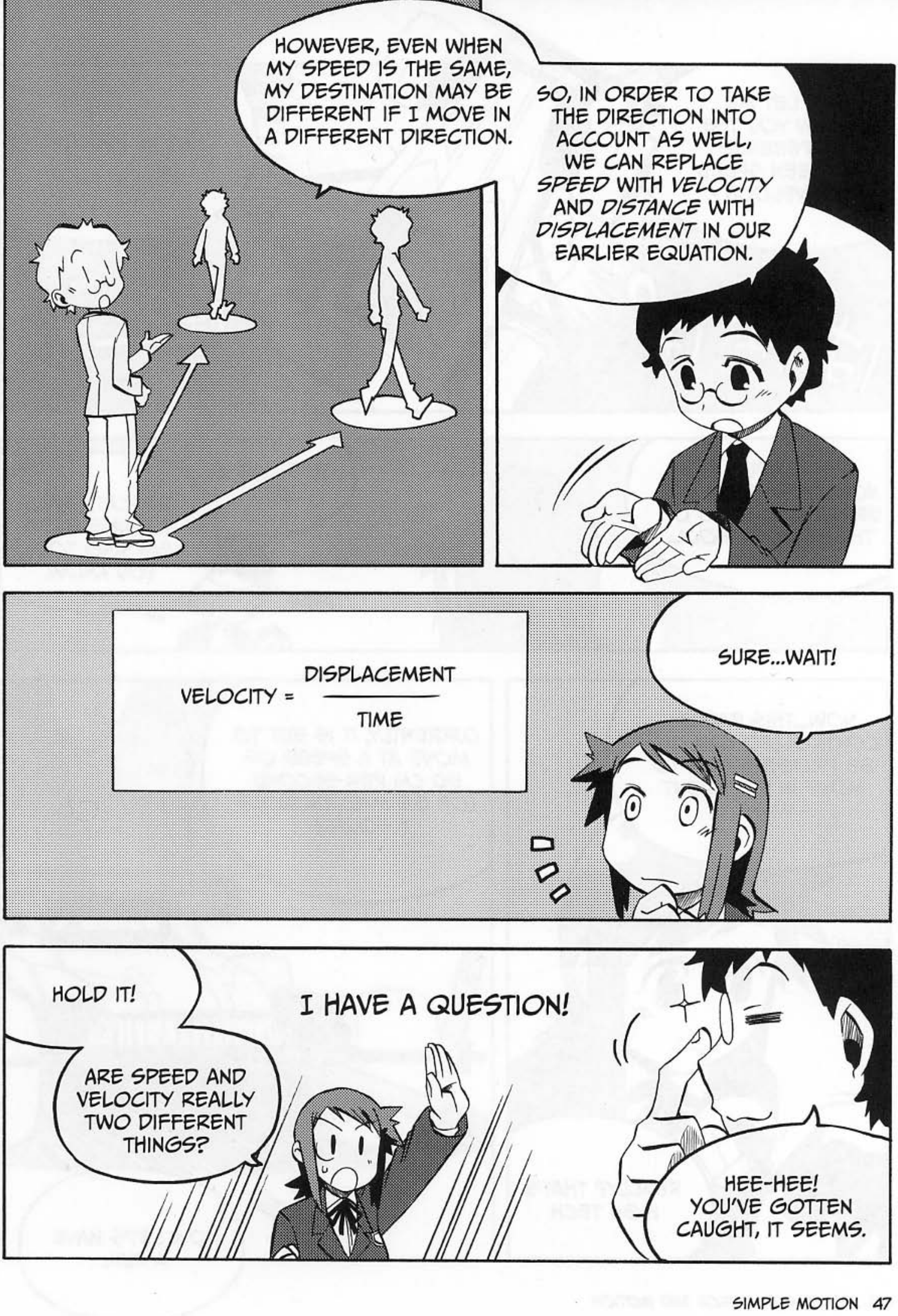
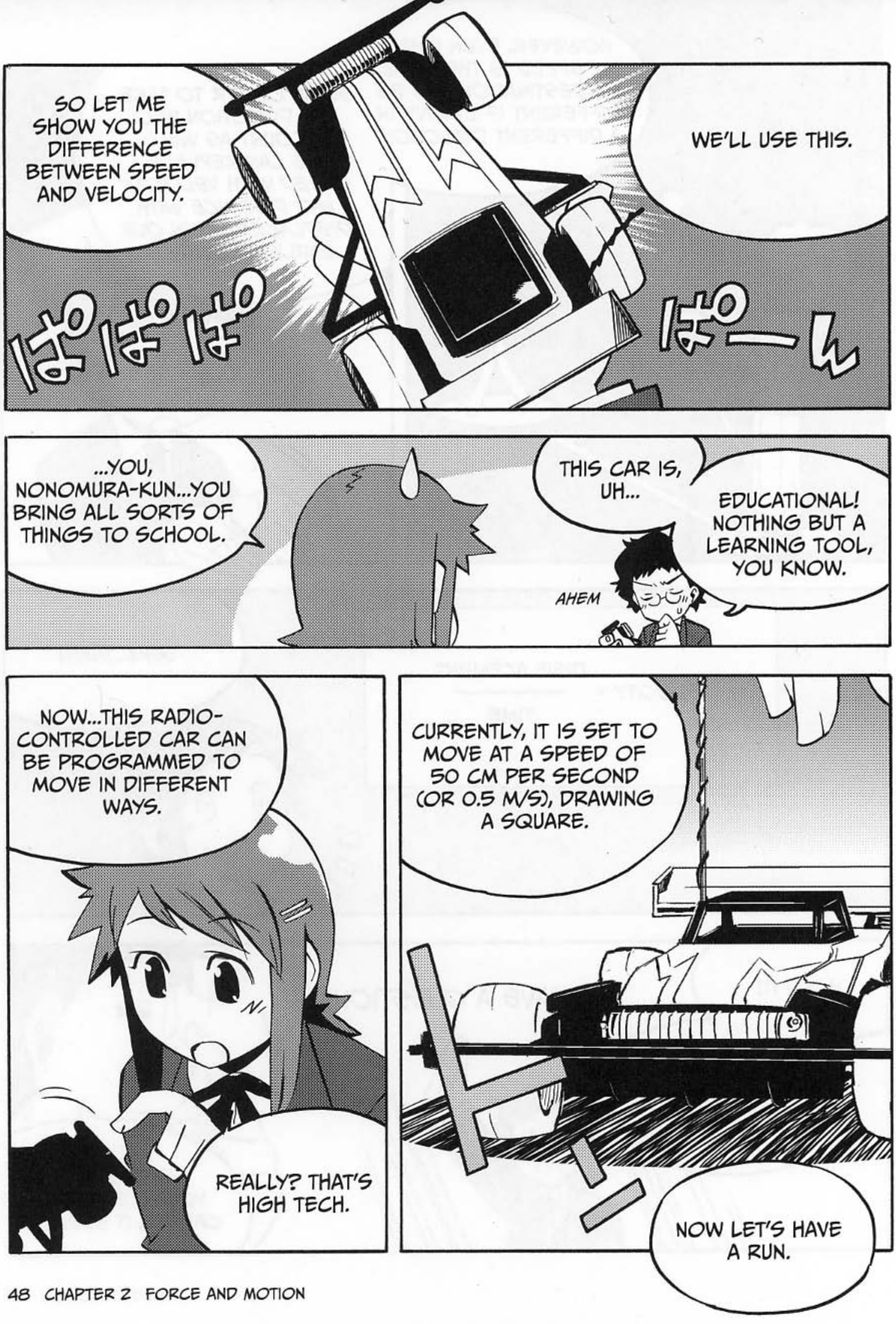
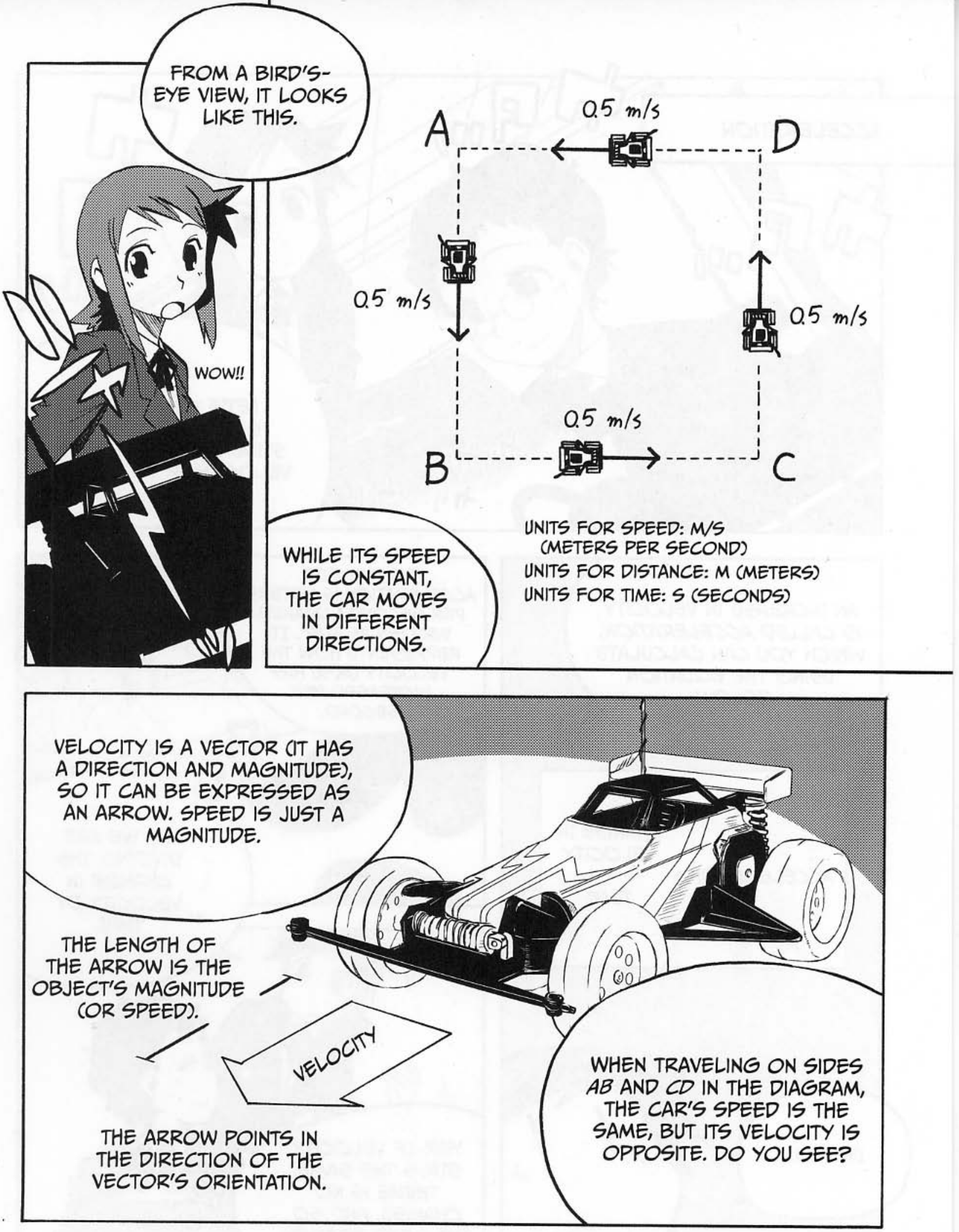
2 FORCE AND MOTION

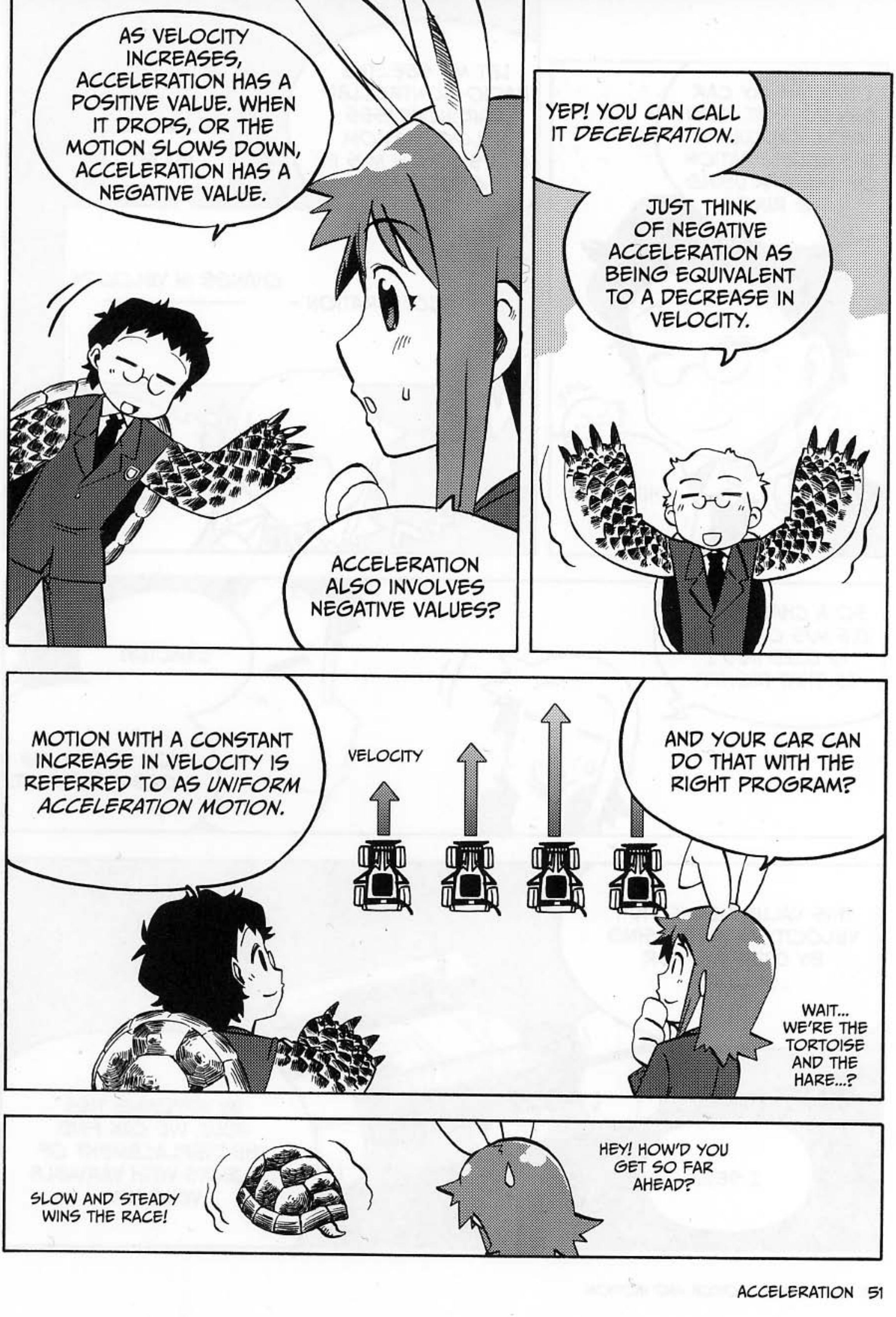
VELOCITY AND ACCELERATION


HOWEVER, EVEN WHEN MY SPEED IS THE SAME, MY DESTINATION MAY BE DIFFERENT IF I MOVE IN A DIFFERENT DIRECTION.
SO, IN ORDER TO TAKE THE DIRECTION INTO ACCOUNT AS WELL, WE CAN REPLACE *SPEED* WITH *VELOCITY* AND *DISTANCE* WITH *DISPLACEMENT* IN OUR EARLIER EQUATION.
VELOCITY = DISPLACEMENT / TIME
SURE...WAIT!
HOLD IT!
I HAVE A QUESTION!
ARE SPEED AND VELOCITY REALLY TWO DIFFERENT THINGS?
HEE-HEE! YOU'VE GOTTEN CAUGHT, IT SEEMS.


SO LET ME SHOW YOU THE DIFFERENCE BETWEEN SPEED AND VELOCITY.
WE'LL USE THIS.
ぱぱぱ
ぱーん
...YOU, NONOMURA-KUN...YOU BRING ALL SORTS OF THINGS TO SCHOOL.
THIS CAR IS, UH...
EDUCATIONAL! NOTHING BUT A LEARNING TOOL, YOU KNOW.
AHEM
NOW...THIS RADIO-CONTROLLED CAR CAN BE PROGRAMMED TO MOVE IN DIFFERENT WAYS.
REALLY? THAT'S HIGH TECH.
CURRENTLY, IT IS SET TO MOVE AT A SPEED OF 50 CM PER SECOND (OR 0.5 M/S), DRAWING A SQUARE.
NOW LET'S HAVE A RUN.


FROM A BIRD'S-EYE VIEW, IT LOOKS LIKE THIS.
WOW!!
A
D
B
C
0.5 m/s
0.5 m/s
0.5 m/s
0.5 m/s
WHILE ITS SPEED IS CONSTANT, THE CAR MOVES IN DIFFERENT DIRECTIONS.
UNITS FOR SPEED: M/S (METERS PER SECOND)
UNITS FOR DISTANCE: M (METERS)
UNITS FOR TIME: S (SECONDS)
VELOCITY IS A VECTOR (IT HAS A DIRECTION AND MAGNITUDE), SO IT CAN BE EXPRESSED AS AN ARROW. SPEED IS JUST A MAGNITUDE.
THE LENGTH OF THE ARROW IS THE OBJECT'S MAGNITUDE (OR SPEED).
VELOCITY
THE ARROW POINTS IN THE DIRECTION OF THE VECTOR'S ORIENTATION.
WHEN TRAVELING ON SIDES *AB* AND *CD* IN THE DIAGRAM, THE CAR'S SPEED IS THE SAME, BUT ITS VELOCITY IS OPPOSITE. DO YOU SEE?

ACCELERATION


AS VELOCITY INCREASES, ACCELERATION HAS A POSITIVE VALUE. WHEN IT DROPS, OR THE MOTION SLOWS DOWN, ACCELERATION HAS A NEGATIVE VALUE.
ACCELERATION ALSO INVOLVES NEGATIVE VALUES?
YEP! YOU CAN CALL IT *DECELERATION*.
JUST THINK OF NEGATIVE ACCELERATION AS BEING EQUIVALENT TO A DECREASE IN VELOCITY.
MOTION WITH A CONSTANT INCREASE IN VELOCITY IS REFERRED TO AS *UNIFORM ACCELERATION MOTION*.
VELOCITY
AND YOUR CAR CAN DO THAT WITH THE RIGHT PROGRAM?
WAIT... WE'RE THE TORTOISE AND THE HARE...?
HEY! HOW'D YOU GET SO FAR AHEAD?
SLOW AND STEADY WINS THE RACE!


OH, YEAH, MY CAR CAN DO THAT. NOW WE'LL CALCULATE THE ACCELERATION OF THE CAR USING THE RULE.
HERE WE GO!
LET ME SEE...THE RADIO-CONTROLLED CAR INCREASES VELOCITY FROM 0 M/S TO 0.5 M/S IN 4 SECONDS.
RULE:
ACCELERATION = CHANGE IN VELOCITY / TIME
WE CAN ASSIGN THESE VALUES TO THE RULE.
SO A CHANGE OF 0.5 M/S OVER 4 S IS 0.125 M/S²! IS THAT RIGHT?
EXACTLY!
YOU SHOULD BE MORE CONFIDENT.
THIS VALUE MEANS THAT VELOCITY IS INCREASING BY 0.125 M/S PER SECOND.
I SEE.
BY APPLYING THIS RULE, WE CAN FIND THE DISPLACEMENT OF OBJECTS WITH VARIABLE VELOCITY.

LABORATORY

FINDING THE DISTANCE TRAVELED WHEN VELOCITY VARIES

Let's change the setting so as to steadily increase the velocity up to 0.5 m/s. Here's a quiz for you. Given that velocity has attained 0.5 m/s in four seconds, how far has the radio-controlled car moved?

Hmm . . . starting at 0 m/s, the peak velocity is 0.5 m/s. So let me calculate, assuming the average speed, 0.25 m/s, for the velocity. 0.25 m/s × 4 s = 1 m!

That's right! You are so sharp. But can you explain why you can get the right answer with that calculation?

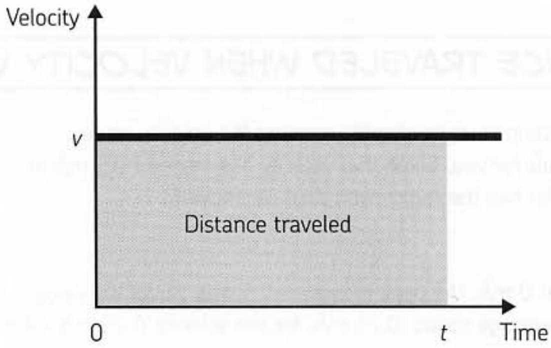
Uhm . . . remember, teaching me is *your* job, Nonomura-kun!

Ha ha, true enough. Before giving you a direct answer, let me explain how we can find the distance traveled when the velocity varies. When velocity is constant, we've learned that the distance traveled can be found by calculating the expression (speed × time). Now, given that d m (meters) represents the distance traveled in t s (seconds) and the constant velocity is v m/s, then distance = speed × time can be expressed in the following equation:

$$d = vt$$

Well, duh!

If you plot that relationship with velocity on the vertical axis and time on the horizontal axis, you get the following graph.



The shaded area represents the distance traveled. This chart is commonly referred to as a *v-t graph*, as it graphs velocity and time. That's the area of a rectangle having a horizontal length of t and a vertical length of v.

I see. It seems a little strange that an area represents a distance.

The area here is not a typical geometric area—this is a graph, like the ones you've seen in math class. The area of a geometric rectangle might be measured in square meters (m^2). But in our example, the units are time (seconds) for the horizontal axis and velocity (m/s) for the vertical axis. So the product of these two is equal to s × m/s = m. That's our unit for distance.

It's easy to find a distance when an object goes at a constant speed. But what about finding the distance when the speed is variable?

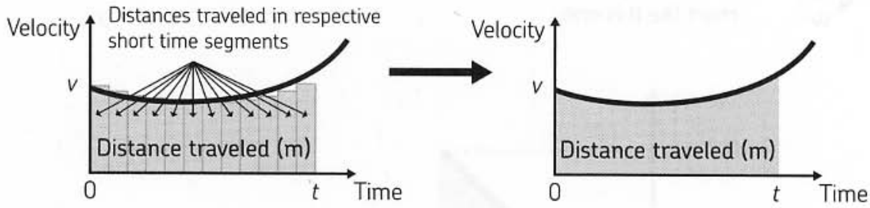
The only tool available to us is this equation:

distance = speed × time

So we can divide the time into segments to create a lot of "small rectangles" and then calculate distances respectively, assuming a constant velocity for each time segment.

What do you mean?

Look at the chart on the left below.



So we can find the area of each slender rectangle created by dividing time into short segments, and then adding up the areas to find the distance traveled.

It bothers me that those little rectangles won't exactly fit the graph. Wouldn't they bring about errors?

I see your concern. Then we can sub-divide the rectangles into smaller segments. By repeating division into even smaller segments until everything fits as shown in the chart on the right above, the distance we get becomes more and more precise.

Well, I guess so . . . if you could do that . . .

If we divided them into infinitely slender rectangles, we'd find exactly how far the object has moved. After all, the ultimate answer we get by dividing distance = speed × time into short time segments is the area created under a v-t graph. That's how we can find the distance traveled by finding the corresponding area. In summary,

distance traveled = area under a v-t graph

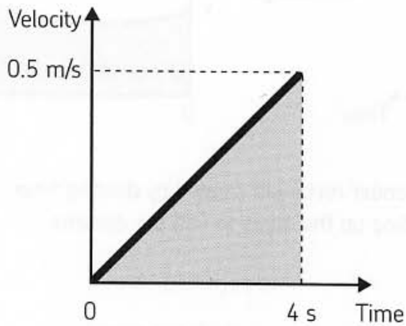
Just like that.*

* Students of calculus may notice that this process of finding an area under a graph is identical to *integration*.

Now, keeping in mind what we've learned so far, let's examine the reason why the distance you got intuitively is the right answer.

All right!

Your original calculation is the same as calculating an area on a velocity-time graph. The example with a radio-controlled car can be plotted into a chart like this one.



The area under the graph, as obtained from the rule for the area of a triangle, is as follows:

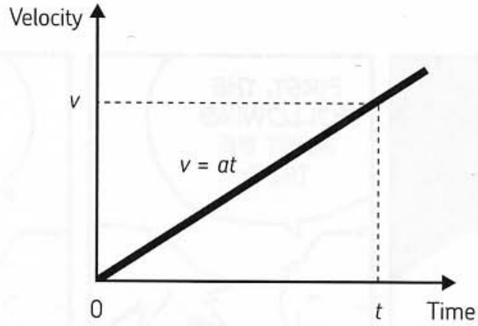
$$\frac{1}{2} \times \text{base (time)} \times \text{height (max velocity)} = \frac{1}{2} \times 4 \text{ s} \times 0.5 \text{ m/s} = 1 \text{ m}$$

This represents the distance traveled.

We got 1 meter for the answer, just as we should.

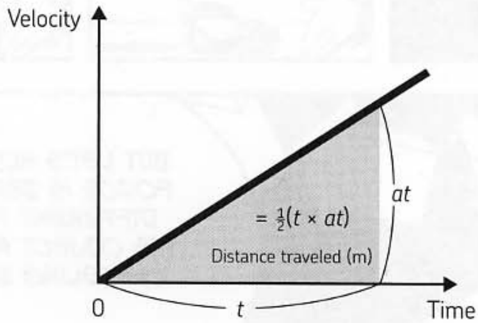
Let's find a general expression for the distance traveled, rather than using specific numeric values. Assuming velocity to be v and acceleration to be a, the relationship between the velocity and time for uniform accelerated motion is $v = at$.

That can be plotted into a v-t graph, as shown below.



Let's assume d is the distance traveled in time t; its value should be equivalent to the area of a triangle with a base of t and height of at (which equals the final velocity of the object).

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



You see?

Ummmm . . . oh, I see how that works! The value we get by calculating $\frac{1}{2} \times 0.125\ \text{m/s}^2 \times (4\ \text{s})^2 = 1\ \text{m}$. As it should be!

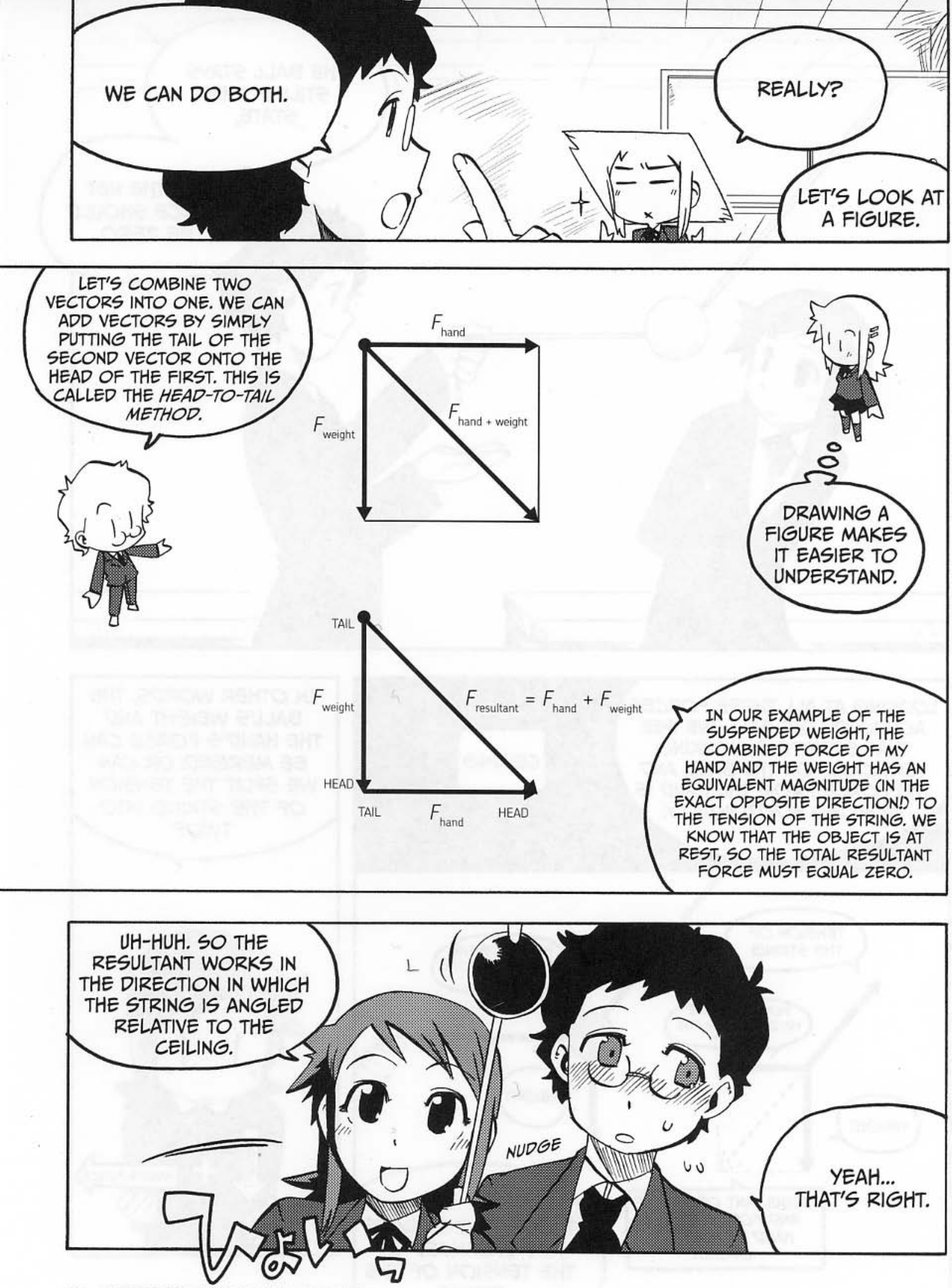
Now, Ninomiya-san, you can also calculate a distance traveled in uniform accelerated motion not by intuition but by the proper method.

NEWTON'S FIRST AND SECOND LAWS


SO AN OBJECT AT REST CAN HAVE FORCES IMPOSED ON IT, PROVIDED THAT THE SUM OF THOSE FORCES IS ZERO.
TO MAKE IT EASIER FOR YOU...
LOOK WHAT I HAVE PREPARED!
WHAT ON EARTH IS THIS?
YOU DON'T HAVE TO BE APPALLED. IT'S JUST A BALL WITH TWO STRINGS COMING OUT OF IT.
SORRY. I'M A SPAZ.
CEILING
TENSION OF THE STRING
WEIGHT
TENSION OF THE STRING
+
WEIGHT
=
0
ZERO
AT THE MOMENT, THE BALL IS STATIC.
SO A FORCE MUST BE IMPOSED FROM THE STRING THAT CAN CANCEL THE FORCE OF GRAVITY (THE BALL'S WEIGHT) TO YIELD A RESULT OF A ZERO MAGNITUDE.
YOU MEAN THE TENSION OF THE STRING IS EQUIVALENT TO THE FORCE OF GRAVITY?
HOW CAN YOU SAY SO WITHOUT TAKING ANY MEASUREMENTS?
THAT'S MY POINT.


IN FACT, AN OBJECT AT REST, SUCH AS THIS BALL, IS RELATED TO NEWTON'S FIRST LAW OF MOTION.
1
HOW!?
YOU CAN CHECK THAT THE TENSION OF THE STRING IS EQUIVALENT TO THE BALL'S WEIGHT USING AN INSTRUMENT.
BUT THE FIRST LAW OF MOTION TELLS US THAT THE NET FORCE ON AN OBJECT IN A STATIC STATE *MUST* BE ZERO.
I SEE.
SO...I WONDER IF THE NET FORCE COULD BE ZERO IF THE OBJECT WAS PULLED BY THE SECOND STRING?
I THOUGHT I'D EXPLAIN IT...
BUT INSTEAD, LET'S ACTUALLY PULL THE STRING TIED TO THE BALL.
UPSY-DAISY

THE BALL STAYS STILL IN THIS STATE,
SO THE NET FORCE SHOULD BE ZERO.
LOOKING AT ALL THREE FORCES ACTING ON THE BALL, WE SEE THAT GRAVITY IS WORKING VERTICALLY ON THE BALL, AND THE FORCE FROM THE HAND IS WORKING HORIZONTALLY.
CEILING
TENSION OF THE STRING
FORCE OF THE HAND PULLING THE OBJECT
FORCE OF THE HAND PULLING THE OBJECT
WEIGHT
WEIGHT
RESULTANT OF WEIGHT AND FORCE OF THE HAND PULLING THE OBJECT
THOSE TWO FORCES ARE BALANCED BY THE TENSION OF THE STRING.
IN OTHER WORDS, THE BALL'S WEIGHT AND THE HAND'S FORCE CAN BE MERGED. OR CAN WE SPLIT THE TENSION OF THE STRING INTO TWO?
WEIGHT
HAND'S FORCE


WE CAN DO BOTH.
REALLY?
LET'S LOOK AT A FIGURE.
LET'S COMBINE TWO VECTORS INTO ONE. WE CAN ADD VECTORS BY SIMPLY PUTTING THE TAIL OF THE SECOND VECTOR ONTO THE HEAD OF THE FIRST. THIS IS CALLED THE *HEAD-TO-TAIL METHOD.*
F_{hand}
F_{weight}
$F_{hand + weight}$
DRAWING A FIGURE MAKES IT EASIER TO UNDERSTAND.
TAIL
F_{weight}
$F_{resultant} = F_{hand} + F_{weight}$
HEAD
TAIL
F_{hand}
HEAD
IN OUR EXAMPLE OF THE SUSPENDED WEIGHT, THE COMBINED FORCE OF MY HAND AND THE WEIGHT HAS AN EQUIVALENT MAGNITUDE (IN THE EXACT OPPOSITE DIRECTION!) TO THE TENSION OF THE STRING. WE KNOW THAT THE OBJECT IS AT REST, SO THE TOTAL RESULTANT FORCE MUST EQUAL ZERO.
UH-HUH. SO THE RESULTANT WORKS IN THE DIRECTION IN WHICH THE STRING IS ANGLED RELATIVE TO THE CEILING.
NUDGE
ひょいっ
YEAH... THAT'S RIGHT.

* IN ORBIT, OBJECTS ARE IN A STATE OF CONSTANT FREE FALL, MAKING THEIR APPARENT WEIGHT ZERO.


NORMALLY, FRICTION FROM THE AIR OR COLLISION WITH THE GROUND WILL STOP AN OBJECT (UNLESS YOU KEEP APPLYING A FORCE).
WHOOPEE!
BUT IN DEEP OUTER SPACE, IT IS POSSIBLE TO ACHIEVE A ZERO-FORCE STATE, AS THERE IS NO GRAVITY OR AIR RESISTANCE TO CONSIDER.
YES, INDEED! IN THAT CASE, YOU MEAN, WE COULD KEEP MOVING FOREVER, EVEN WITH NO FORCE IMPOSED?
EXACTLY!
IS THAT GUY ALL RIGHT?
A CONSTANT-VELOCITY, OR *UNIFORM*, MOTION OCCURS WHEN THE NET FORCE IS ZERO.
HISS
HE LOOKS LIKE HE'S LEAVING.
WELL...

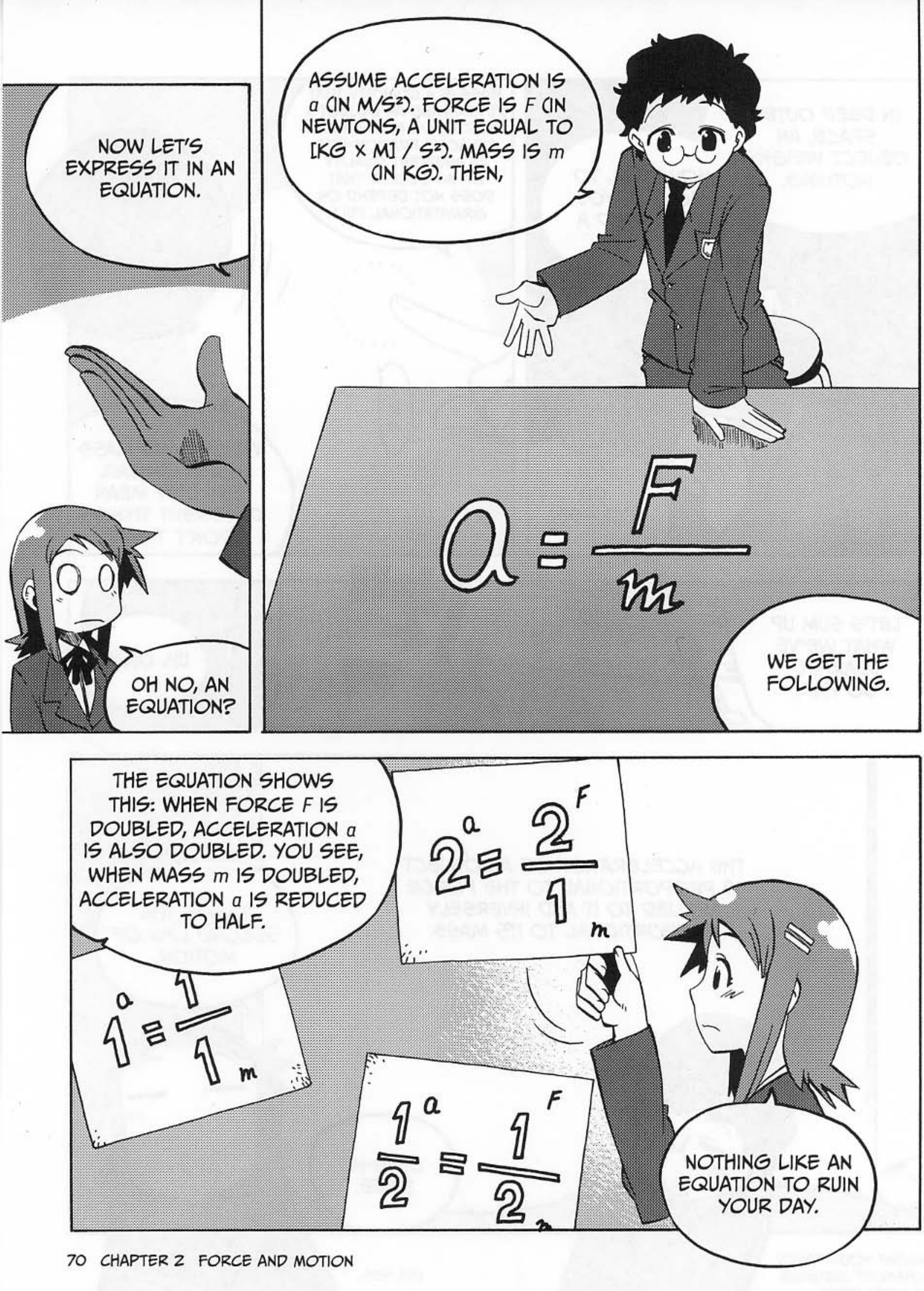

YOU KNOW, ALL THESE PHENOMENA CAN BE EXPLAINED USING NEWTON'S FIRST LAW.
REALLY?
IT DESCRIBES THE BEHAVIOR OF AN OBJECT WHEN THE NET FORCE ON IT IS ZERO.
IT IS ALSO CALLED THE FIRST LAW OF MOTION, OR THE LAW OF INERTIA.
AN OBJECT CONTINUES TO MAINTAIN ITS STATE OF REST OR OF UNIFORM MOTION UNLESS ACTED UPON BY AN EXTERNAL NET FORCE.
WE CALL THIS QUALITY OF OBJECTS TO RESIST CHANGES IN THEIR VELOCITY *INERTIA.*
OH!
THE LAW OF INERTIA SOUNDS FAMILIAR!
THAT'S THE SAME THING AS NEWTON'S FIRST LAW OF MOTION.
YAY!
THAT'S RIGHT.

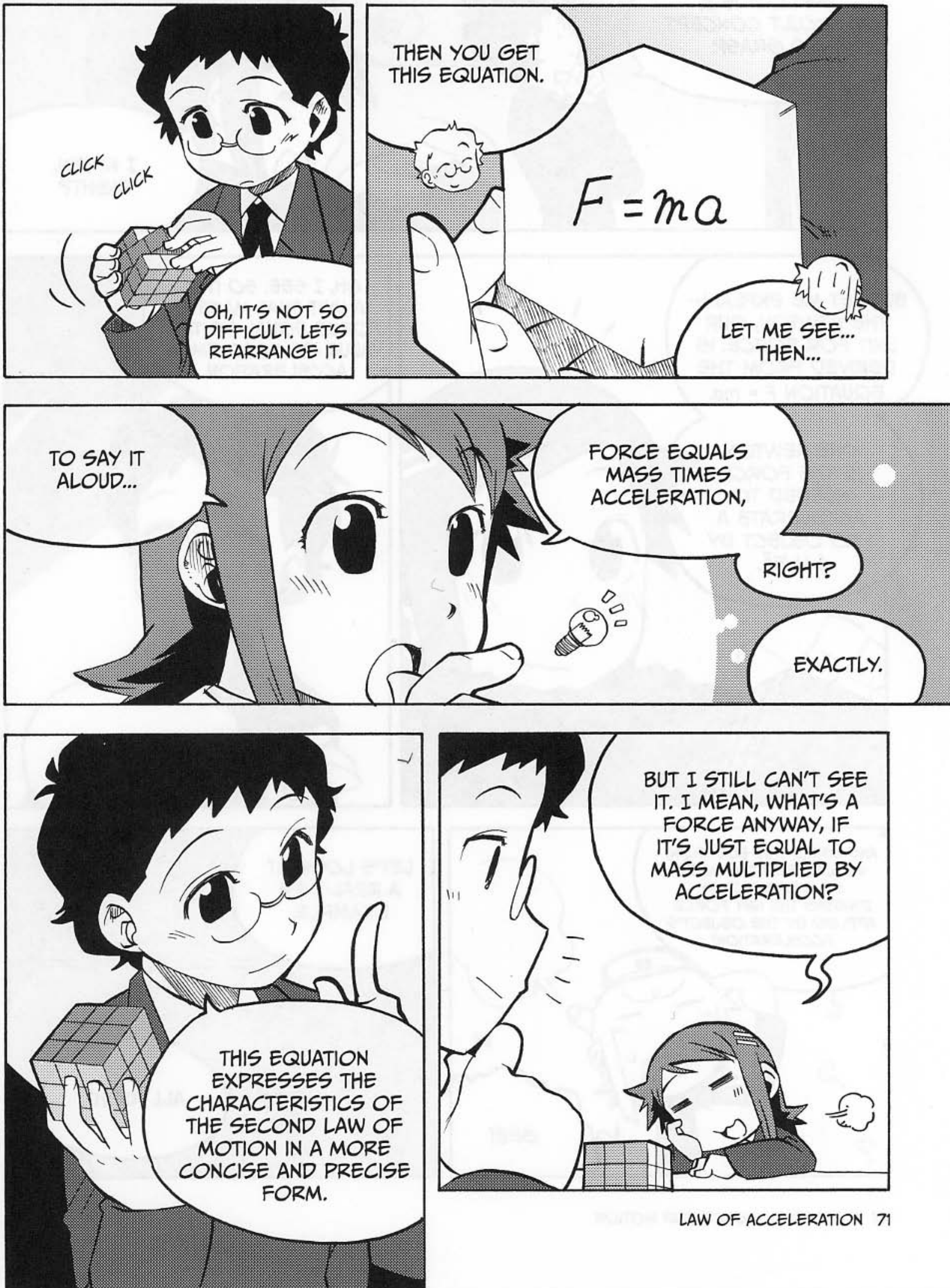

LAW OF ACCELERATION
NEXT, LET'S EXAMINE THE MOTION OF AN OBJECT WHEN A NET FORCE IS WORKING.
YOU COMMUTE BY BICYCLE, DON'T YOU, NINOMIYA-SAN?
HEY, IT'S MEGU!
HI GUYS!
YES, I DO. THOUGH IT'S A RATHER LONG WAY FROM HOME.
OF COURSE, YOU INTUITIVELY KNOW THAT A BICYCLE AT REST MUST BE PEDALED TO START MOVING.
IN OTHER WORDS, YOU CAN SAY THAT ITS VELOCITY HAS CHANGED.
YOU COULD SAY THAT THE APPLICATION OF FORCE (FROM YOUR LEGS) HAS GENERATED ACCELERATION.
UH-HUH.


AND THE GREATER THE FORCE IS, THE GREATER THE ACCELERATION BECOMES.
HAVE TO HURRY! I'M RUNNING LATE...
MY INTUITION TELLS ME THAT.
IN TURN, TO STOP YOUR BIKE, YOU NEED TO APPLY A FORCE IN THE OPPOSITE DIRECTION OF YOUR VELOCITY—THIS IS YOUR BRAKES.
THE LIGHT IS RED!
CREATING AN ACCELERATION OPPOSITE TO YOUR VELOCITY (THAT IS, A NEGATIVE ACCELERATION, OR DECELERATION) LEADS TO A SLOWER VELOCITY AND WILL EVENTUALLY BRING YOUR BIKE TO A HALT.
WHEN YOU LOOK AT IT THIS WAY, YOUR BRAKING IS CREATING A NEGATIVE ACCELERATION, NOT REDUCING YOUR INITIAL ACCELERATION.
GIVEN THESE OBSERVATIONS, WE CAN SAFELY SAY THAT THE FORCE IS DIRECTLY PROPORTIONAL TO THE ACCELERATION.
OKAY...

NOW, LET'S FOCUS ON MASS.
THAT'S HUGE! AND HEAVY!
WITH A HEAVY LOAD IN YOUR BASKET, YOU MUST EXERCISE A HUGE FORCE WHEN YOU INITIALLY TRY TO PUSH THE PEDAL.
OH
OH
OH
CREEEAK
CREEEAK
SEE, THE LOAD MAKES IT HARDER TO ACCELERATE.
PUFF
PUFF
PUFF
WHEEZE
GIVEN THAT, WE CAN ASSUME THAT THE MASS IS INVERSELY PROPORTIONAL TO ACCELERATION.
THAT MEANS THE LARGER THE MASS, THE SMALLER THE ACCELERATION.
WAIT, WHAT'S THE DIFFERENCE BETWEEN WEIGHT AND MASS?
TO PUT IT SIMPLY, WEIGHT IS A FORCE IMPOSED ON AN OBJECT BY GRAVITY.
THIS MEANS AN OBJECT WILL HAVE A DIFFERENT WEIGHT ON THE MOON THAN ON EARTH.
SO WHAT ABOUT MASS?

IN DEEP OUTER SPACE, AN OBJECT WEIGHS NOTHING.
HOWEVER, TO MOVE IT, YOU STILL NEED A FORCE.
OF COURSE!
MASS IS A QUANTITY THAT DETERMINES AN OBJECT'S INERTIA, OR RESISTANCE TO ACCELERATION—IT'S AN INHERENT QUALITY OF AN OBJECT THAT DOES NOT DEPEND ON GRAVITATIONAL PULL.
TUM
WEIGHT AND MASS SEEM SIMILAR, BUT THEY MEAN DIFFERENT THINGS, DON'T THEY?
LET'S SUM UP WHAT WE'VE LEARNED SO FAR!
ばっ
UH, OKAY.
THE ACCELERATION OF AN OBJECT IS PROPORTIONAL TO THE FORCE APPLIED TO IT AND INVERSELY PROPORTIONAL TO ITS MASS.
THIS IS THE SECOND LAW OF MOTION.
OH-H-H! I SEE.
HAS IT CAUGHT YOUR FANCY BY ANY CHANCE? JUDGING FROM YOUR POSE...
OH, YES.


NOW LET'S EXPRESS IT IN AN EQUATION.
ASSUME ACCELERATION IS a (IN M/S²). FORCE IS F (IN NEWTONS, A UNIT EQUAL TO [KG × M] / S²). MASS IS m (IN KG). THEN,
OH NO, AN EQUATION?
a = F / m
WE GET THE FOLLOWING.
THE EQUATION SHOWS THIS: WHEN FORCE F IS DOUBLED, ACCELERATION a IS ALSO DOUBLED. YOU SEE, WHEN MASS m IS DOUBLED, ACCELERATION a IS REDUCED TO HALF.
2 a = 2 F / 1 m
1 a = 1 / 1 m
1/2 a = 1 F / 2 m
NOTHING LIKE AN EQUATION TO RUIN YOUR DAY.


CLICK
CLICK
OH, IT'S NOT SO DIFFICULT. LET'S REARRANGE IT.
THEN YOU GET THIS EQUATION.
F = ma
LET ME SEE... THEN...
TO SAY IT ALOUD...
FORCE EQUALS MASS TIMES ACCELERATION,
RIGHT?
EXACTLY.
BUT I STILL CAN'T SEE IT. I MEAN, WHAT'S A FORCE ANYWAY, IF IT'S JUST EQUAL TO MASS MULTIPLIED BY ACCELERATION?
THIS EQUATION EXPRESSES THE CHARACTERISTICS OF THE SECOND LAW OF MOTION IN A MORE CONCISE AND PRECISE FORM.


WELL, IT IS A DIFFICULT CONCEPT TO GRASP.
I KNOW, RIGHT?
BUT LET ME EXPLAIN— THE NEWTON, OUR UNIT FOR FORCE, IS DERIVED FROM THE EQUATION $F = ma$.
ONE NEWTON IS THE FORCE NEEDED TO ACCELERATE A 1 KG OBJECT BY 1 M/S^2.
OH, I SEE. SO IT'S A UNIT THAT MAKES FORCE EQUAL TO THE VALUE OF MASS TIMES ACCELERATION.
EXACTLY.
AND USING THIS EQUATION, WE CAN FIND THE MASS OF AN OBJECT BY DIVIDING THE NET FORCE APPLIED BY THE OBJECT'S ACCELERATION!
GEE!
LET'S LOOK AT A REAL-LIFE EXAMPLE.
ALL RIGHT.

LABORATORY

FINDING THE PRECISE VALUE OF A FORCE

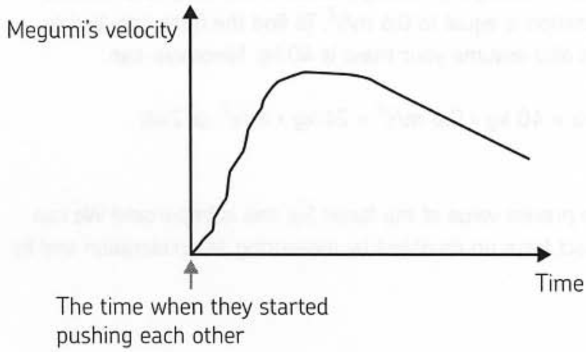
Earlier, we pushed each other while we were on roller blades. Let's say that I captured our motion on video.

I didn't realize you were taping us!

Oh, that's just the scenario I'm setting up.

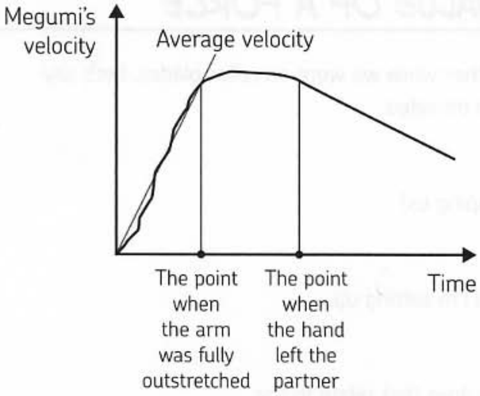
Jeez, don't scare me. How does that relate to the second law of motion?

Suppose I have analyzed the video, and I've created a v-t graph of your motion.



We can see that velocity increases sharply from zero, which must be when I'm at rest, and then drops gradually after that. But the initial increase in velocity is wobbly.

In a case like this, it may be a good idea to draw a line segment that represents the average increase in velocity. In other words, we'll simplify the scenario to assume this is a case of uniform acceleration.



I see.

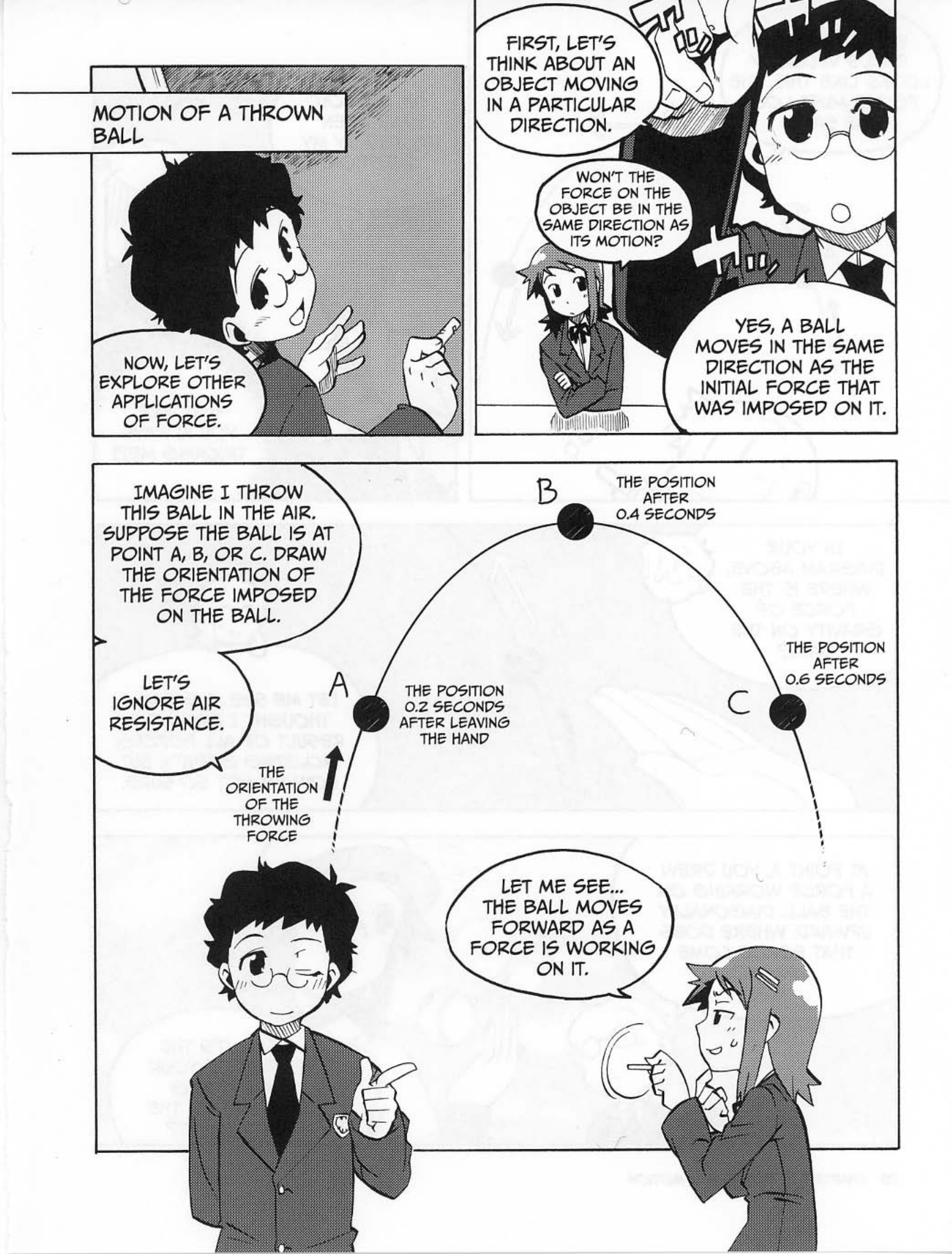
You can find acceleration by calculating the change in acceleration over time—acceleration = change in velocity / time. In this case, let's assume that your acceleration is equal to 0.6 m/s^2. To find the force I applied to your hands, let's also assume your mass is 40 kg, Ninomiya-san.

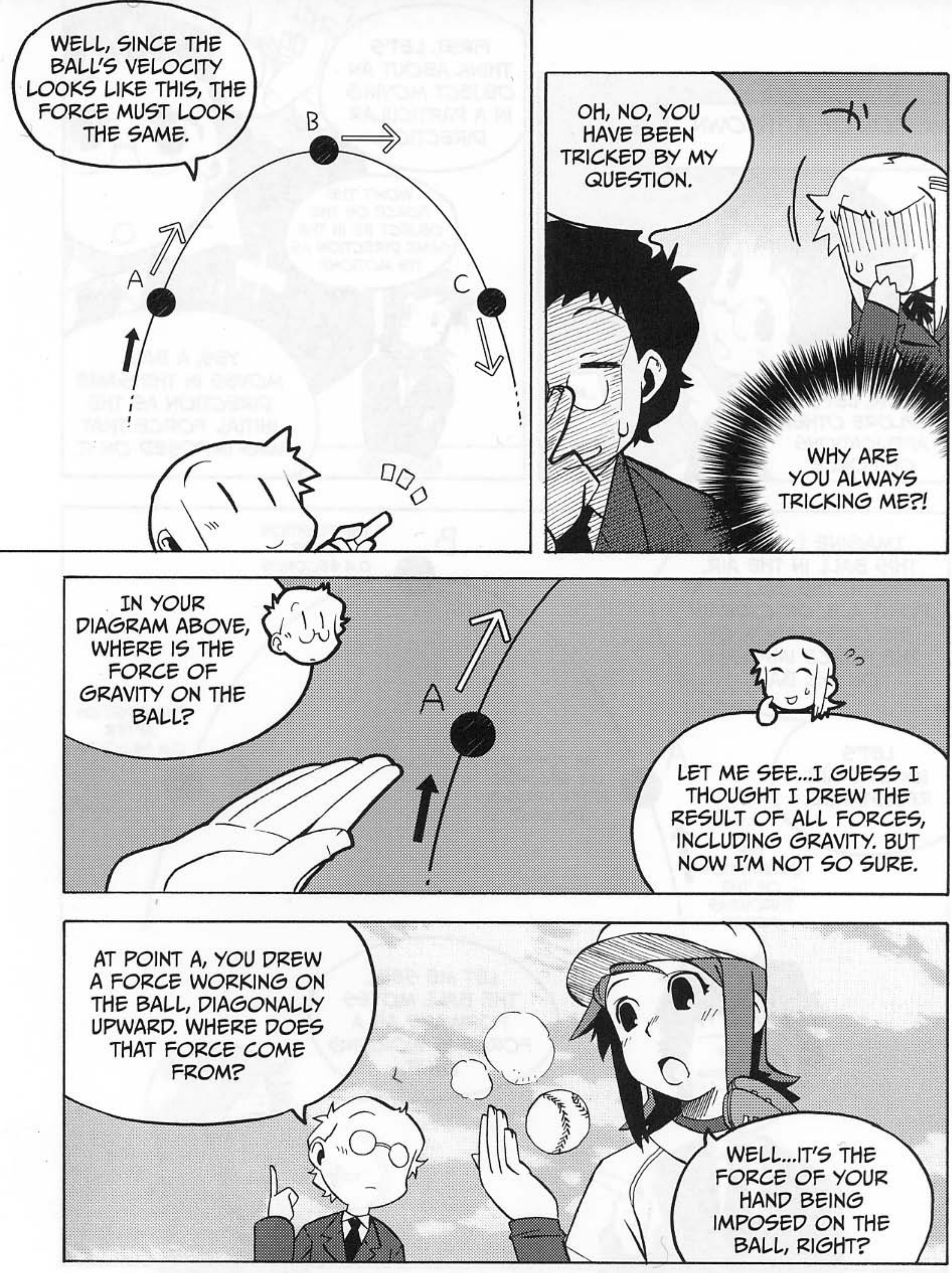
$$F = ma = 40 \text{ kg} \times 0.6 \text{ m/s}^2 = 24 \text{ kg} \times \text{m/s}^2\text{, or } 24\text{N}$$

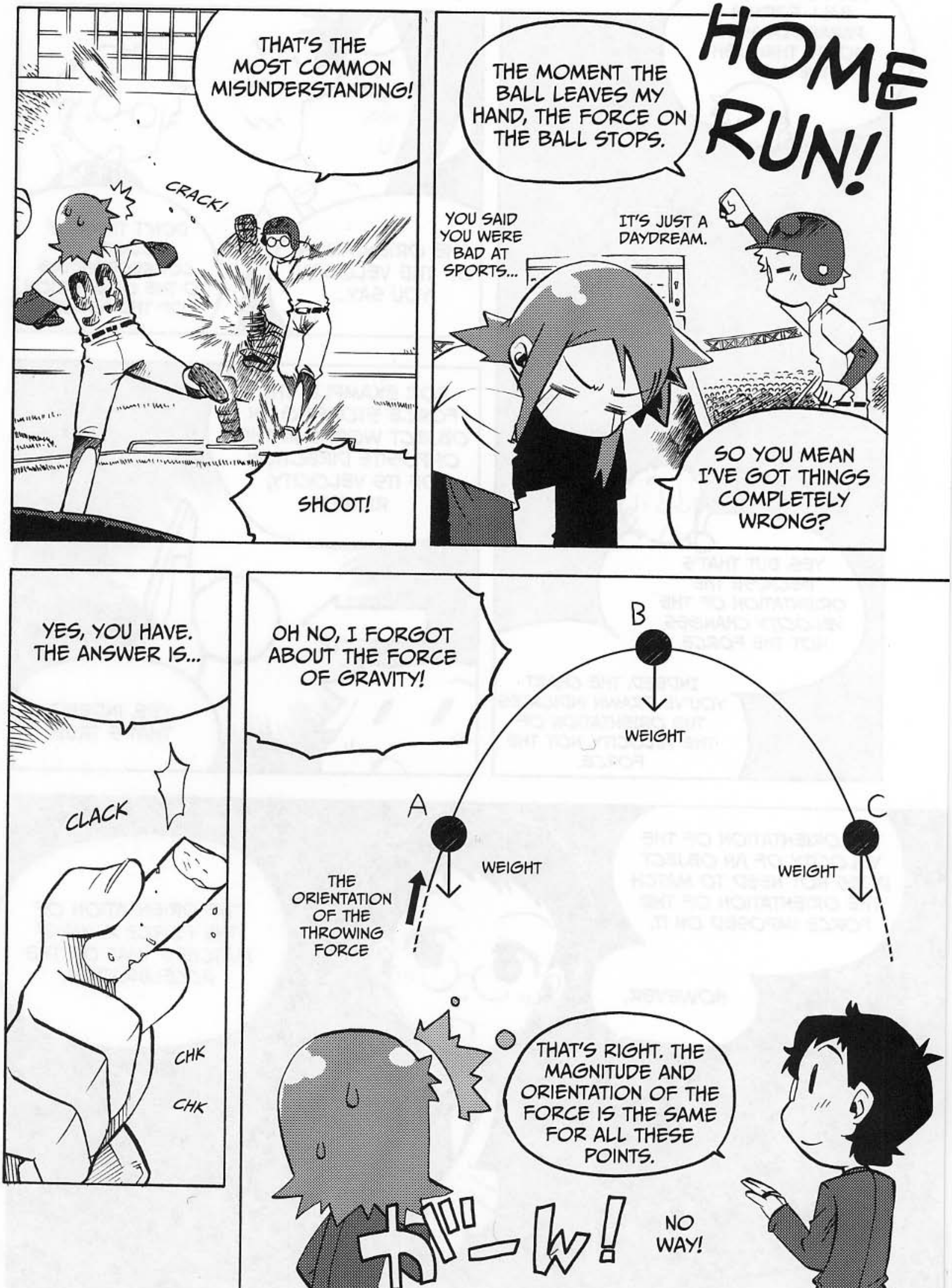
We've found the precise value of the force! So, this is important! We can measure the exact force on an object by measuring its acceleration and its mass.

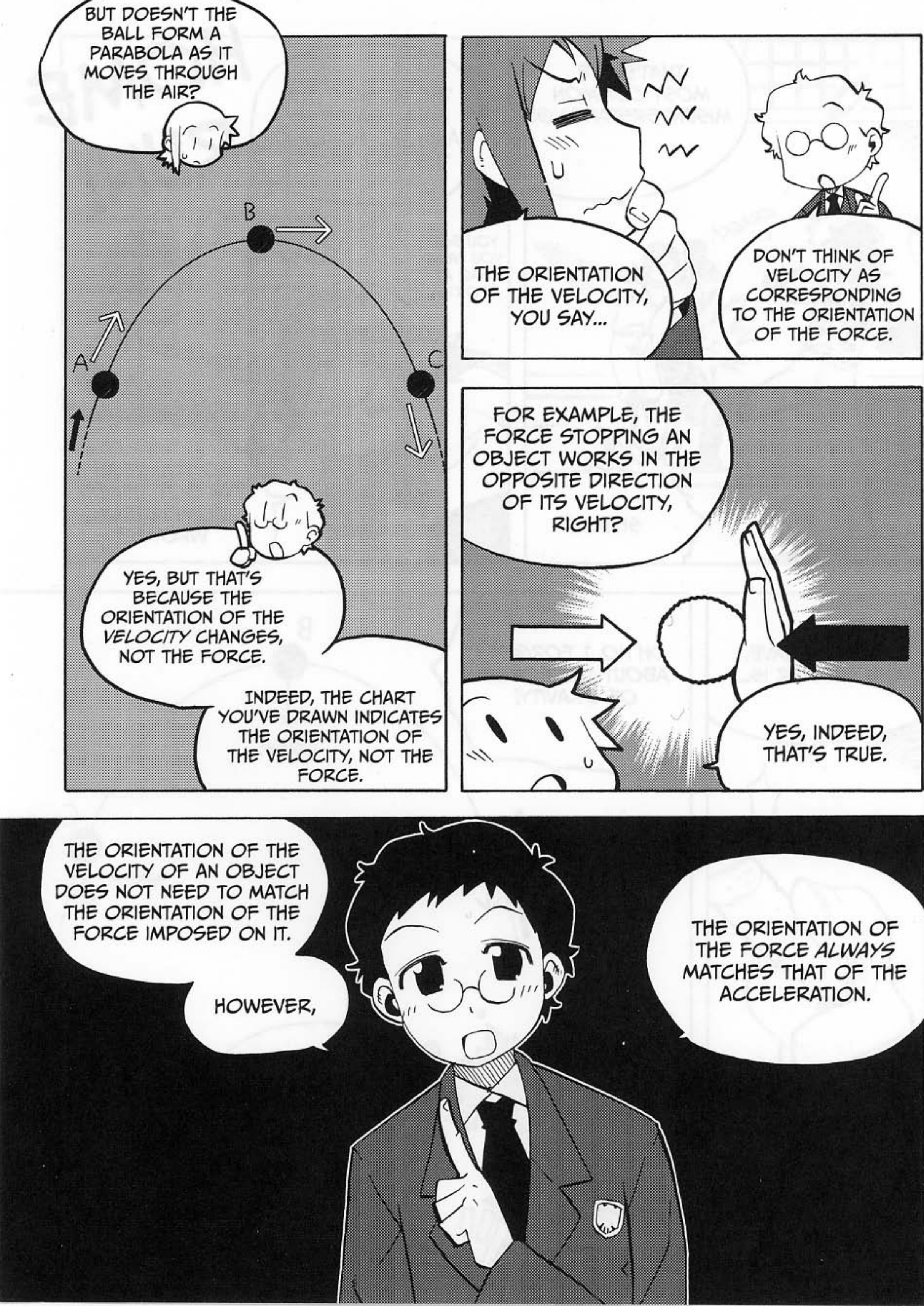
Now, if you know that I weigh 60 kg, can you predict my acceleration, due to the application of an equal and opposite 24N of force?

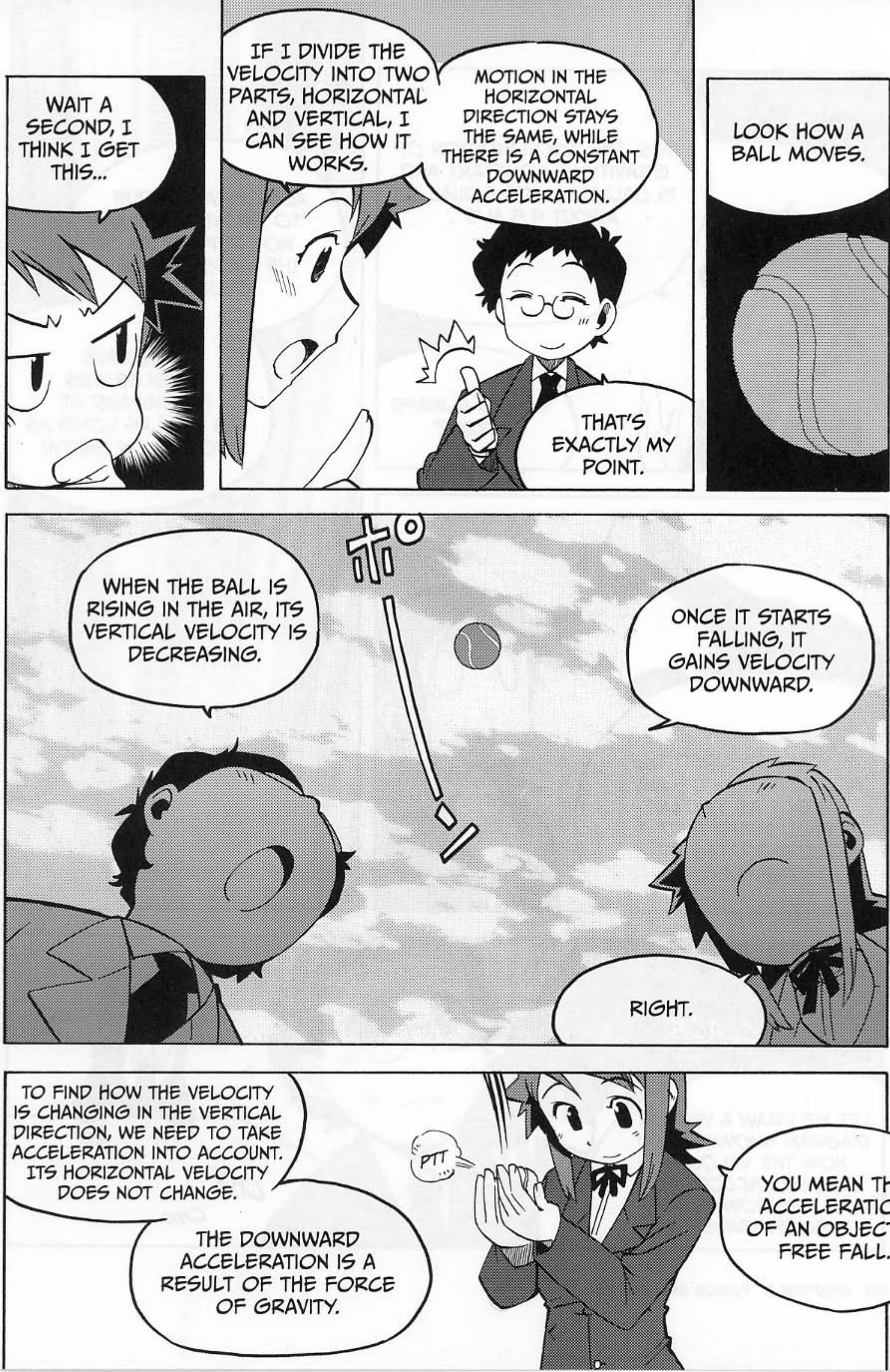
Oh, I see. We're combining the second and third laws of motion. F_{Megumi} must equal F_{Ryota}. Since $F = ma$, we know that $F / m = a$. In your case, that's 24N / 60 kg, or 0.4 m/s^2. So we can use these laws to predict the movement of objects. Neat!


MOTION OF A THROWN BALL
NOW, LET'S EXPLORE OTHER APPLICATIONS OF FORCE.
FIRST, LET'S THINK ABOUT AN OBJECT MOVING IN A PARTICULAR DIRECTION.
WON'T THE FORCE ON THE OBJECT BE IN THE SAME DIRECTION AS ITS MOTION?
YES, A BALL MOVES IN THE SAME DIRECTION AS THE INITIAL FORCE THAT WAS IMPOSED ON IT.
IMAGINE I THROW THIS BALL IN THE AIR. SUPPOSE THE BALL IS AT POINT A, B, OR C. DRAW THE ORIENTATION OF THE FORCE IMPOSED ON THE BALL.
LET'S IGNORE AIR RESISTANCE.
B
THE POSITION AFTER 0.4 SECONDS
A
THE POSITION 0.2 SECONDS AFTER LEAVING THE HAND
C
THE POSITION AFTER 0.6 SECONDS
THE ORIENTATION OF THE THROWING FORCE
LET ME SEE... THE BALL MOVES FORWARD AS A FORCE IS WORKING ON IT.

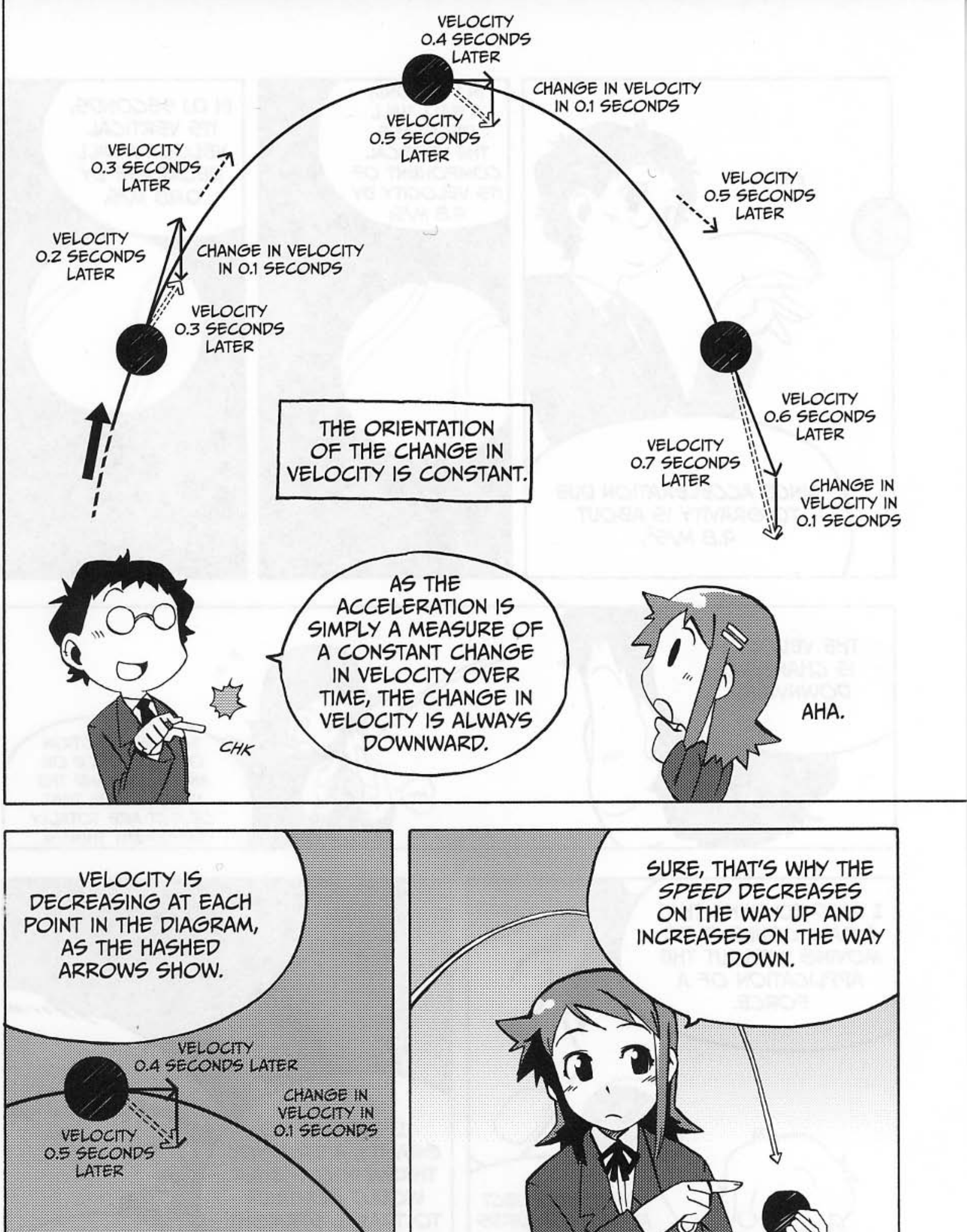

WELL, SINCE THE BALL'S VELOCITY LOOKS LIKE THIS, THE FORCE MUST LOOK THE SAME.
B
A
C
OH, NO, YOU HAVE BEEN TRICKED BY MY QUESTION.
WHY ARE YOU ALWAYS TRICKING ME?!
IN YOUR DIAGRAM ABOVE, WHERE IS THE FORCE OF GRAVITY ON THE BALL?
A
LET ME SEE...I GUESS I THOUGHT I DREW THE RESULT OF ALL FORCES, INCLUDING GRAVITY. BUT NOW I'M NOT SO SURE.
AT POINT A, YOU DREW A FORCE WORKING ON THE BALL, DIAGONALLY UPWARD. WHERE DOES THAT FORCE COME FROM?
WELL...IT'S THE FORCE OF YOUR HAND BEING IMPOSED ON THE BALL, RIGHT?


THAT'S THE MOST COMMON MISUNDERSTANDING!
CRACK!
SHOOT!
THE MOMENT THE BALL LEAVES MY HAND, THE FORCE ON THE BALL STOPS.
HOME RUN!
YOU SAID YOU WERE BAD AT SPORTS...
IT'S JUST A DAYDREAM.
SO YOU MEAN I'VE GOT THINGS COMPLETELY WRONG?
YES, YOU HAVE. THE ANSWER IS...
CLACK
CHK
CHK
OH NO, I FORGOT ABOUT THE FORCE OF GRAVITY!
B
WEIGHT
A
WEIGHT
THE ORIENTATION OF THE THROWING FORCE
C
WEIGHT
THAT'S RIGHT. THE MAGNITUDE AND ORIENTATION OF THE FORCE IS THE SAME FOR ALL THESE POINTS.
NO WAY!


BUT DOESN'T THE BALL FORM A PARABOLA AS IT MOVES THROUGH THE AIR?
B
A
C
YES, BUT THAT'S BECAUSE THE ORIENTATION OF THE *VELOCITY* CHANGES, NOT THE FORCE.
INDEED, THE CHART YOU'VE DRAWN INDICATES THE ORIENTATION OF THE VELOCITY, NOT THE FORCE.
THE ORIENTATION OF THE VELOCITY, YOU SAY...
DON'T THINK OF VELOCITY AS CORRESPONDING TO THE ORIENTATION OF THE FORCE.
FOR EXAMPLE, THE FORCE STOPPING AN OBJECT WORKS IN THE OPPOSITE DIRECTION OF ITS VELOCITY, RIGHT?
YES, INDEED, THAT'S TRUE.
THE ORIENTATION OF THE VELOCITY OF AN OBJECT DOES NOT NEED TO MATCH THE ORIENTATION OF THE FORCE IMPOSED ON IT.
HOWEVER,
THE ORIENTATION OF THE FORCE *ALWAYS* MATCHES THAT OF THE ACCELERATION.


WAIT A SECOND, I THINK I GET THIS...
IF I DIVIDE THE VELOCITY INTO TWO PARTS, HORIZONTAL AND VERTICAL, I CAN SEE HOW IT WORKS.
MOTION IN THE HORIZONTAL DIRECTION STAYS THE SAME, WHILE THERE IS A CONSTANT DOWNWARD ACCELERATION.
THAT'S EXACTLY MY POINT.
LOOK HOW A BALL MOVES.
WHEN THE BALL IS RISING IN THE AIR, ITS VERTICAL VELOCITY IS DECREASING.
ONCE IT STARTS FALLING, IT GAINS VELOCITY DOWNWARD.
RIGHT.
TO FIND HOW THE VELOCITY IS CHANGING IN THE VERTICAL DIRECTION, WE NEED TO TAKE ACCELERATION INTO ACCOUNT. ITS HORIZONTAL VELOCITY DOES NOT CHANGE.
THE DOWNWARD ACCELERATION IS A RESULT OF THE FORCE OF GRAVITY.
PTT
YOU MEAN THE ACCELERATION OF AN OBJECT IN FREE FALL.


YES. THE ACCELERATION OF GRAVITY IS CONSTANT AND IS CALLED g. IT'S EQUAL TO ABOUT 9.8 M/S².
SO IT'S ALWAYS FIXED?
ACCELERATION DUE TO GRAVITY DOES NOT DEPEND ON THE MASS OF THE OBJECT.
IT ALWAYS ACCELERATES DOWNWARD AT 9.8 M/S² AS LONG AS YOU'RE ON EARTH!
HUM.
IF YOU MEASURED THE ACCELERATION OF ANY OBJECT AS YOU LET IT FALL, YOU'D FIND IT ACCELERATES AT 9.8 M/S².
CLACK
CLACK
LET ME DRAW A VECTOR DIAGRAM SHOWING YOU HOW THE VELOCITY CHANGES ACCORDING TO THIS DOWNWARD ACCELERATION.
GO! GO!
CHK
CHK


VELOCITY 0.4 SECONDS LATER
CHANGE IN VELOCITY IN 0.1 SECONDS
VELOCITY 0.5 SECONDS LATER
VELOCITY 0.3 SECONDS LATER
VELOCITY 0.2 SECONDS LATER
CHANGE IN VELOCITY IN 0.1 SECONDS
VELOCITY 0.3 SECONDS LATER
VELOCITY 0.5 SECONDS LATER
VELOCITY 0.6 SECONDS LATER
VELOCITY 0.7 SECONDS LATER
CHANGE IN VELOCITY IN 0.1 SECONDS
THE ORIENTATION OF THE CHANGE IN VELOCITY IS CONSTANT.
AS THE ACCELERATION IS SIMPLY A MEASURE OF A CONSTANT CHANGE IN VELOCITY OVER TIME, THE CHANGE IN VELOCITY IS ALWAYS DOWNWARD.
CHK
AHA.
VELOCITY IS DECREASING AT EACH POINT IN THE DIAGRAM, AS THE HASHED ARROWS SHOW.
VELOCITY 0.4 SECONDS LATER
CHANGE IN VELOCITY IN 0.1 SECONDS
VELOCITY 0.5 SECONDS LATER
SURE, THAT'S WHY THE SPEED DECREASES ON THE WAY UP AND INCREASES ON THE WAY DOWN.


FWP
SINCE ACCELERATION DUE TO GRAVITY IS ABOUT 9.8 M/S²,
IN 1 SECOND, A BALL WILL DECREASE THE VERTICAL COMPONENT OF ITS VELOCITY BY 9.8 M/S;
IN 0.1 SECONDS, ITS VERTICAL VELOCITY WILL DECREASE BY 0.98 M/S.
THE VELOCITY IS CHANGING DOWNWARD.
PT
SO THE DIRECTION OF THE FORCE ON AN OBJECT AND THE VELOCITY OF THAT OBJECT ARE TOTALLY DIFFERENT THINGS.
I USED TO THINK THAT A BALL COULDN'T BE MOVING WITHOUT THE APPLICATION OF A FORCE.
WHILE AN OBJECT AT REST REQUIRES FORCE TO START MOVING, ONCE IT IS IN MOTION, THE LAW OF INERTIA WORKS.
IF WE HAD NO GRAVITY, A BALL YOU THREW INTO THE AIR WOULD CONTINUE TO TRAVEL STRAIGHT UPWARD FOREVER.
AHA, I SEE.


NOW, MAY I ASK YOU SOMETHING, NINOMIYA-SAN?
DO YOU UNDERSTAND THE DISTINCTION BETWEEN THE TERM "FORCE" IN DAILY SPEECH, AND THE "FORCE" WE USE IN PHYSICS?
YES, THANKS TO YOUR LESSON, IT'S QUITE CLEAR.
NOW THAT YOU KNOW NEWTON'S THREE LAWS, YOU KNOW THE BASICS. DON'T FORGET THE LAW OF INERTIA, F = ma, AND THE LAW OF ACTION AND REACTION.
HIP, HIP, HURRAY!
YOU'VE GIVEN ME SUCH A HELPFUL EXPLANATION, NONOMURA-KUN.
MY PLEASURE.


THE PHYSICS OF MOTION IS MADE OF THREE LAWS—THE ONES WE'VE LEARNED. NO EXAGGERATION!
WOW, REALLY? THEY MUST BE PRETTY GREAT LAWS!
NEXT, WE'RE GOING TO LEARN ABOUT MOMENTUM.
LET'S KEEP UP THE PACE!
ALL RIGHT! HA, HA.
WE STAYED SO LATE AGAIN!
...THOSE TWO...
WHY ARE THEY ALWAYS STUDYING TOGETHER IN THE PHYSICS LAB?
SUSPICIOUS...