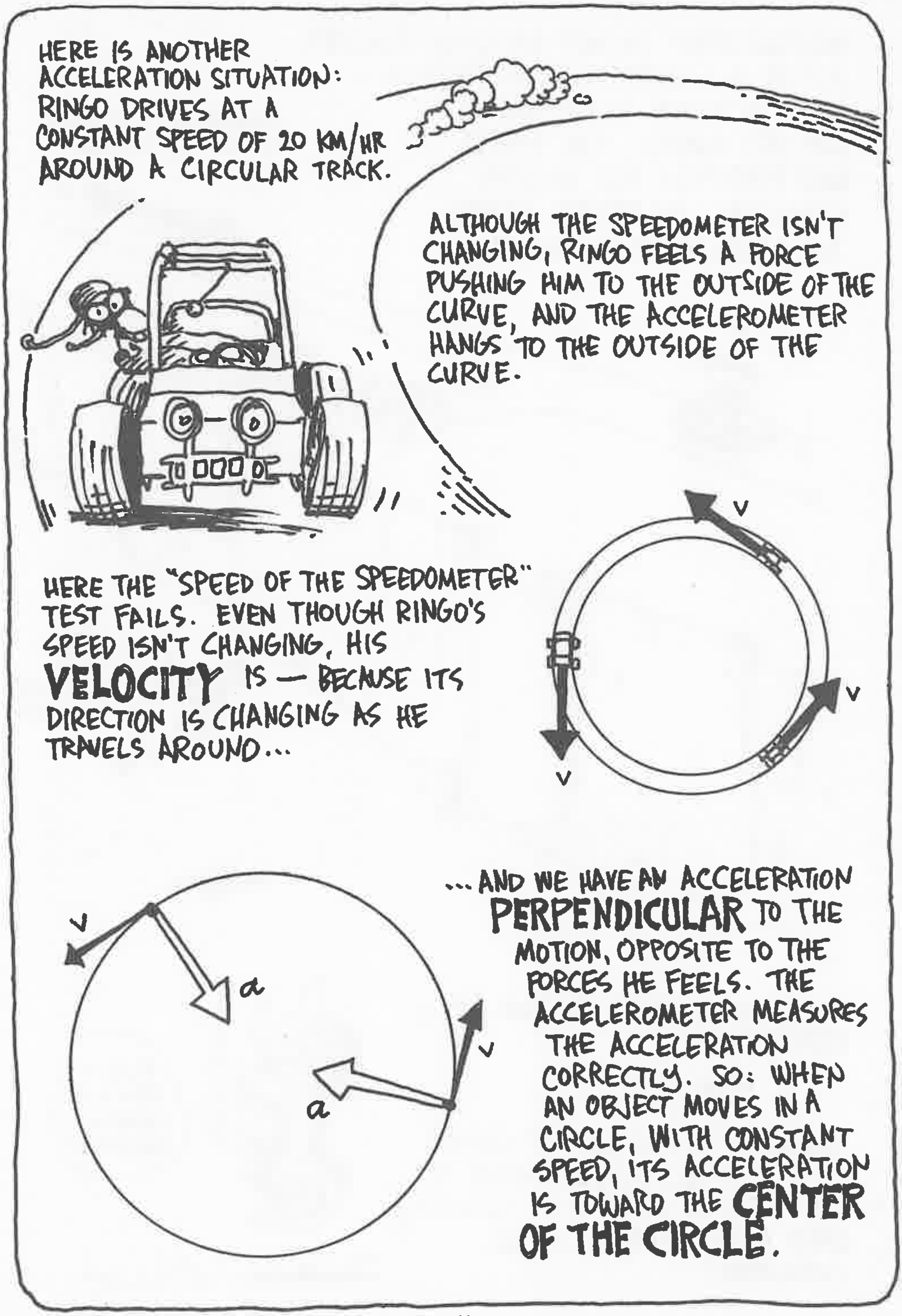
THESE TWO FACTORS ARE BOTH EQUAL TO 1 — WE INTRODUCE THEM TO CONVERT HOURS TO SECONDS AND METERS TO KILOMETERS.

NOTE THAT THE UNITS OF ACCELERATION ARE M/S^2 — METERS PER SECOND PER SECOND!

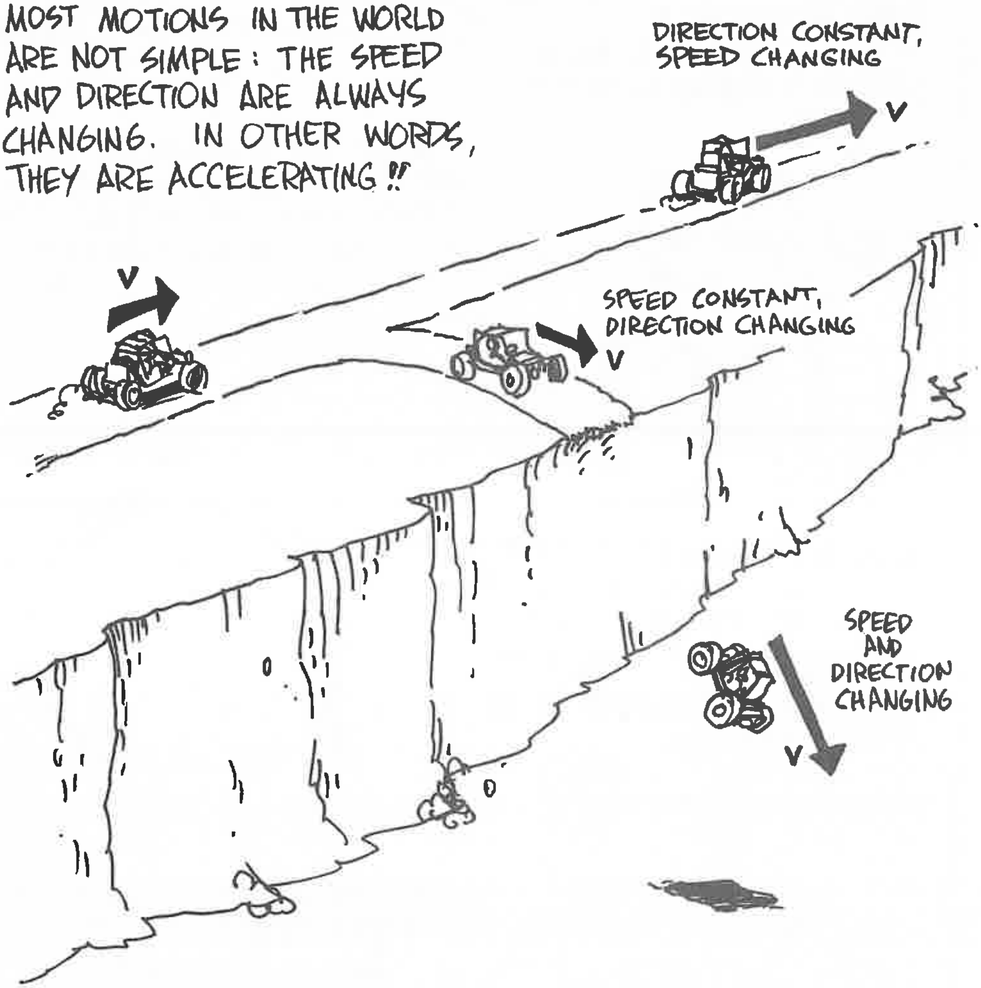


DID YOU NOTICE ANOTHER EFFECT WHEN RINGO WAS ACCELERATING? WHENEVER THE CAR ACCELERATED FORWARD, RINGO WAS PUSHED BACK INTO HIS SEAT.
IN GENERAL,
FORCES ARE ASSOCIATED WITH ACCELERATION!
NOW RINGO APPLIES THE BRAKES.
MUST BE DOWN HERE SOMEWHERE...
THE CAR SLOWS DOWN, AND RINGO FEELS A FORCE PUSHING HIM FORWARD.
IN THIS BRAKING, OR DECELERATION SITUATION, THE SPEEDOMETER INDICATOR MOVES TO THE LEFT— I.E., ITS VELOCITY IS NEGATIVE.
0
10
20
30
40
SO THE CAR HAS NEGATIVE ACCELERATION WHEN IT SLOWS DOWN.
RUMBLE
RUMBLE
RUMBLE
!


DID YOU NOTICE THAT THE ACCELERATION IS OPPOSITE TO THE DIRECTION OF THE FORCE YOU FEEL?
I FEEL SO MUCH...
THE CAR HAS NEGATIVE ACCELERATION IF IT IS SLOWING DOWN FROM A POSITIVE VELOCITY, OR IF IT'S SPEEDING UP IN THE NEGATIVE DIRECTION.
EITHER WAY, THE SPEEDOMETER IS MOVING TO THE LEFT!
0 10 20 30 4
WE CAN USE THE ACCELERATION FORCES TO MAKE AN INDICATOR OF ACCELERATION — AN ACCELEROMETER. WE SIMPLY SUSPEND A MASS BY A STRING FROM RINGO'S ROLL BAR.
WHEN HE ACCELERATES FORWARD, THE MASS SWINGS BACK TO AN ANGLE FROM THE VERTICAL.
WITH NEGATIVE ACCELERATION, THE MASS MOVES TO A FORWARD ANGLE.
THE MASS MOVES IN A DIRECTION OPPOSITE TO THE ACCELERATION, AND THE ANGLE EVEN GIVES A MEASURE OF THE ACCELERATION.
A
a=g tan A
(WHAT'S g? SEE BELOW!)


HERE IS ANOTHER ACCELERATION SITUATION: RINGO DRIVES AT A CONSTANT SPEED OF 20 KM/HR AROUND A CIRCULAR TRACK.
ALTHOUGH THE SPEEDOMETER ISN'T CHANGING, RINGO FEELS A FORCE PUSHING HIM TO THE OUTSIDE OF THE CURVE, AND THE ACCELEROMETER HANGS TO THE OUTSIDE OF THE CURVE.
HERE THE "SPEED OF THE SPEEDOMETER" TEST FAILS. EVEN THOUGH RINGO'S SPEED ISN'T CHANGING, HIS VELOCITY IS — BECAUSE ITS DIRECTION IS CHANGING AS HE TRAVELS AROUND...
v
v
v
...AND WE HAVE AN ACCELERATION PERPENDICULAR TO THE MOTION, OPPOSITE TO THE FORCES HE FEELS. THE ACCELEROMETER MEASURES THE ACCELERATION CORRECTLY. SO: WHEN AN OBJECT MOVES IN A CIRCLE, WITH CONSTANT SPEED, ITS ACCELERATION IS TOWARD THE CENTER OF THE CIRCLE.
v
a
v
a

ACCELERATION IS NOT AN EASY CONCEPT, BUT IT IS A BASIC ONE IN PHYSICS. MOST MOTIONS IN THE WORLD ARE NOT SIMPLE: THE SPEED AND DIRECTION ARE ALWAYS CHANGING. IN OTHER WORDS, THEY ARE ACCELERATING!!



VELOCITY IS GIVEN BY THE BASIC EQUATION

$$v = d/t.$$

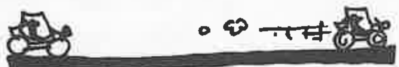
VELOCITY IS THE RATE OF CHANGE OF DISTANCE. ACCELERATION IS THE RATE OF CHANGE OF VELOCITY. EVEN ACCELERATION CAN BE CHANGING!

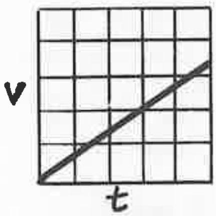
BUT IN BEGINNING PHYSICS, WE USUALLY STICK TO

CONSTANT ACCELERATION

SITUATIONS.

SUPPOSE YOU START FROM REST AND UNDERGO CONSTANT ACCELERATION a FOR A PERIOD OF TIME t. HOW FAR DO YOU GO IN THIS TIME?





WELL, YOUR INITIAL SPEED IS ZERO, AND IT INCREASED UNIFORMLY. TO $v=at$ IN TIME t. SO YOUR **AVERAGE** SPEED DURING THIS INTERVAL WAS:

$$v_{AVERAGE} = \frac{0+at}{2} = \frac{1}{2}at$$

THEN THE DISTANCE TRAVELED d IS THE AVERAGE SPEED TIMES TIME t, OR

$$d = \frac{1}{2}at \cdot t$$

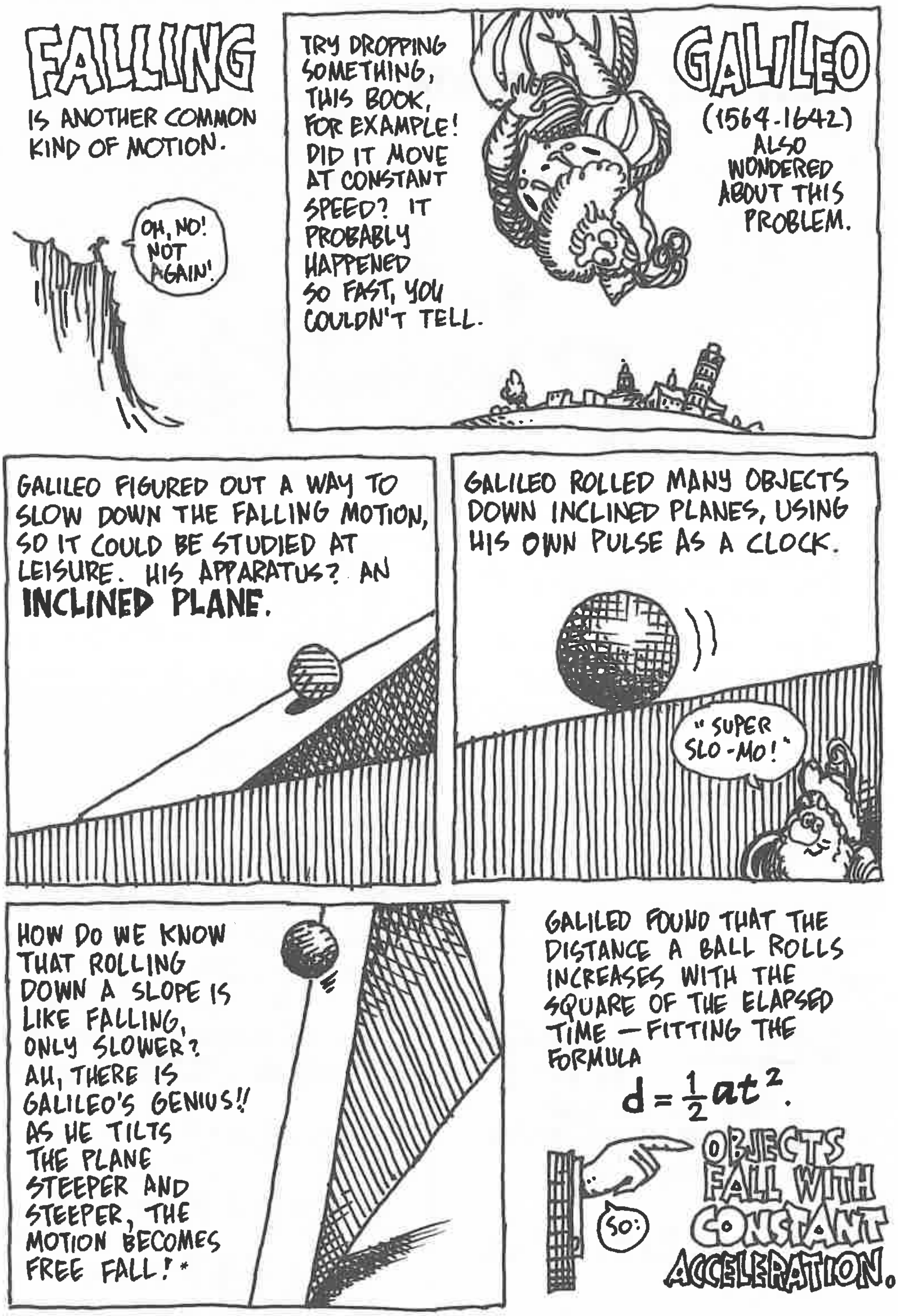
$$d = \frac{1}{2}at^2$$

FOR EXAMPLE, SUPPOSE RINGO ACCELERATES FROM 0 TO 50 KM/HR IN 5 SEC. LET'S SEE HOW FAR HE GOES. THIS PROBLEM HAS TWO STEPS. FIRST, WE MUST FIND THE ACCELERATION. THIS WE ALREADY DID ON PAGE 8, FINDING $a = 2.78\ m/sec^2$, SO

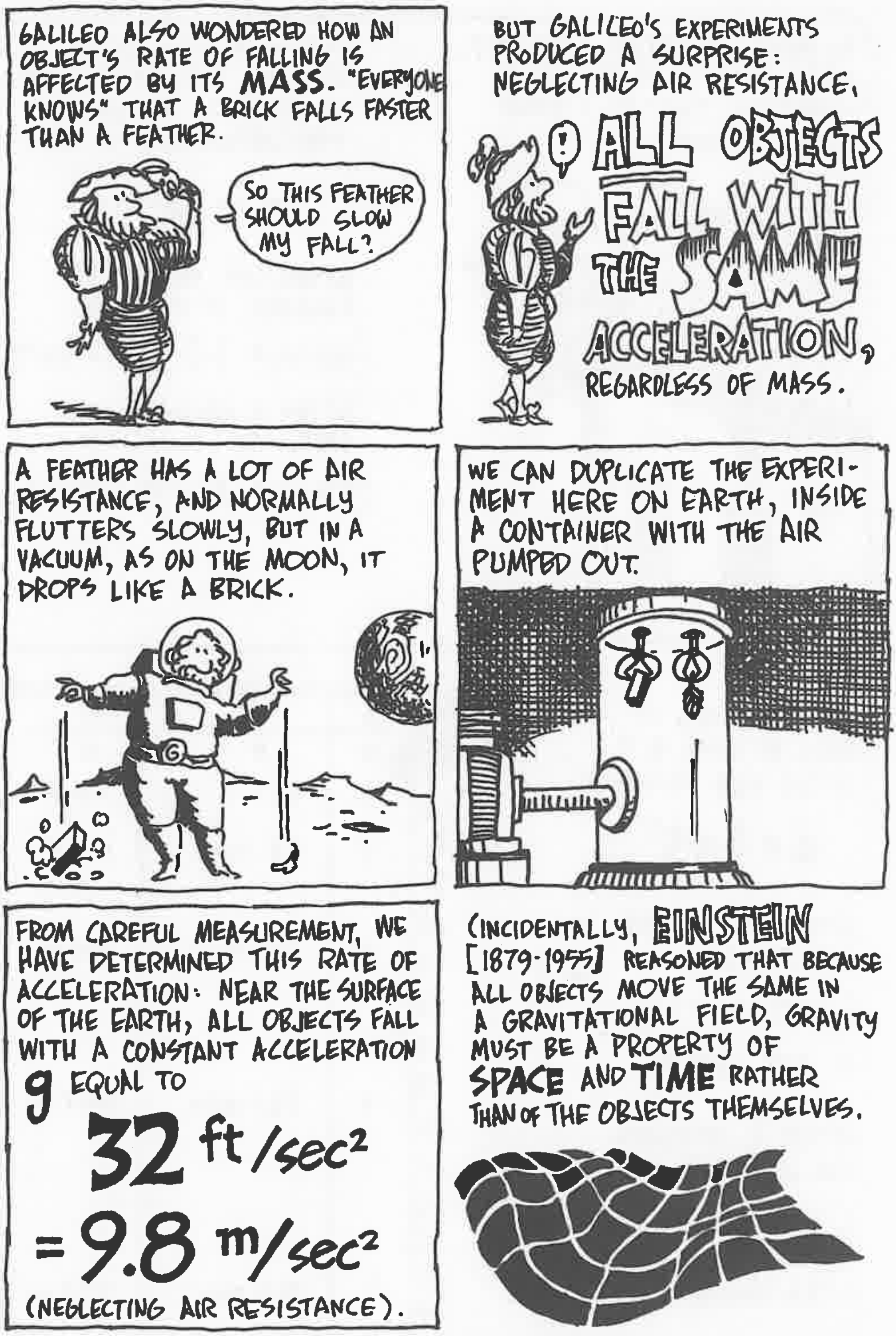
$$d = \frac{1}{2}at^2$$

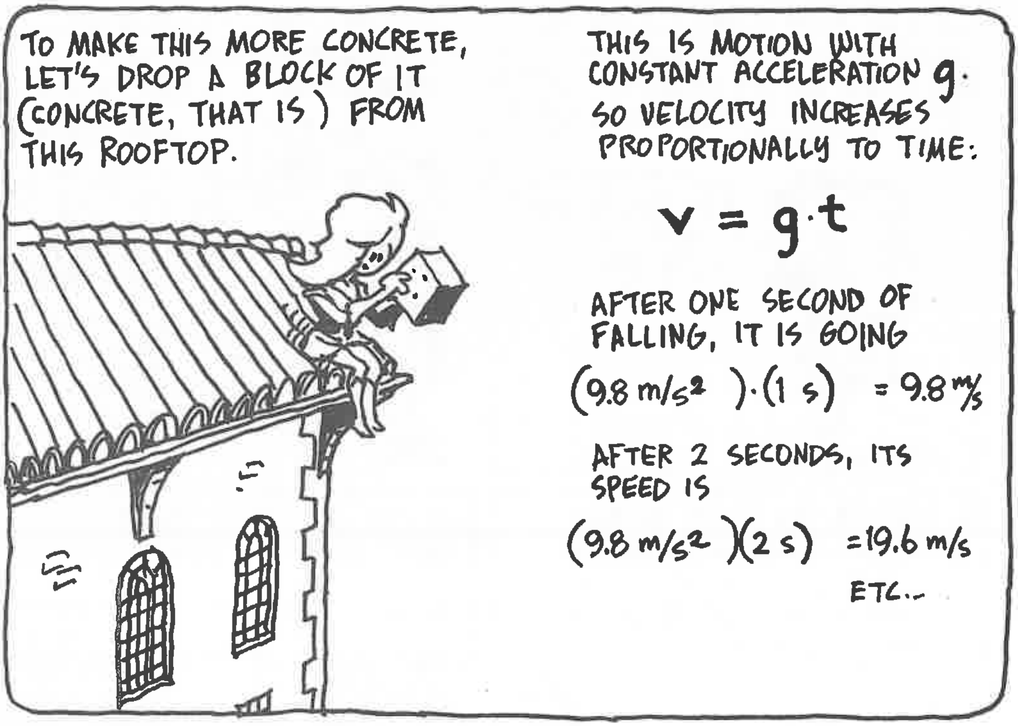
$$= \frac{1}{2}(2.78\ m/s^2)\cdot(5s)^2$$

$$= \mathbf{34.7}\ \text{METERS}$$



*STRICTLY SPEAKING, THIS ARGUMENT IS VALID ONLY FOR FRICTIONLESS SLIDING OBJECTS.


GALILEO ALSO WONDERED HOW AN OBJECT'S RATE OF FALLING IS AFFECTED BY ITS MASS. "EVERYONE KNOWS" THAT A BRICK FALLS FASTER THAN A FEATHER.
SO THIS FEATHER SHOULD SLOW MY FALL?
BUT GALILEO'S EXPERIMENTS PRODUCED A SURPRISE: NEGLECTING AIR RESISTANCE,
!
ALL OBJECTS FALL WITH THE SAME ACCELERATION,
REGARDLESS OF MASS.
A FEATHER HAS A LOT OF AIR RESISTANCE, AND NORMALLY FLUTTERS SLOWLY, BUT IN A VACUUM, AS ON THE MOON, IT DROPS LIKE A BRICK.
G
WE CAN DUPLICATE THE EXPERIMENT HERE ON EARTH, INSIDE A CONTAINER WITH THE AIR PUMPED OUT.
FROM CAREFUL MEASUREMENT, WE HAVE DETERMINED THIS RATE OF ACCELERATION: NEAR THE SURFACE OF THE EARTH, ALL OBJECTS FALL WITH A CONSTANT ACCELERATION g EQUAL TO
32 ft/sec²
= 9.8 m/sec²
(NEGLECTING AIR RESISTANCE).
(INCIDENTALLY, EINSTEIN [1879-1955] REASONED THAT BECAUSE ALL OBJECTS MOVE THE SAME IN A GRAVITATIONAL FIELD, GRAVITY MUST BE A PROPERTY OF SPACE AND TIME RATHER THAN OF THE OBJECTS THEMSELVES.



HOW FAR DOES IT FALL IN TIME **t**? APPLY OUR FORMULA

$$d = \frac{1}{2} g \cdot t^2$$

AFTER ONE SECOND, IT HAS FALLEN

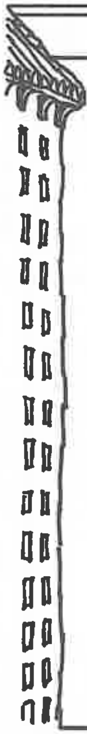
$$\frac{1}{2}(9.8\ m/s^2)\cdot(1\ s)^2$$

$$= 4.9 \text{ meters}$$

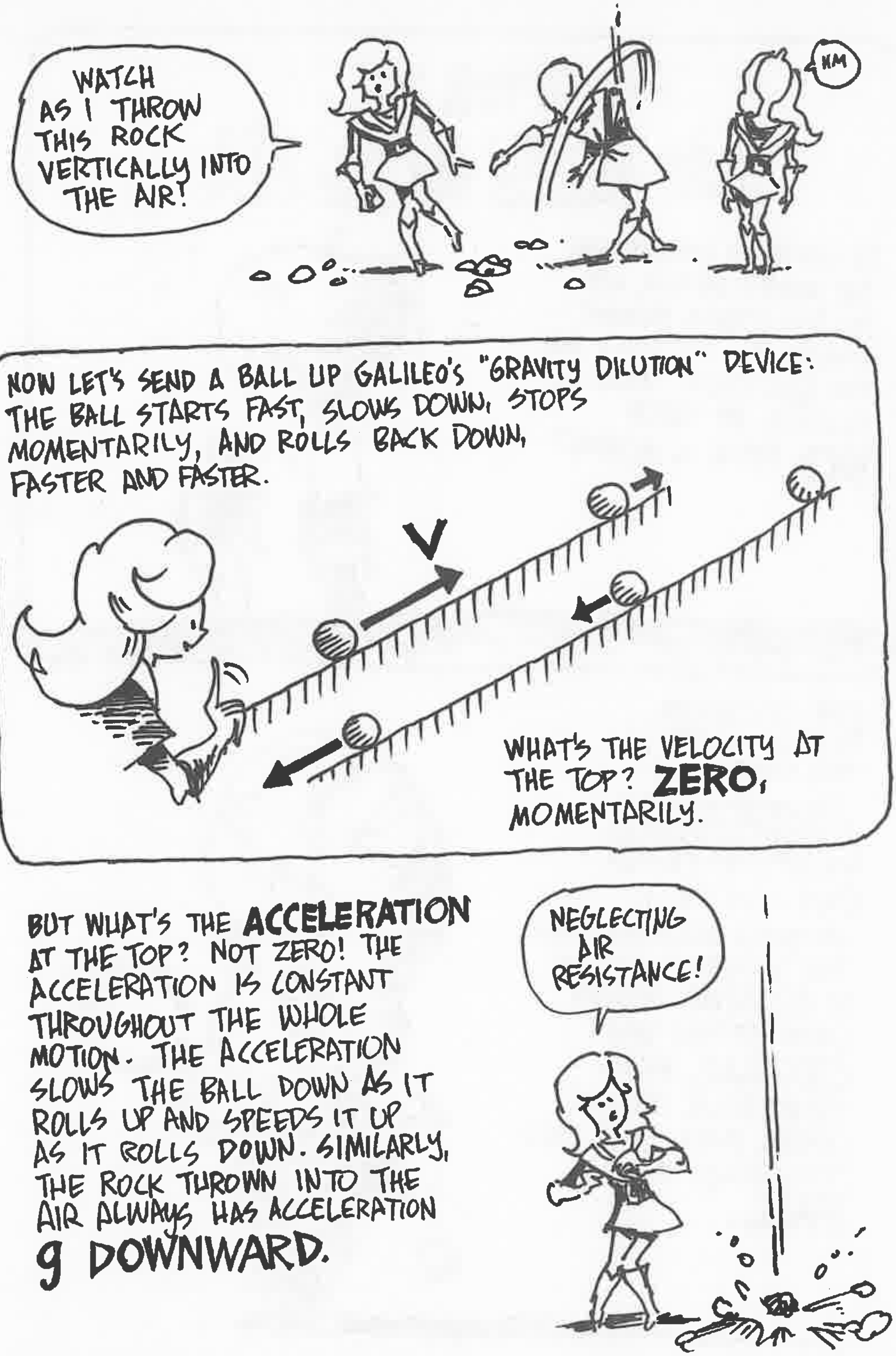
AFTER 2 SECONDS, THE DISTANCE IS

$$\frac{1}{2}(9.8\ m/s^2)(2\ s)^2$$

$$= 19.6 \text{ meters.}$$



t	v	d
0	0	0
0.5	4.9 m/s	1.3 m
1	9.8 m/s	4.9 m
2	19.6 m/s	19.6 m
3	29.4 m/s	44.1 m
4	39.2 m/s	78.4 m


WATCH AS I THROW THIS ROCK VERTICALLY INTO THE AIR!
HM
NOW LET'S SEND A BALL UP GALILEO'S "GRAVITY DILUTION" DEVICE: THE BALL STARTS FAST, SLOWS DOWN, STOPS MOMENTARILY, AND ROLLS BACK DOWN, FASTER AND FASTER.
V
WHAT'S THE VELOCITY AT THE TOP? ZERO, MOMENTARILY.
BUT WHAT'S THE ACCELERATION AT THE TOP? NOT ZERO! THE ACCELERATION IS CONSTANT THROUGHOUT THE WHOLE MOTION. THE ACCELERATION SLOWS THE BALL DOWN AS IT ROLLS UP AND SPEEDS IT UP AS IT ROLLS DOWN. SIMILARLY, THE ROCK THROWN INTO THE AIR ALWAYS HAS ACCELERATION g DOWNWARD.
NEGLECTING AIR RESISTANCE!

◦ CHAPTER 2 ◦

THE APPLE AND THE MOON

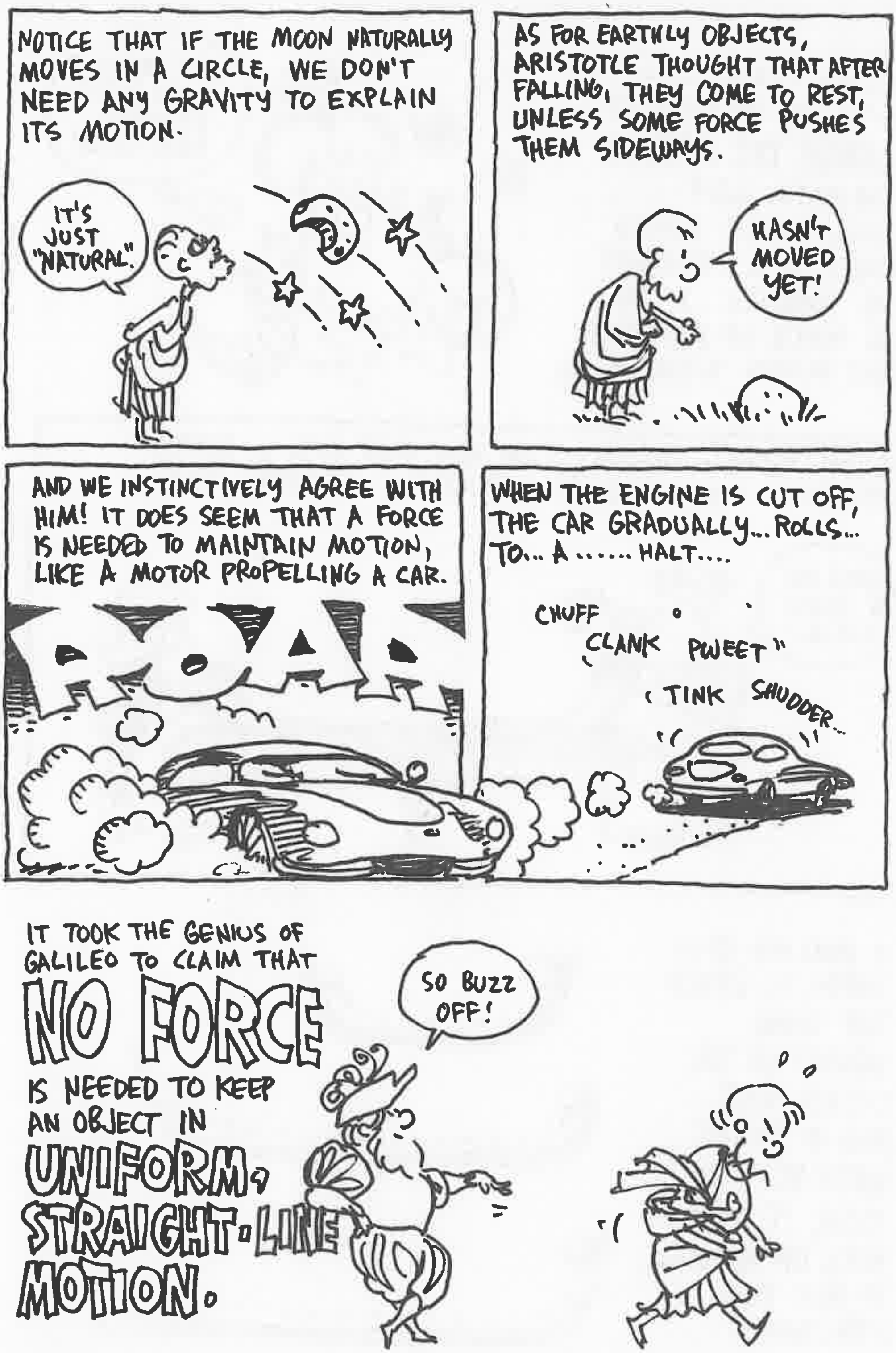
IN ORDER TO UNDERSTAND THE MOON'S MOTION, AND ALL THE OTHER MOTION AROUND US, WE FIRST ASK THE QUESTION: WHAT DO OBJECTS DO WHEN **NO** FORCE IS ACTING?

FOR CENTURIES, PHYSICS SLEPT IN THE SHADOW OF

ARISTOTLE

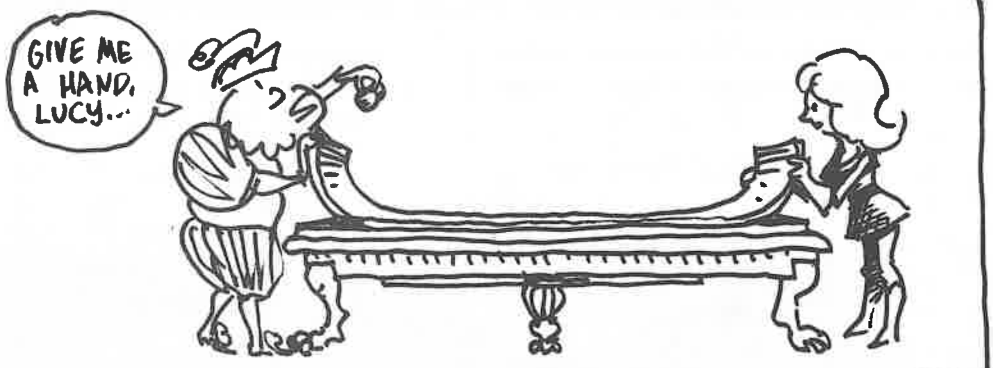
(384-322 B.C.).

ARISTOTLE BELIEVED THAT THE "NATURAL" MOTION OF **CELESTIAL** OBJECTS (MOON, STARS) WAS **CIRCULAR**, WHILE **TERRESTRIAL** OBJECTS (APPLES, ROCKS, YOU) TEND "NATURALLY" TO **FALL**.

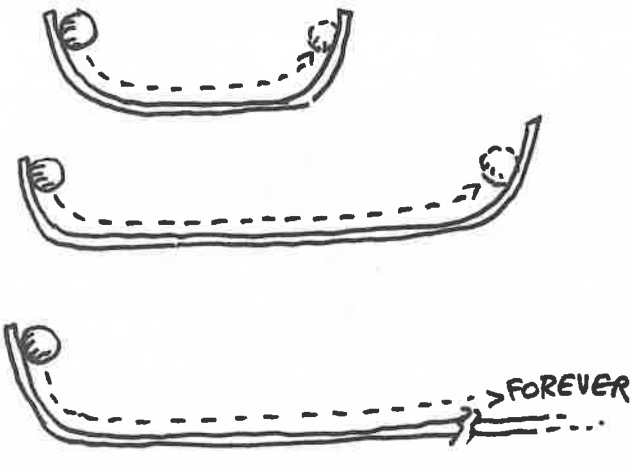

NOTICE THAT IF THE MOON NATURALLY MOVES IN A CIRCLE, WE DON'T NEED ANY GRAVITY TO EXPLAIN ITS MOTION.
IT'S JUST "NATURAL."
AS FOR EARTHLY OBJECTS, ARISTOTLE THOUGHT THAT AFTER FALLING, THEY COME TO REST, UNLESS SOME FORCE PUSHES THEM SIDEWAYS.
HASN'T MOVED YET!
AND WE INSTINCTIVELY AGREE WITH HIM! IT DOES SEEM THAT A FORCE IS NEEDED TO MAINTAIN MOTION, LIKE A MOTOR PROPELLING A CAR.
ROAR
WHEN THE ENGINE IS CUT OFF, THE CAR GRADUALLY... ROLLS... TO... A ...... HALT....
CHUFF
CLANK PWEET
TINK SHUDDER...
IT TOOK THE GENIUS OF GALILEO TO CLAIM THAT NO FORCE IS NEEDED TO KEEP AN OBJECT IN UNIFORM, STRAIGHT-LINE MOTION.
SO BUZZ OFF!

GALILEO'S BRAINSTORM WAS TO SEE THAT FORCES **CHANGE THE MOTION** OF OBJECTS. LEFT ALONE, THINGS WOULD TRAVEL IN A STRAIGHT LINE FOREVER. IT IS THE FORCE OF **FRICTION** THAT SLOWS THEM DOWN.

WE CAN CONVINCE OURSELVES OF THIS IDEA WITH A SIMPLE APPARATUS CONSISTING OF A FLEXIBLE RUBBER MAT:



A ROLLING BALL TENDS TO REACH THE SAME HEIGHT ON THE OTHER SIDE... AND IF THERE WERE NO OTHER SIDE, IT WOULD ROLL ON FOREVER, IF NOT FOR FRICTION.

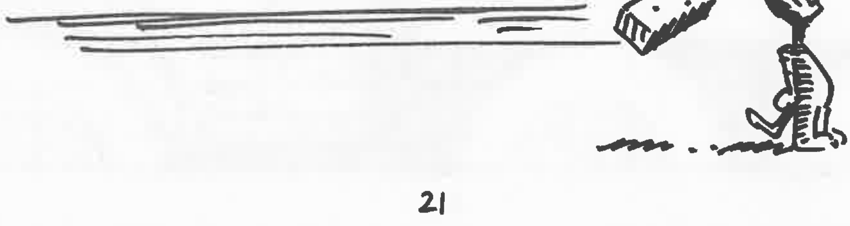


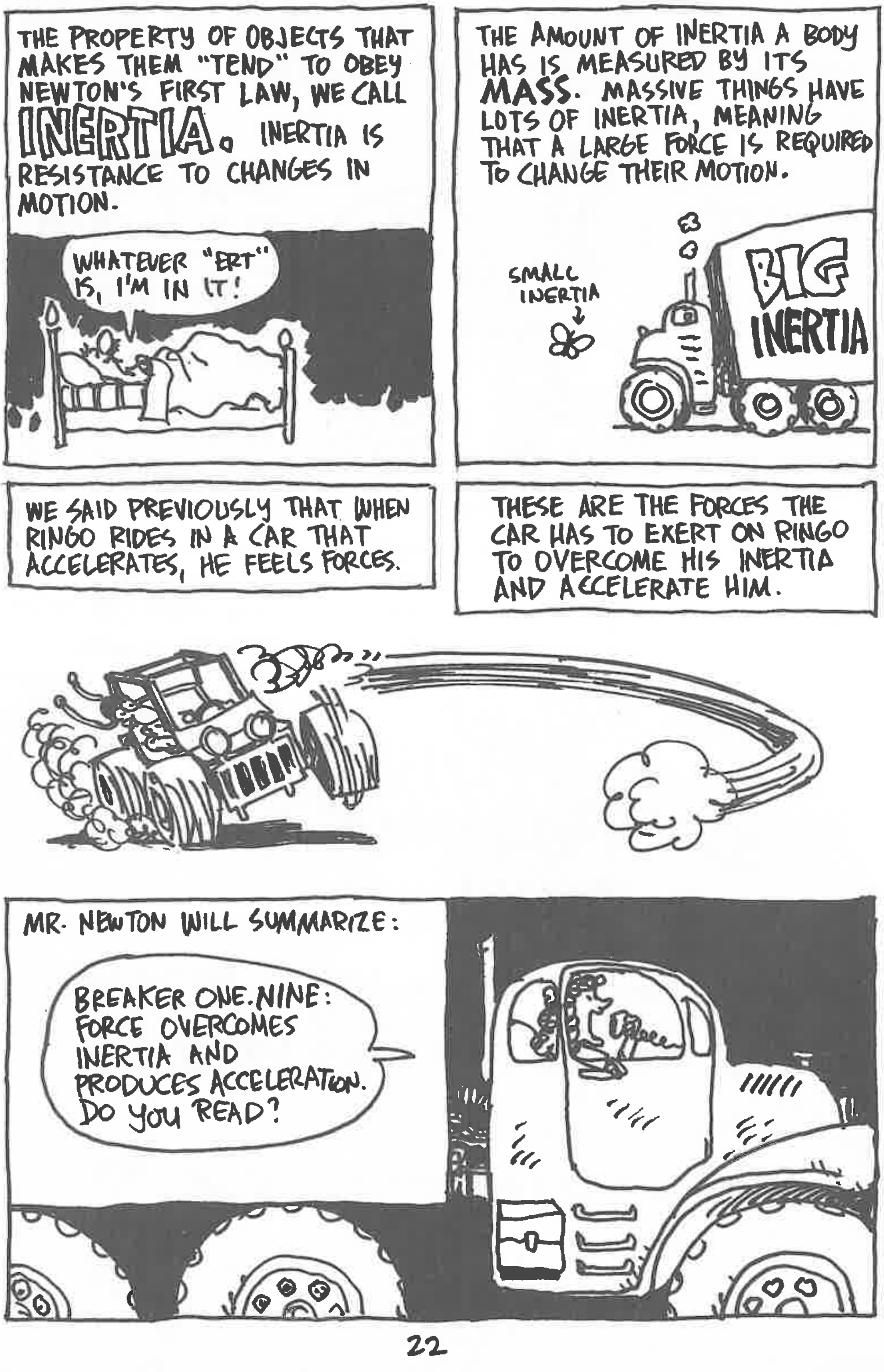
ISAAC **NEWTON** (1642-1727) SUMMARIZED GALILEO'S IDEA AS **NEWTON'S FIRST LAW:**

AN OBJECT AT REST TENDS TO STAY AT REST. AN OBJECT IN MOTION TENDS TO CONTINUE IN MOTION AT CONSTANT SPEED IN A STRAIGHT LINE.

(HE ALSO SAID: "IF I HAVE SEEN FAR, IT IS BECAUSE I HAVE STOOD ON THE SHOULDERS OF GIANTS," MEANING GALILEO OF COURSE...)

IN THE TERMINOLOGY WE DEVELOPED IN CHAPTER ONE, WE WOULD SAY THAT WHEN THERE ARE NO FORCES, OBJECTS MOVE WITH **CONSTANT VELOCITY.**




THE PROPERTY OF OBJECTS THAT MAKES THEM "TEND" TO OBEY NEWTON'S FIRST LAW, WE CALL INERTIA. INERTIA IS RESISTANCE TO CHANGES IN MOTION.
WHATEVER "ERT" IS, I'M IN IT!
THE AMOUNT OF INERTIA A BODY HAS IS MEASURED BY ITS MASS. MASSIVE THINGS HAVE LOTS OF INERTIA, MEANING THAT A LARGE FORCE IS REQUIRED TO CHANGE THEIR MOTION.
SMALL INERTIA
BIG INERTIA
WE SAID PREVIOUSLY THAT WHEN RINGO RIDES IN A CAR THAT ACCELERATES, HE FEELS FORCES.
THESE ARE THE FORCES THE CAR HAS TO EXERT ON RINGO TO OVERCOME HIS INERTIA AND ACCELERATE HIM.
MR. NEWTON WILL SUMMARIZE:
BREAKER ONE-NINE: FORCE OVERCOMES INERTIA AND PRODUCES ACCELERATION. DO YOU READ?

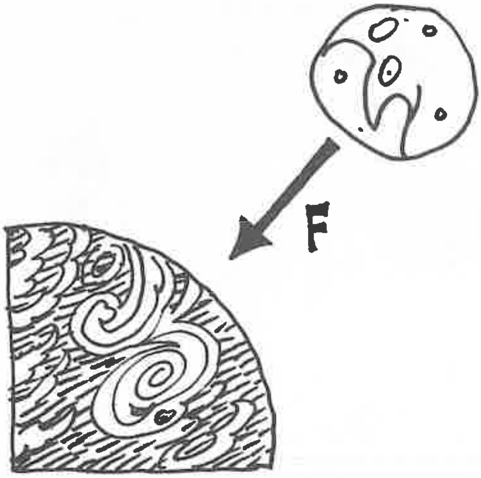
NEWTON PUT THIS RELATIONSHIP AMONG FORCE, MASS, AND ACCELERATION INTO MATHEMATICAL FORM WITH NEWTON'S

SECOND LAW:

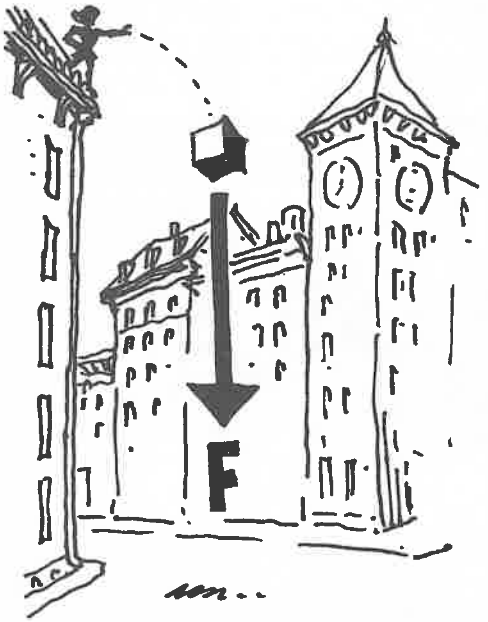
$$F = m \cdot a$$

THE MORE FORCE ON AN OBJECT, THE MORE IT ACCELERATES. BUT THE MORE MASSIVE IT IS, THE MORE IT RESISTS ACCELERATION.

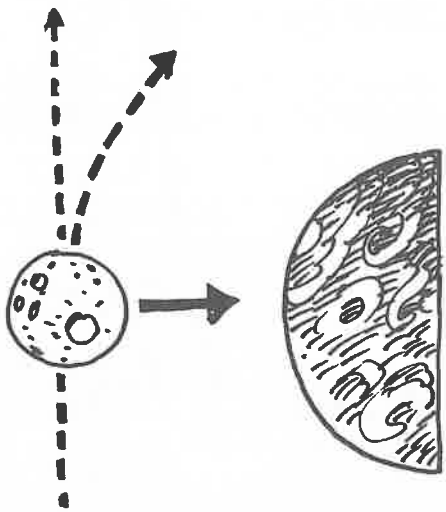
NOW LET'S LOOK AT THE MOON AGAIN. IT GOES IN A CIRCLE AROUND THE EARTH, OR NEARLY SO. AS WE HAVE SEEN, THINGS THAT MOVE IN A CIRCLE ARE ACCELERATING. THEREFORE, IT HAS A FORCE ACTING ON IT. IT MUST BE THAT **THE EARTH IS PULLING ON THE MOON.**



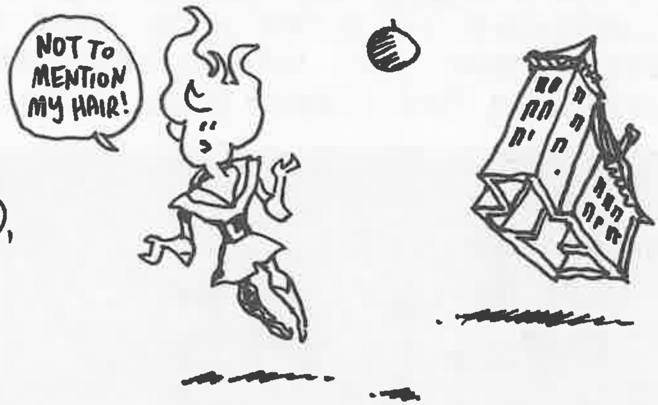
WE KNOW THAT THE EARTH PULLS ON OBJECTS NEAR ITS SURFACE, CAUSING THEM TO ACCELERATE DOWNWARD.



THE SAME FORCE, **GRAVITY**, ACTS ON THE MOON, PULLING IT AWAY FROM THE STRAIGHT LINE IT WOULD HAVE TAKEN IN THE ABSENCE OF GRAVITY.



WHEN RELEASED IN MID-AIR, AN APPLE WOULD HAVE REMAINED AT REST (ITS "NATURAL" MOTION), IF NOT FOR THE EFFECT OF GRAVITY MAKING IT FALL.



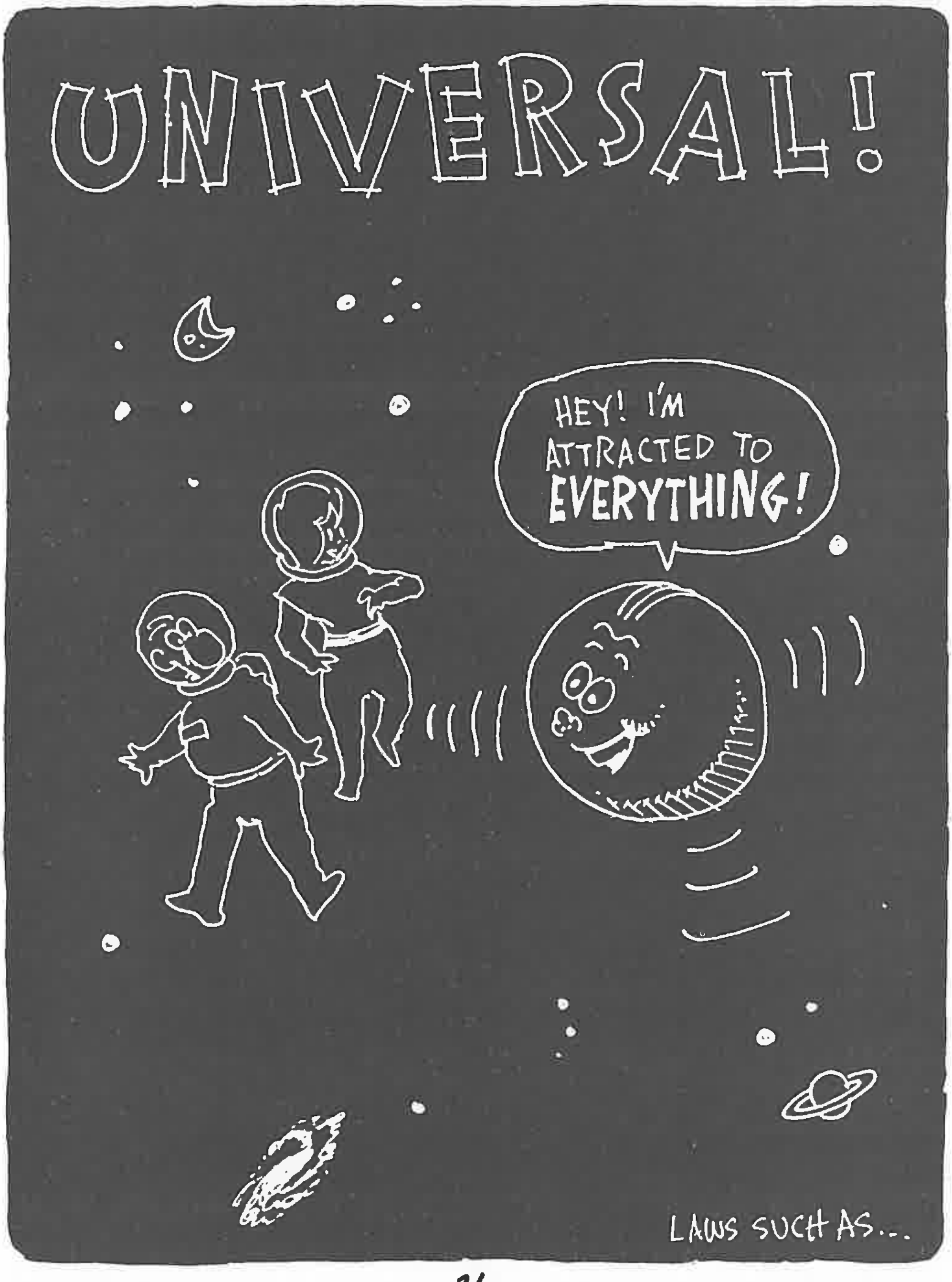
SIMILARLY, IN THE ABSENCE OF GRAVITY (OR OTHER FORCES), THE MOON WOULD CONTINUE ALONG A STRAIGHT LINE AT UNIFORM SPEED. BUT GRAVITY DOES PULL IT, ACCELERATING THE MOON TOWARD THE EARTH. **THE MOON IS FALLING —** FALLING AWAY FROM ITS NATURAL "FIRST LAW" STRAIGHT-LINE MOTION.

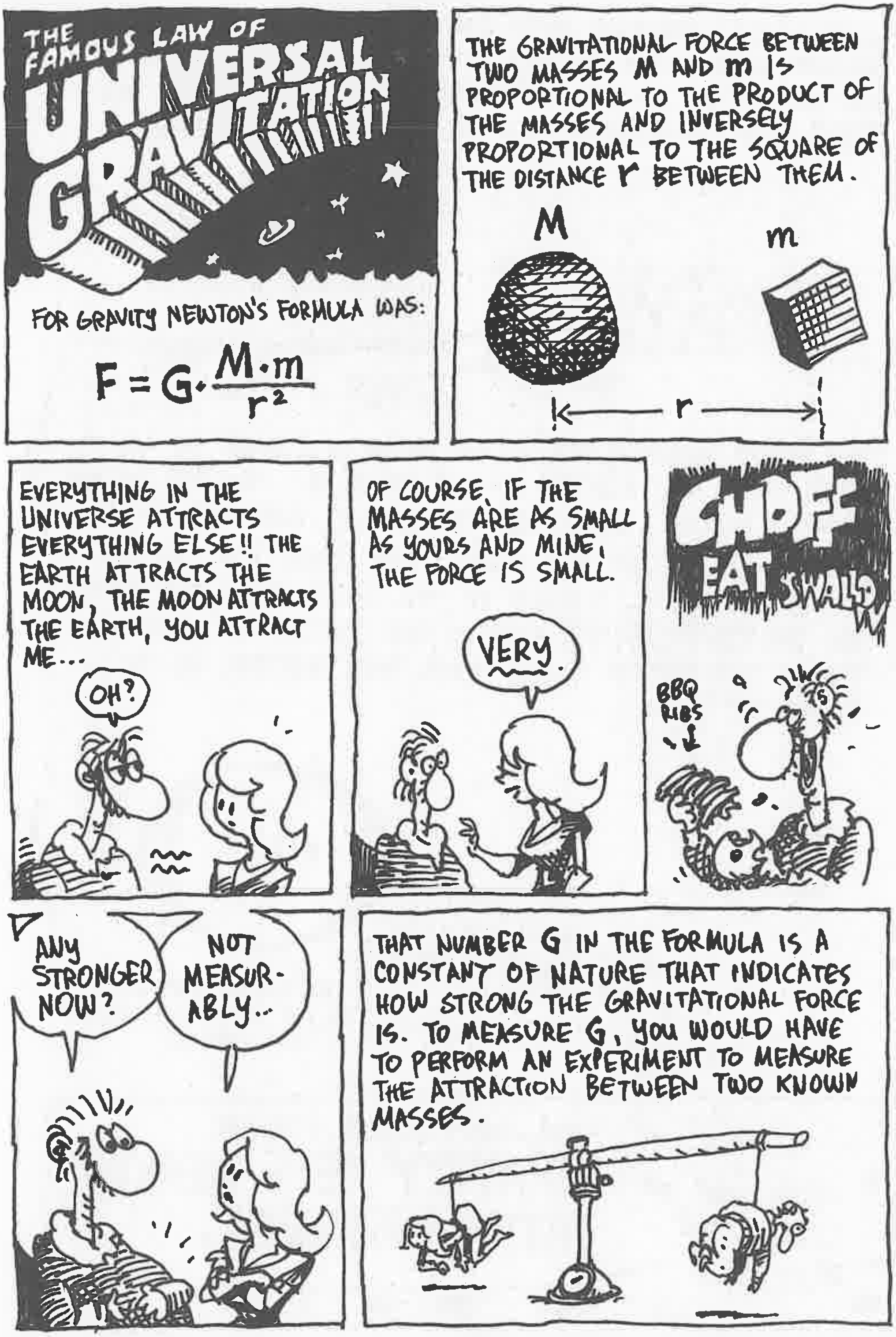
IN ONE SEC., THE MOON FALLS ABOUT 1 mm AWAY FROM A STRAIGHT-LINE PATH

IN ONE SEC., AN APPLE FALLS 4.9 m NEAR THE EARTH'S SURFACE.

THE MOON DOESN'T FALL AS MUCH AS THE APPLE, BECAUSE THE EARTH'S GRAVITY IS WEAKER OUT THERE, FAR FROM THE EARTH.

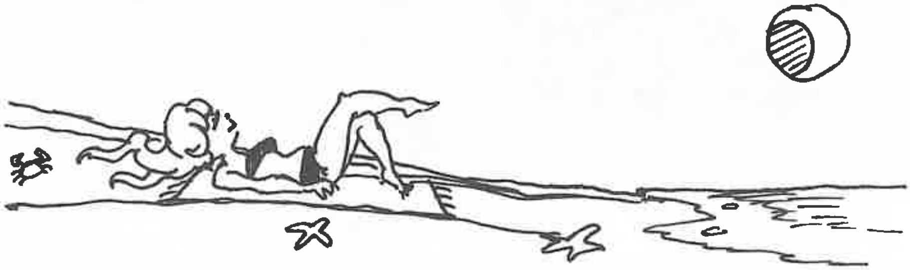
STOP FOR A MOMENT AND CONSIDER WHAT NEWTON ACCOMPLISHED. THE MOTION OF THE APPLE AND THE MOON OBEY THE SAME LAWS. HEAVENLY BODIES BEHAVE NO DIFFERENTLY FROM EARTHLY ONES. NEWTON'S LAWS ARE—



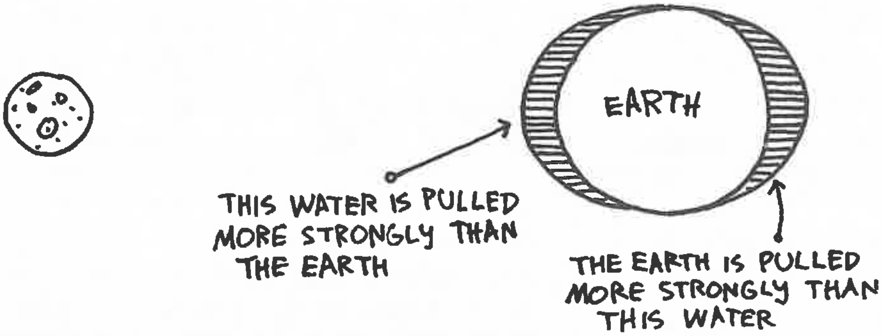


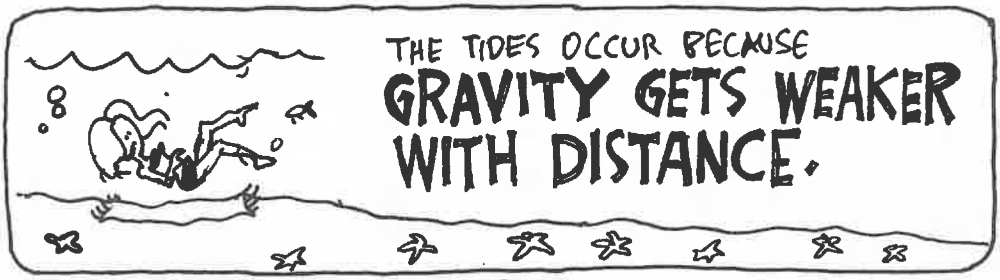
THE FAMOUS LAW OF
UNIVERSAL GRAVITATION
FOR GRAVITY NEWTON'S FORMULA WAS:
$$F = G \cdot \frac{M \cdot m}{r^2}$$
THE GRAVITATIONAL FORCE BETWEEN TWO MASSES M AND m IS PROPORTIONAL TO THE PRODUCT OF THE MASSES AND INVERSELY PROPORTIONAL TO THE SQUARE OF THE DISTANCE r BETWEEN THEM.
M
m
r
EVERYTHING IN THE UNIVERSE ATTRACTS EVERYTHING ELSE!! THE EARTH ATTRACTS THE MOON, THE MOON ATTRACTS THE EARTH, YOU ATTRACT ME...
OH?
OF COURSE, IF THE MASSES ARE AS SMALL AS YOURS AND MINE, THE FORCE IS SMALL.
VERY.
CHOFF
EAT
BBQ RIBS
ANY STRONGER NOW?
NOT MEASURABLY...
THAT NUMBER G IN THE FORMULA IS A CONSTANT OF NATURE THAT INDICATES HOW STRONG THE GRAVITATIONAL FORCE IS. TO MEASURE G, YOU WOULD HAVE TO PERFORM AN EXPERIMENT TO MEASURE THE ATTRACTION BETWEEN TWO KNOWN MASSES.

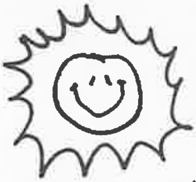
GRAVITY GETS WEAKER WITH DISTANCE: WE SAW THAT THE DISTANT MOON FALLS SLOWER THAN AN EARTHBOUND APPLE. ANOTHER EFFECT OF THIS **INVERSE-SQUARE LAW** IS THE **TIDE**, THE TWICE-DAILY RISE AND FALL OF OCEAN WATER.



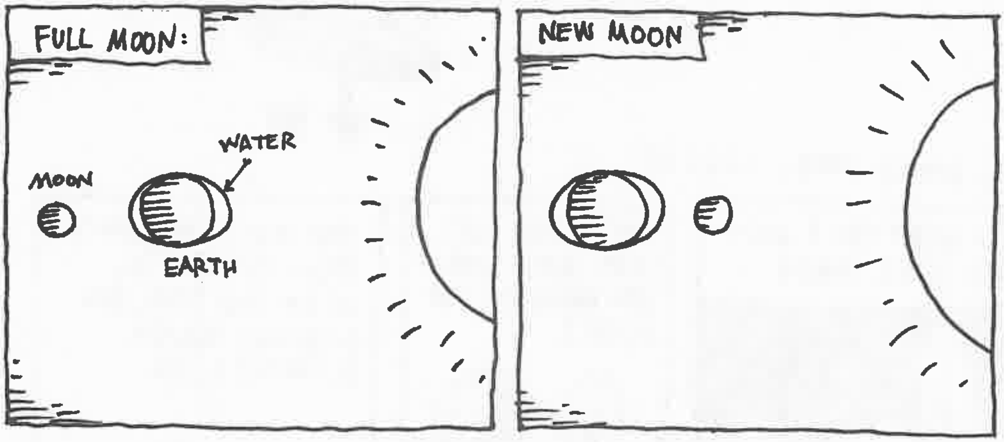
THE WATER DIRECTLY UNDER THE MOON IS CLOSER TO THE MOON THAN THE CENTER OF THE EARTH IS... SO THE MOON'S GRAVITY PULLS HARDER ON THE WATER, AND THE WATER "HEAPS UP" UNDER THE MOON. AND SINCE THE CENTER OF THE EARTH IS CLOSER TO THE MOON THAN THE WATER ON THE **OPPOSITE** SIDE OF THE EARTH, THE MOON PULLS THE EARTH AWAY FROM THAT WATER, SO IT HEAPS UP TOO!



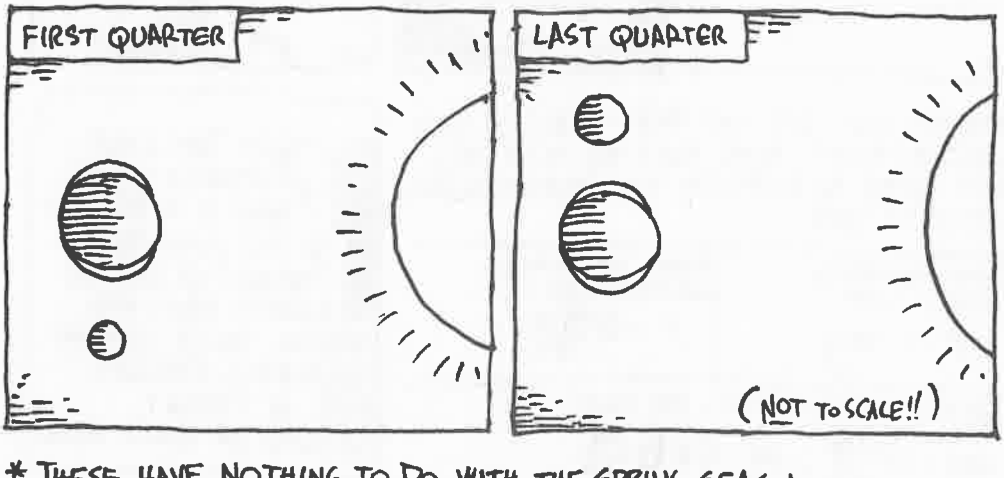




THE SUN ALSO CAUSES TIDES IN THE SAME WAY BUT LESS SO, BECAUSE OF THE SUN'S GREATER DISTANCE. AT FULL MOON AND NEW MOON EACH MONTH, THE SUN IS IN LINE WITH THE MOON AND THE EARTH. THEN THE SUN AND MOON TOGETHER PRODUCE EXTRA-HIGH AND EXTRA-LOW TIDES. THESE ARE THE TWICE-MONTHLY **SPRING TIDES.***



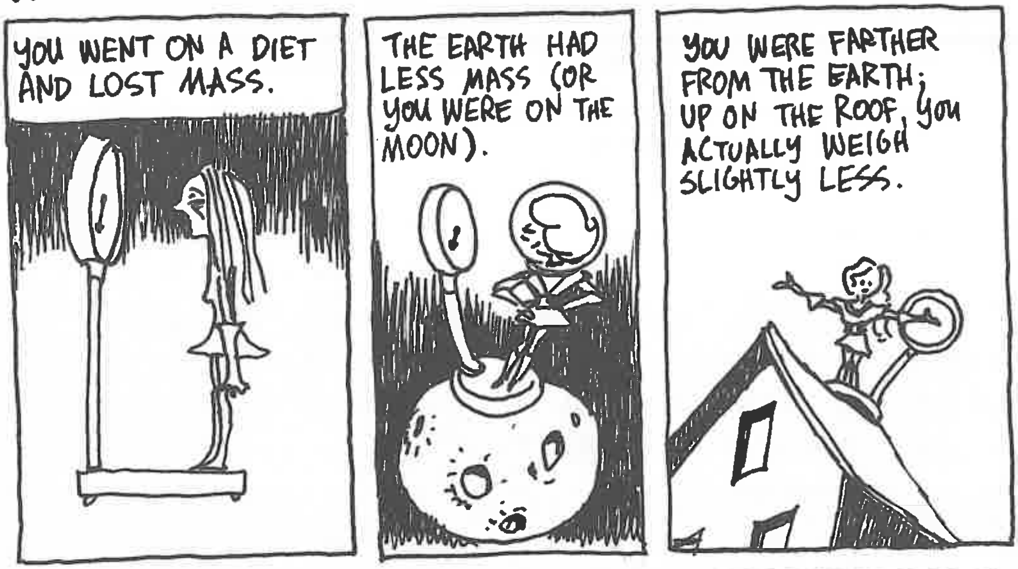
AT FIRST QUARTER AND LAST QUARTER, THE SUN AND MOON ARE AT RIGHT ANGLES. THE SUN'S TIDE IS SUBTRACTED FROM THE MOON'S, AND THE VARIATION IN TIDES IS LESS. THESE ARE THE **NEAP TIDES.**



* THESE HAVE NOTHING TO DO WITH THE SPRING SEASON.

NOW LET'S THINK ABOUT GRAVITY'S EFFECTS ON THINGS NEAR THE EARTH, YOU, FOR EXAMPLE. THE GRAVITATIONAL FORCE ON YOU IS YOUR **WEIGHT**.

YOU WOULD WEIGH LESS IF:



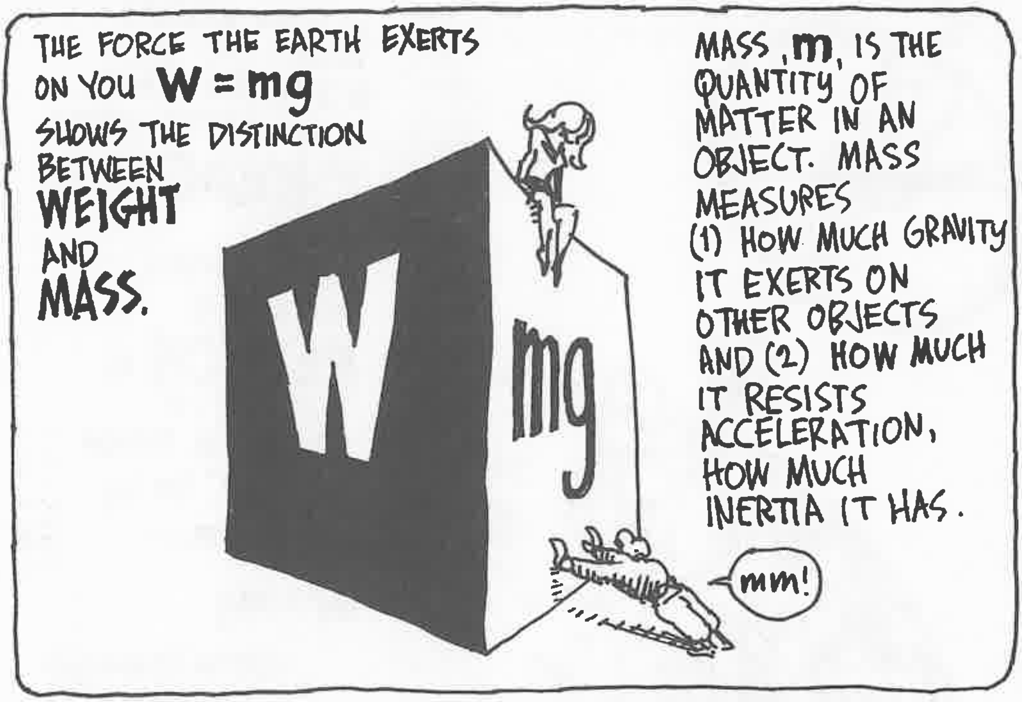
NOW YOU JUMP OFF THE ROOF — WHAT IS YOUR ACCELERATION? NOTE THAT WE NOW HAVE TWO WAYS TO EXPRESS THE GRAVITATIONAL FORCE ON YOU:

FROM NEWTON'S SECOND LAW:	FROM UNIVERSAL GRAVITATION:
$F = mg$	$F = G\frac{Mm}{r^2}$

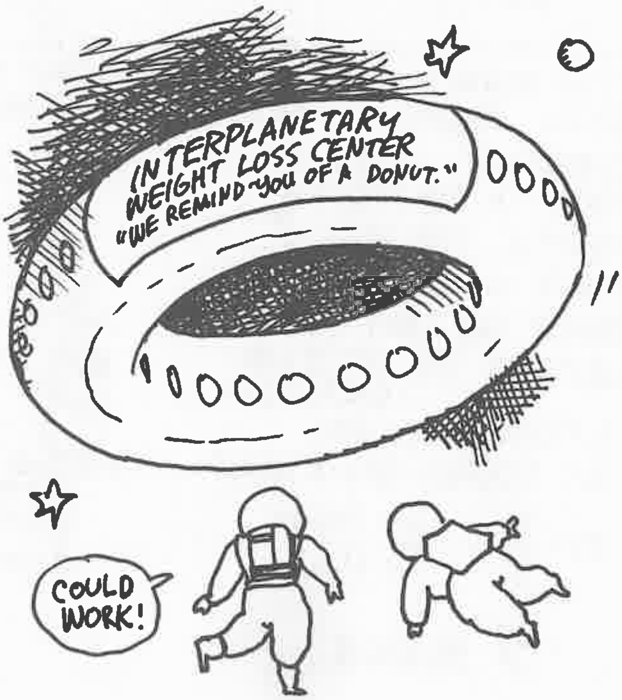
SETTING THESE EQUAL, WE FIND:

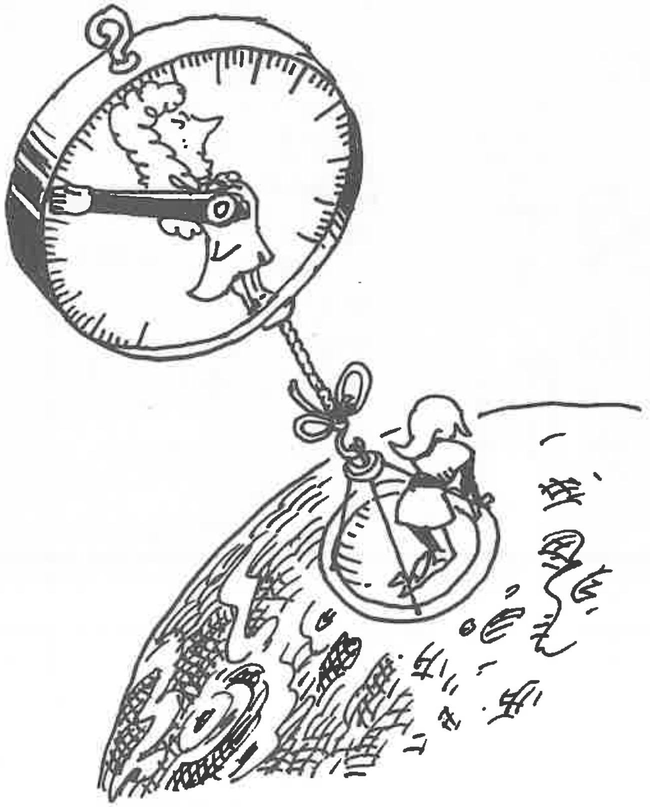
$$mg = G\frac{Mm}{r^2}, \text{ so } g = G\frac{M}{r^2}$$

THIS LAST FORMULA SHOWS HOW g IS RELATED TO THE FUNDAMENTAL CONSTANT G AND THE EARTH'S MASS AND RADIUS. NOTE THAT m, YOUR MASS, CANCELS OUT. g DOESN'T DEPEND ON YOUR MASS!



WEIGHT, **W**, IS THE AMOUNT OF GRAVITATIONAL PULL ON THE OBJECT. WEIGHT VARIES ACCORDING TO WHERE YOU ARE: IN DEEP SPACE, YOUR WEIGHT MIGHT BE ZERO, BUT YOUR MASS IS THE SAME WHEREVER YOU GO!





WE EVEN MEASURE WEIGHT AND MASS IN DIFFERENT UNITS. IN THE METRIC SYSTEM, THE **KILOGRAM** IS THE UNIT OF MASS, WHILE THE **NEWTON** IS THE UNIT OF WEIGHT. A PERSON "MASSING" 50 Kg HAS A WEIGHT

$$W = mg$$

$$= (50\ \text{KG})(9.8\ \text{m/s}^2)$$

$$= 490\ \text{NEWTONS}$$

IT IS TECHNICALLY INCORRECT TO SAY THAT SOMETHING "WEIGHS" 50 kg. WEIGHT IS STATED IN UNITS OF FORCE, NEWTONS.

CONFUSING? LISTEN TO THIS: IN THE ENGLISH SYSTEM, THE UNIT OF FORCE IS THE **POUND**, WHILE THE UNIT OF MASS IS THE **SLUG**.

A PERSON WEIGHING 160 POUNDS HAS A MASS

$$m = \frac{W}{g} = \frac{160\ \text{POUNDS}}{32\ \text{ft/sec}^2}$$

$$= \mathbf{5\ SLUGS}.$$