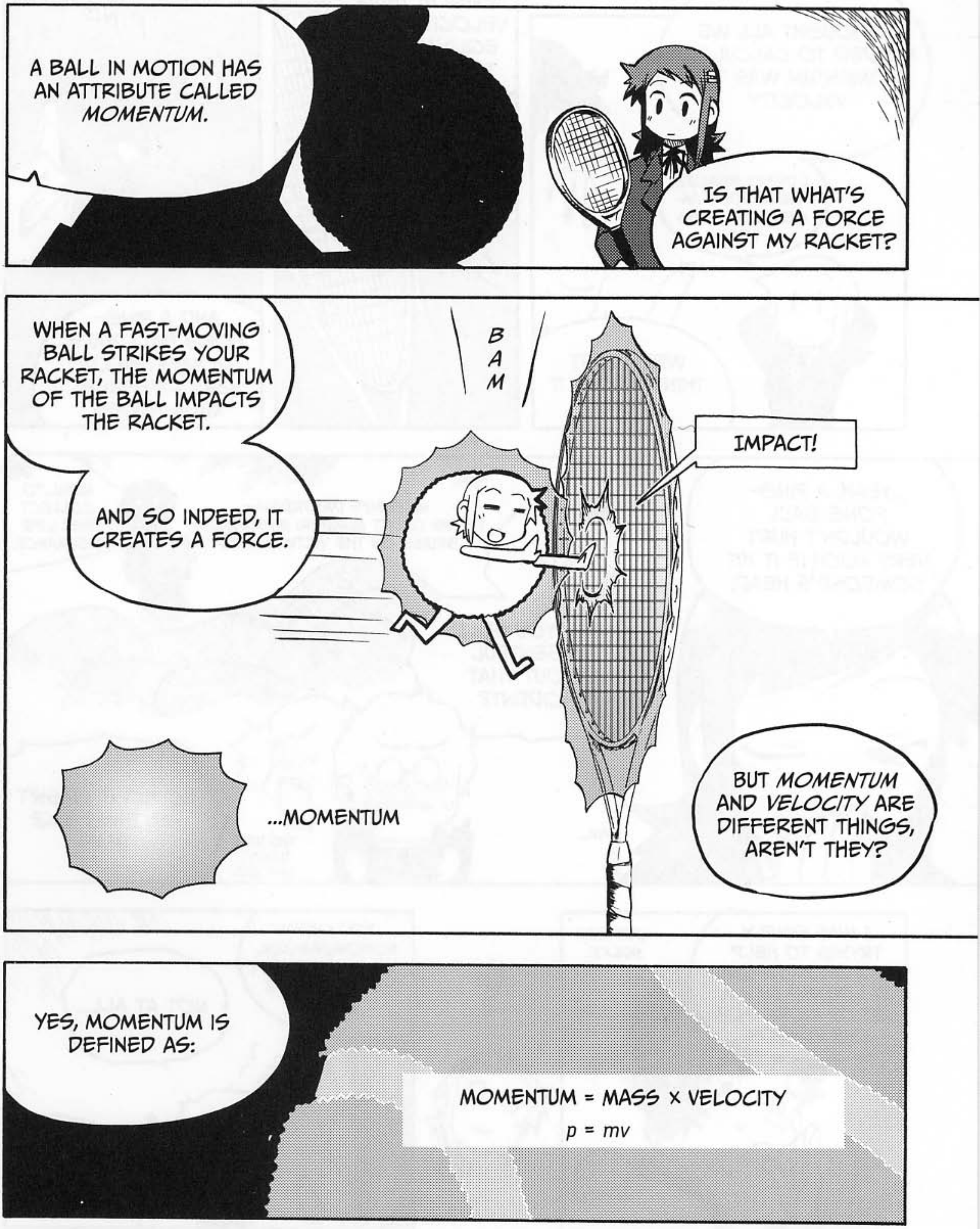
3

MOMENTUM


* GIRLS' LOCKER ROOM
MEGU!
WANT TO HANG OUT AT NORN, GRAB A PIECE OF CAKE OR SOMETHING?
COME ON!
ER, SORRY.
I'M AFRAID I CAN'T COME WITH. I HAVE TO GO MEET MY MOTHER.
OH YEAH? TOO BAD...
AREN'T YOU A BUSY LITTLE BEE THESE DAYS!
WHAT ARE YOU TALKING ABOUT, SAYAKA?
HARUMPH.


I KNOW ABOUT YOUR LITTLE SECRET.
HUH?!
OH, FORGET I SAID ANYTHING.
JUST DON'T FORGET ABOUT OUR CHALLENGE MATCH!
YOU'RE NUMBER TWO ON THE TEAM FOR A REASON!
ビッ!!
ARE YOU TRYING TO PSYCH ME OUT?!
I JUST HOPE YOU'VE BEEN PRACTICING TENNIS, TOO, EGGHEAD...
STOMP STOMP BANG!
WHAT'S UP HER BUTT?
WHO KNOWS!
MAYBE SAYAKA KNOWS ABOUT ME AND RYOTA STUDYING TOGETHER!


UNDERSTANDING MOMENTUM
SO YOU'RE HAVING ANOTHER MATCH WITH KODA-SAN?
YEAH!
SAYAKA'S GOING DOWN, BIG TIME.
AH, THE JOY OF REVENGE.
BY THE WAY, I WANTED TO ASK YOU ABOUT SOMETHING.
A BALL IN MOTION HAS NO FORCE BEING IMPOSED ON IT, RIGHT?
BUT WHEN I HIT THE BALL BACK, I FEEL A FORCE.
I CAN FEEL IT ON MY ARM!
ISN'T THE BALL CREATING SOMETHING LIKE A FORCE AGAINST THE RACKET?
THAT'S A GOOD POINT.


A BALL IN MOTION HAS AN ATTRIBUTE CALLED *MOMENTUM.*
IS THAT WHAT'S CREATING A FORCE AGAINST MY RACKET?
WHEN A FAST-MOVING BALL STRIKES YOUR RACKET, THE MOMENTUM OF THE BALL IMPACTS THE RACKET.
AND SO INDEED, IT CREATES A FORCE.
BAM
IMPACT!
...MOMENTUM
BUT *MOMENTUM* AND *VELOCITY* ARE DIFFERENT THINGS, AREN'T THEY?
YES, MOMENTUM IS DEFINED AS:
MOMENTUM = MASS × VELOCITY
$p = mv$

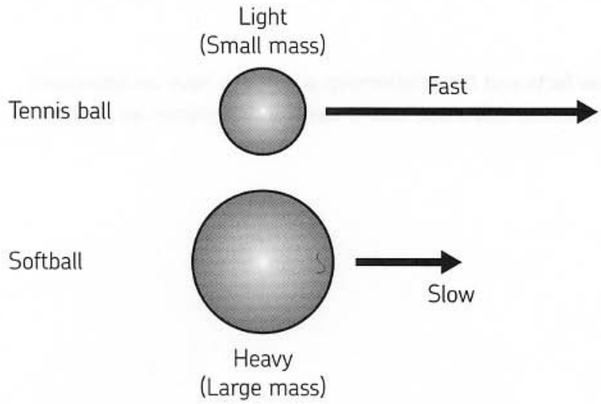

I THOUGHT ALL WE NEEDED TO CALCULATE MOMENTUM WAS THE VELOCITY.
I DIDN'T REALIZE WE NEEDED AN OBJECT'S MASS TOO!
WELL, JUST THINK ABOUT IT A BIT.
EVEN IF THEIR VELOCITY WERE EQUIVALENT, A TENNIS BALL...
SHHTOCK
PING
AND A PING-PONG BALL HAVE MOMENTUM OF VERY DIFFERENT MAGNITUDES.
...YEAH, A PING-PONG BALL WOULDN'T HURT VERY MUCH IF IT HIT SOMEONE'S HEAD.
MEGUMI'S DAYDREAM— TENNIS COURT MURDER: MYSTERIOUS BRUISE ON THE VICTIM'S HEAD
NOW...TO COLLECT HER LIFE INSURANCE.
WHAT?
ARE YOU STILL RESENTFUL ABOUT THAT INCIDENT?
HMM...
THE BALL WASN'T THAT BIG.
NO NO, IT WASN'T ANYTHING LIKE THAT!
I WAS SIMPLY TRYING TO HELP YOU, NINOMIYA-SAN. IT LOOKED LIKE A LOT OF WORK FOR ONE PERSON.
GETTING SULKY...
OH, I'M JUST KIDDING.
YOU KNOW, NONOMURA-KUN, YOU TEND TO GET SULKY RATHER EASILY.
NOT AT ALL...
HERE SHE GOES AGAIN...

LABORATORY

DIFFERENCE IN MOMENTUM DUE TO A DIFFERENCE IN MASS

To help you understand how momentum works, I've brought in a softball and a tennis ball.

Let's examine the momentum of a softball traveling slowly and a tennis ball traveling quickly.



Let me see, the softball is much heavier than the tennis ball, right?

Yes, of course. We know the following about the two balls:

$$m_{\text{softball}} > m_{\text{tennis ball}}$$

$$v_{\text{softball}} < v_{\text{tennis ball}}$$

However, we can't tell which ball has the greater momentum. Recall that momentum can be calculated as mass multiplied by velocity ($p = mv$). We'd need to know numerical values to determine the difference precisely.

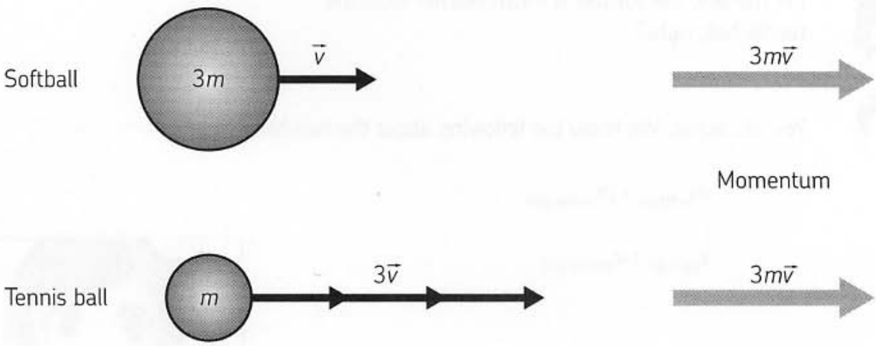
Well, I know that a tennis ball has a mass of about 60 g.

And a softball is about 180 g.

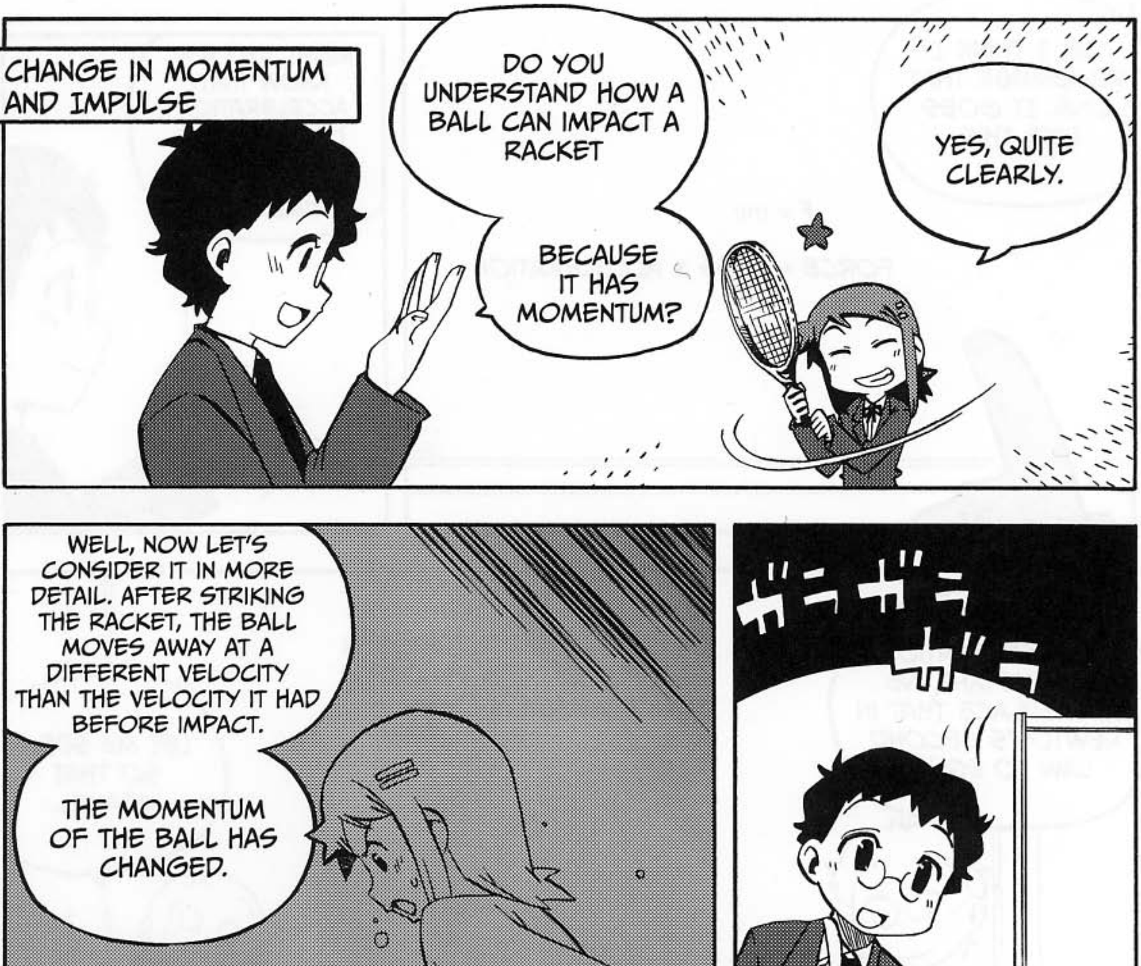
So we're almost there. It's 60 g versus 180 g—the mass of a softball is about three times as great as that of a tennis ball.

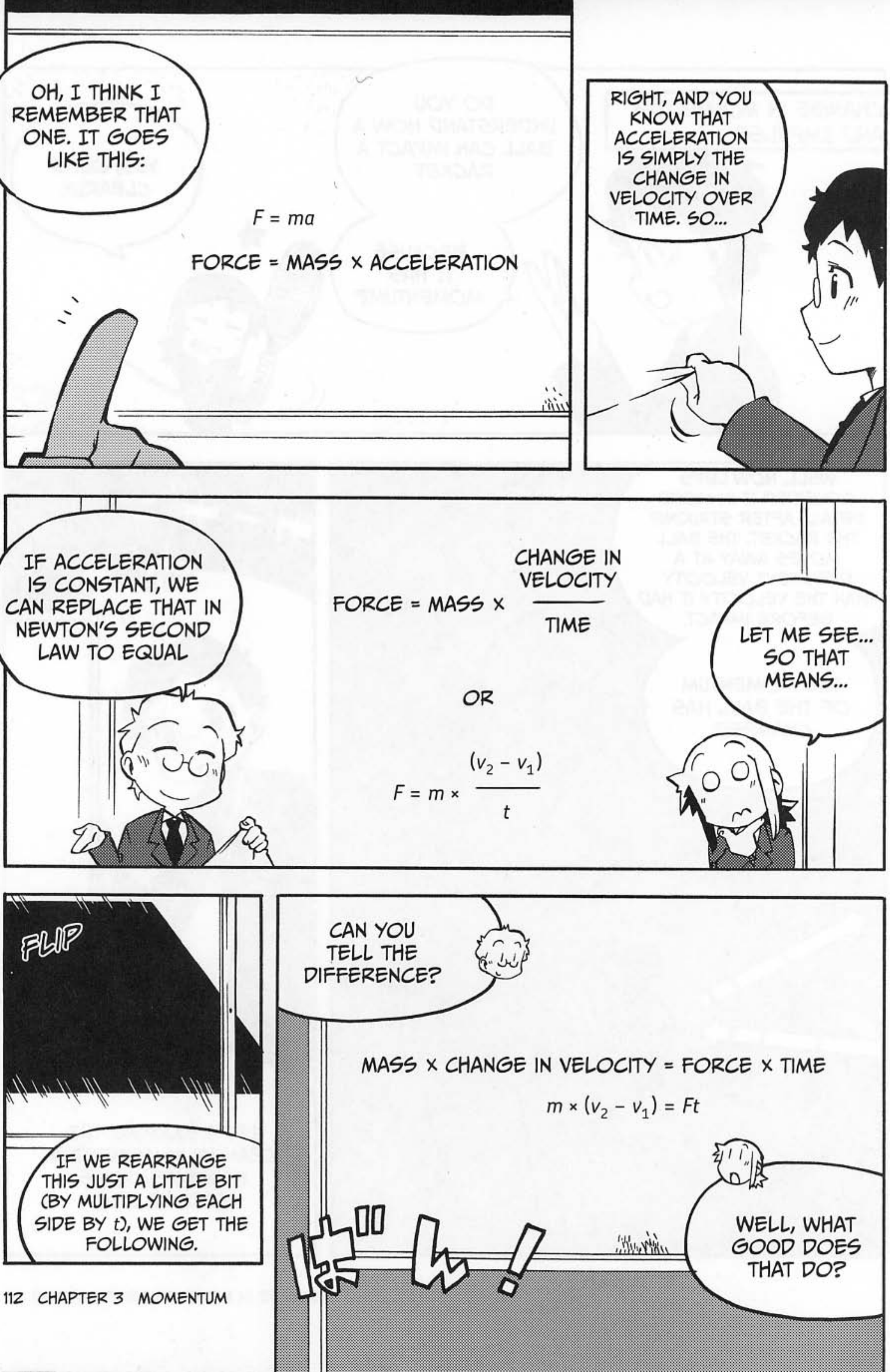
Given these new facts and the relationship $p = mv$, to have an equivalent momentum, the tennis ball must have a velocity three times as great as the softball.

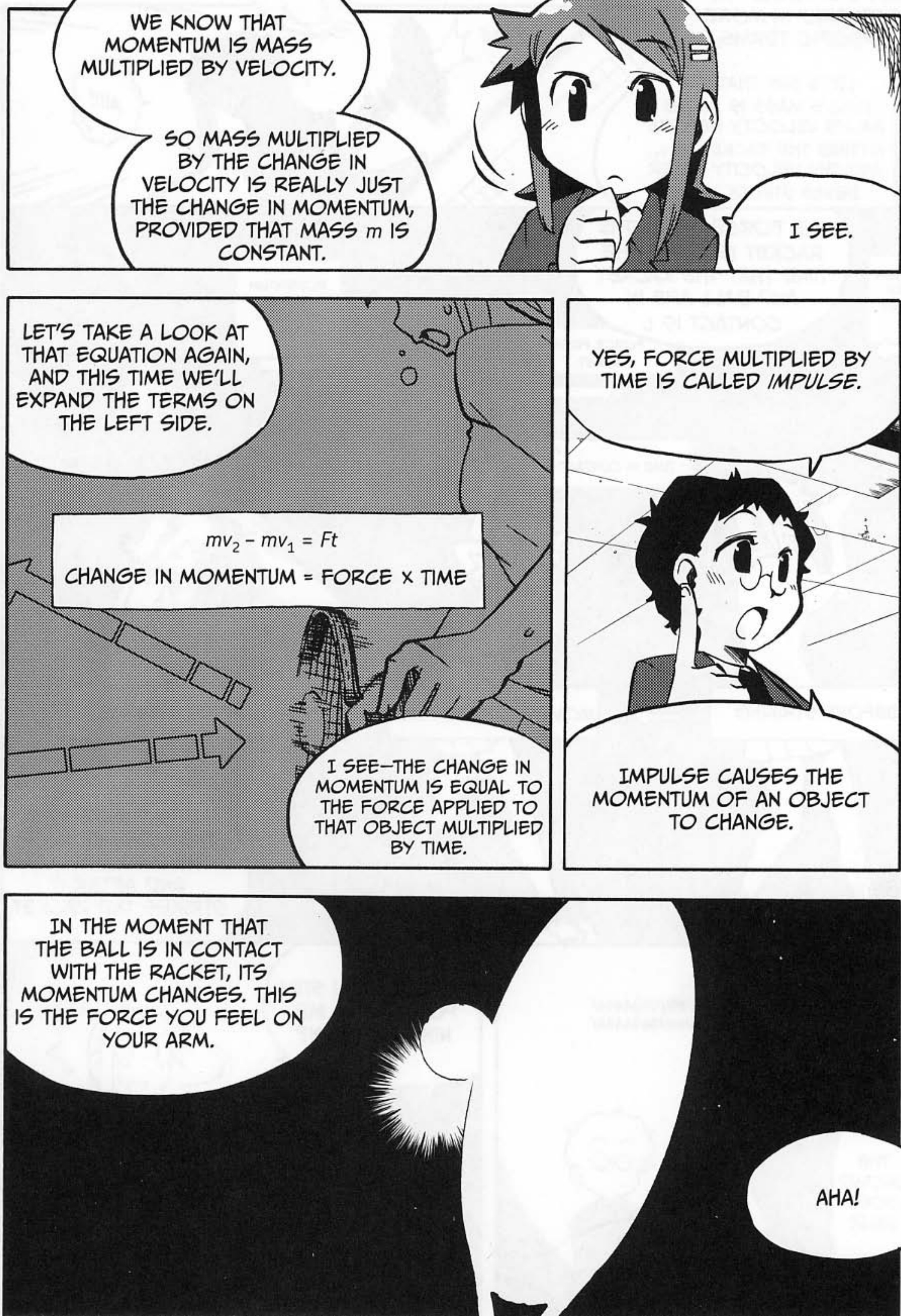
Oh, I see.

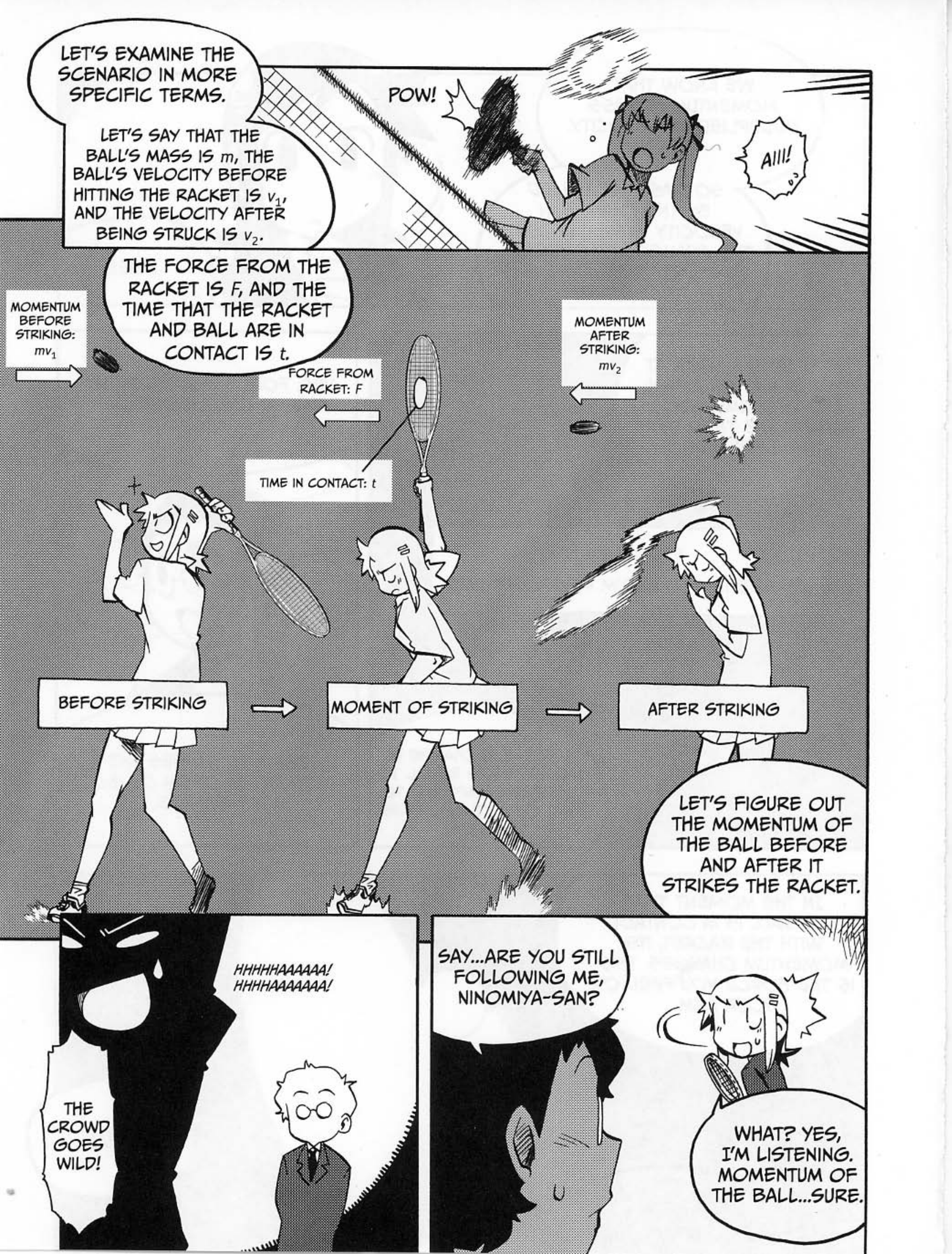


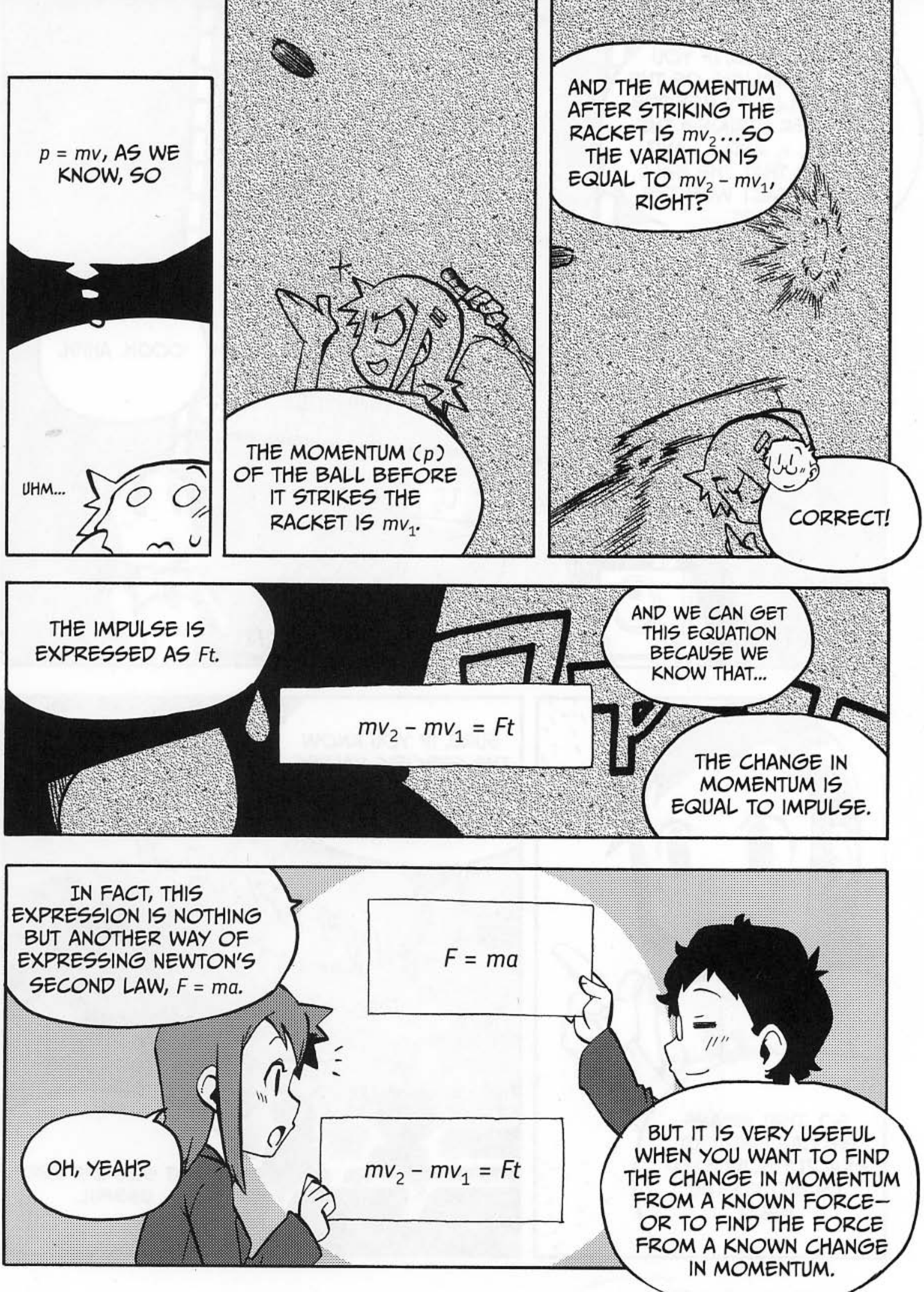
CHANGE IN MOMENTUM AND IMPULSE




OH, I THINK I REMEMBER THAT ONE. IT GOES LIKE THIS:
$F = ma$
FORCE = MASS × ACCELERATION
RIGHT, AND YOU KNOW THAT ACCELERATION IS SIMPLY THE CHANGE IN VELOCITY OVER TIME. SO...
IF ACCELERATION IS CONSTANT, WE CAN REPLACE THAT IN NEWTON'S SECOND LAW TO EQUAL
FORCE = MASS × CHANGE IN VELOCITY / TIME
OR
$F = m \times \frac{(v_2 - v_1)}{t}$
LET ME SEE... SO THAT MEANS...
FLIP
IF WE REARRANGE THIS JUST A LITTLE BIT (BY MULTIPLYING EACH SIDE BY t), WE GET THE FOLLOWING.
CAN YOU TELL THE DIFFERENCE?
MASS × CHANGE IN VELOCITY = FORCE × TIME
$m \times (v_2 - v_1) = Ft$
ばーん!
WELL, WHAT GOOD DOES THAT DO?


WE KNOW THAT MOMENTUM IS MASS MULTIPLIED BY VELOCITY.
SO MASS MULTIPLIED BY THE CHANGE IN VELOCITY IS REALLY JUST THE CHANGE IN MOMENTUM, PROVIDED THAT MASS m IS CONSTANT.
I SEE.
LET'S TAKE A LOOK AT THAT EQUATION AGAIN, AND THIS TIME WE'LL EXPAND THE TERMS ON THE LEFT SIDE.
$mv_2 - mv_1 = Ft$
CHANGE IN MOMENTUM = FORCE × TIME
I SEE—THE CHANGE IN MOMENTUM IS EQUAL TO THE FORCE APPLIED TO THAT OBJECT MULTIPLIED BY TIME.
YES, FORCE MULTIPLIED BY TIME IS CALLED IMPULSE.
IMPULSE CAUSES THE MOMENTUM OF AN OBJECT TO CHANGE.
IN THE MOMENT THAT THE BALL IS IN CONTACT WITH THE RACKET, ITS MOMENTUM CHANGES. THIS IS THE FORCE YOU FEEL ON YOUR ARM.
AHA!


LET'S EXAMINE THE SCENARIO IN MORE SPECIFIC TERMS.
LET'S SAY THAT THE BALL'S MASS IS m, THE BALL'S VELOCITY BEFORE HITTING THE RACKET IS v_1, AND THE VELOCITY AFTER BEING STRUCK IS v_2.
POW!
AIII!
THE FORCE FROM THE RACKET IS F, AND THE TIME THAT THE RACKET AND BALL ARE IN CONTACT IS t.
MOMENTUM BEFORE STRIKING: mv_1
FORCE FROM RACKET: F
TIME IN CONTACT: t
MOMENTUM AFTER STRIKING: mv_2
BEFORE STRIKING
MOMENT OF STRIKING
AFTER STRIKING
LET'S FIGURE OUT THE MOMENTUM OF THE BALL BEFORE AND AFTER IT STRIKES THE RACKET.
HHHHHAAAAAA! HHHHHAAAAAAA!
THE CROWD GOES WILD!
SAY...ARE YOU STILL FOLLOWING ME, NINOMIYA-SAN?
WHAT? YES, I'M LISTENING. MOMENTUM OF THE BALL...SURE.


$p = mv$, AS WE KNOW, SO
UHM...
THE MOMENTUM (p) OF THE BALL BEFORE IT STRIKES THE RACKET IS mv_1.
AND THE MOMENTUM AFTER STRIKING THE RACKET IS mv_2...SO THE VARIATION IS EQUAL TO $mv_2 - mv_1$, RIGHT?
CORRECT!
THE IMPULSE IS EXPRESSED AS Ft.
$mv_2 - mv_1 = Ft$
AND WE CAN GET THIS EQUATION BECAUSE WE KNOW THAT...
THE CHANGE IN MOMENTUM IS EQUAL TO IMPULSE.
IN FACT, THIS EXPRESSION IS NOTHING BUT ANOTHER WAY OF EXPRESSING NEWTON'S SECOND LAW, $F = ma$.
$F = ma$
OH, YEAH?
$mv_2 - mv_1 = Ft$
BUT IT IS VERY USEFUL WHEN YOU WANT TO FIND THE CHANGE IN MOMENTUM FROM A KNOWN FORCE—OR TO FIND THE FORCE FROM A KNOWN CHANGE IN MOMENTUM.


FOR EXAMPLE, IF YOU KNOW THE VALUES OF THE BALL'S VELOCITY BEFORE AND AFTER STRIKING THE RACKET, v_1 AND v_2, AND THE TIME THAT THE BALL IS IN CONTACT WITH THE RACKET...
YOU CAN EASILY FIND THE FORCE F THAT THE RACKET IMPOSES ON THE BALL.
OOOH. AHHH.
SO...THAT MEANS WE CAN FIND OUT EXACTLY HOW HARD I'M HITTING THE BALL!
SURE, IF YOU KNOW THE SPECIFIC VALUES OF VELOCITY AND THE TIME OF CONTACT.
TENNIS APOCALYPSE!
THAT SOUNDS VERY USEFUL.

LABORATORY

FINDING THE MOMENTUM OF A STROKE

Let's actually analyze this scenario, Ninomiya-san, and find out the force you're applying to the ball. During your match with Sayaka, I filmed your motion with a high-speed camera. We'll analyze a time when you returned her smash.

Here you go again. Yet another make-believe scenario.

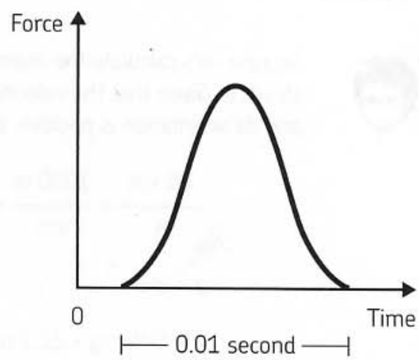
This time, I really did shoot the footage.

What on earth . . . ?

It's all in the name of science. Anyway, I analyzed the images and learned that the velocity of the ball when it hit the racket was about 100 km per hour, and you returned the ball at about 80 km per hour. And I measured the time that the ball was in contact with your racket—it was 0.01 second.

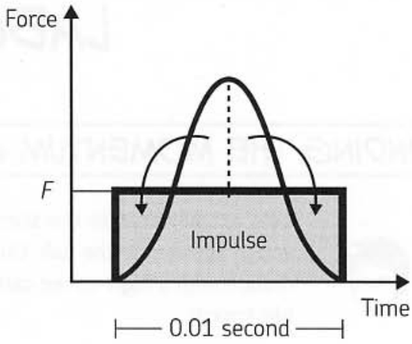
So we should have all the numbers we need!

Using these values, we can find the magnitude of the force your racket imposed on the ball. But it's actually not so simple. A graph of the force over time looks like this.



However, we'll assume an average magnitude of F in this example.

That makes the calculation much easier.



First, let's calculate the momentum of the ball before you hit it. The mass of a tennis ball is 0.06 kg. The velocity is negative 100 km per hour, as viewed from the direction of the return. As 1 km = 1000 m, and 1 hour = 3600 seconds, we'll convert our units for velocity into meters per second (m/s) as follows: 1 km/h = 1000 m / 3600 s. The calculation looks like this:

$$\frac{-100\ \text{km}}{\text{h}} \times \frac{1000\ \text{m}}{\text{km}} \times \frac{1\ \text{h}}{3600\ \text{s}} = -27.8\ \frac{\text{m}}{\text{s}}$$

$$p = mv$$

$$p = 0.06\ \text{kg} \times -27.8\ \text{m/s}$$

$$p = -1.7\ \text{kg} \times \text{m/s}$$

Now we know the ball's initial momentum. It's a little weird that the value is negative, but I guess it just indicates the direction from my point of view.

So now let's calculate the momentum of the ball after you've struck it. Given that the velocity of the ball afterwards is 80 km/h, and its orientation is positive, the result is as follows:

$$\frac{80\ \text{km}}{\text{h}} \times \frac{1000\ \text{m}}{\text{km}} \times \frac{1\ \text{h}}{3600\ \text{s}} = 22.2\ \frac{\text{m}}{\text{s}}$$

$$p = mv$$

$$p = 0.06\ \text{kg} \times 22.2\ \text{m/s}$$

$$p = 1.3\ \text{kg} \times \text{m/s}$$

Now we can find the change in these two values.

The change in momentum can be calculated like so:

$$1.3 \text{ kg} \times \text{m/s} - (-1.7 \text{ kg} \times \text{m/s}) = 3.0 \text{ kg} \times \text{m/s} = \Delta p$$

So that's the change in the ball's momentum. And since the force was working for 0.01 seconds, we can figure out the force, using this equation:

$$\Delta p = Ft \qquad \text{or} \qquad \frac{\Delta p}{t} = F$$

In our example, that means (3.0 kg × m/s) / 0.01 s = 300N. That's the force on my racket, I bet.

Yes, that's it. Since you probably don't know what a newton feels like, let's find the equivalent force generated by 1 kg weight, assuming that 1 kg is about equal to 9.8N:

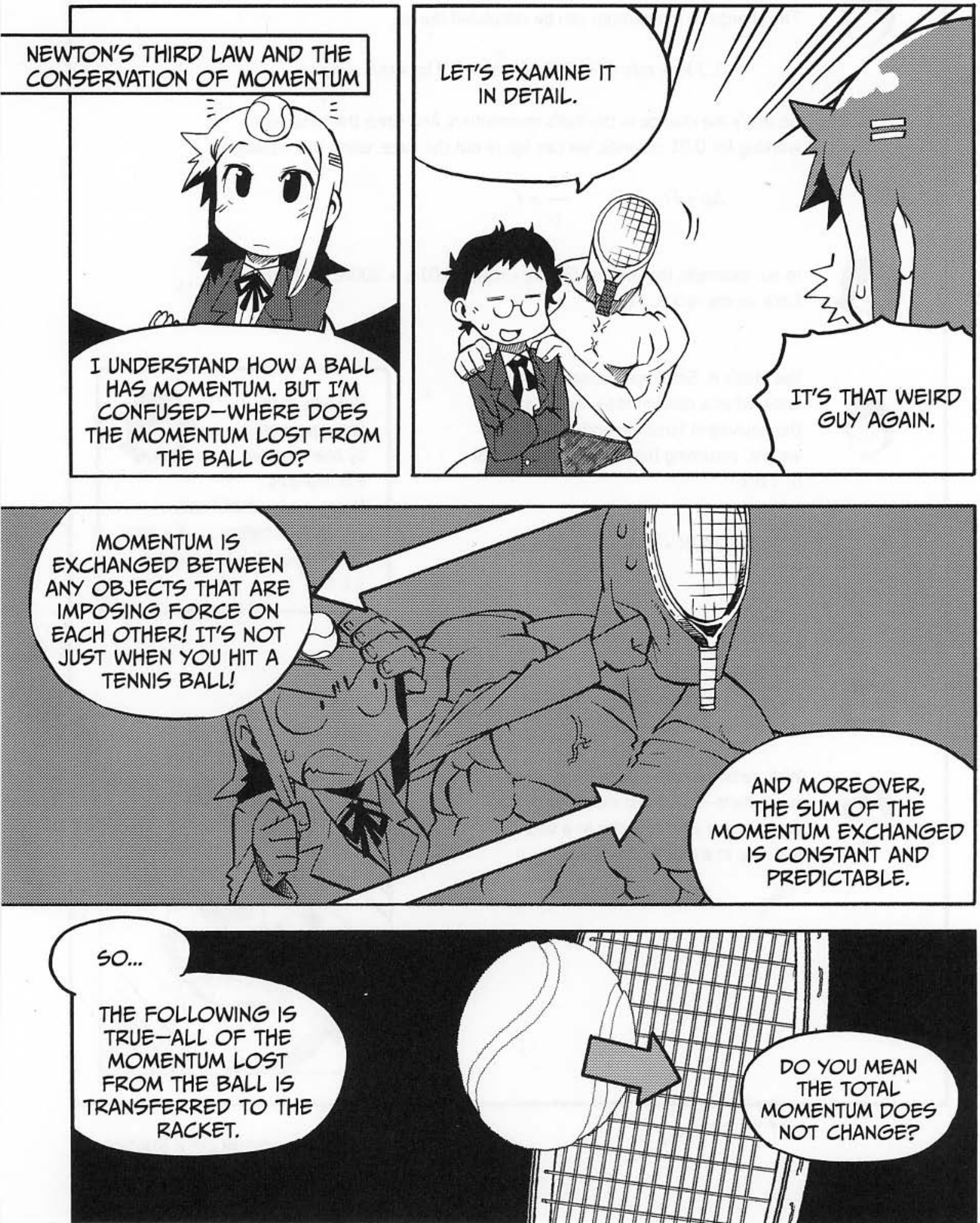
$$300\text{N} \times \frac{1 \text{ kg}}{9.8\text{N}} = 30.6 \text{ kg}$$

But why is the force generated by one kilogram 9.8 newtons . . . ? Nevermind, I think I see. We did that before . . . $F = ma$. Acceleration due to gravity is 9.8 m/s^2.

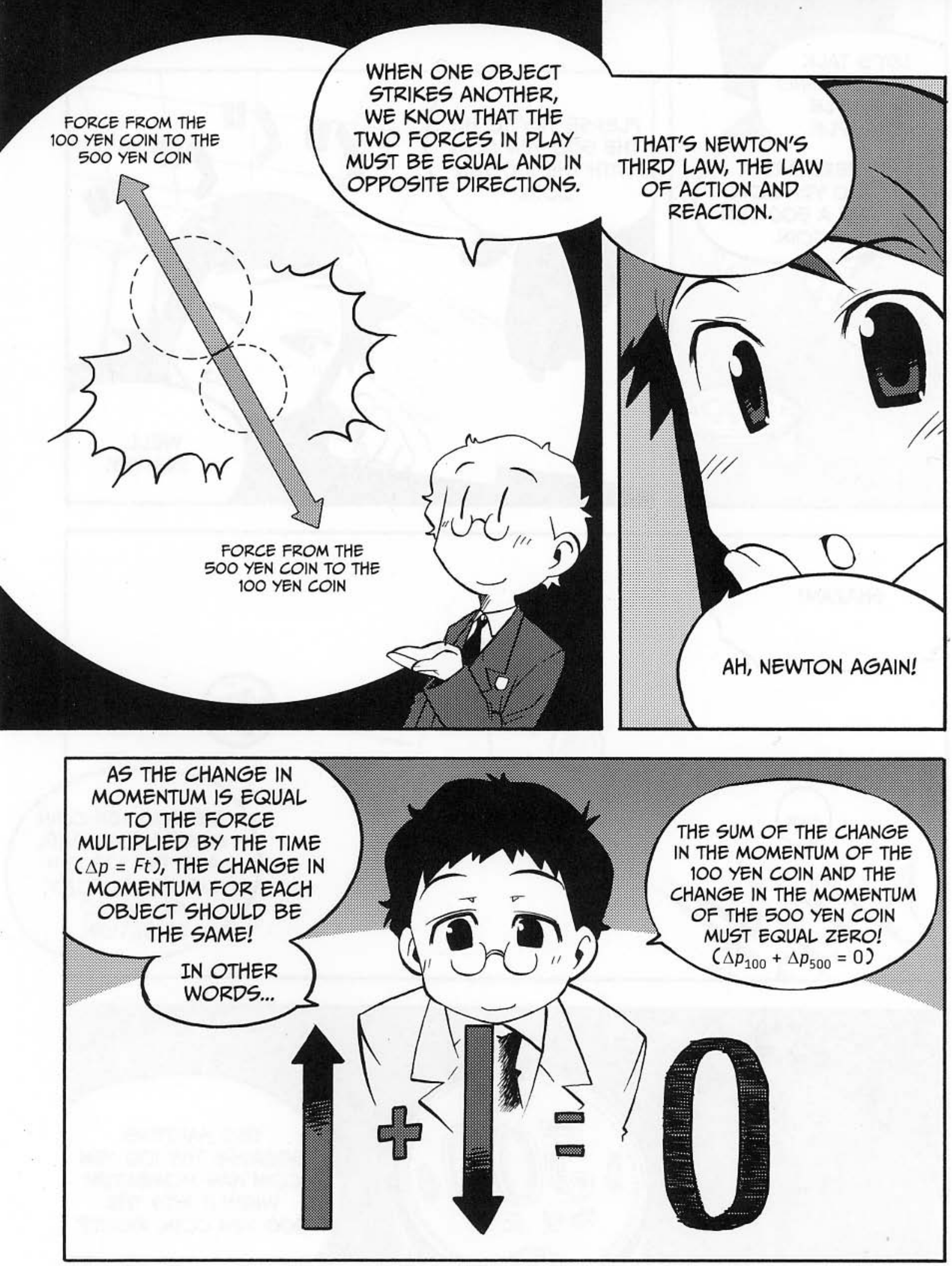
Wow, that's a lot to lift!

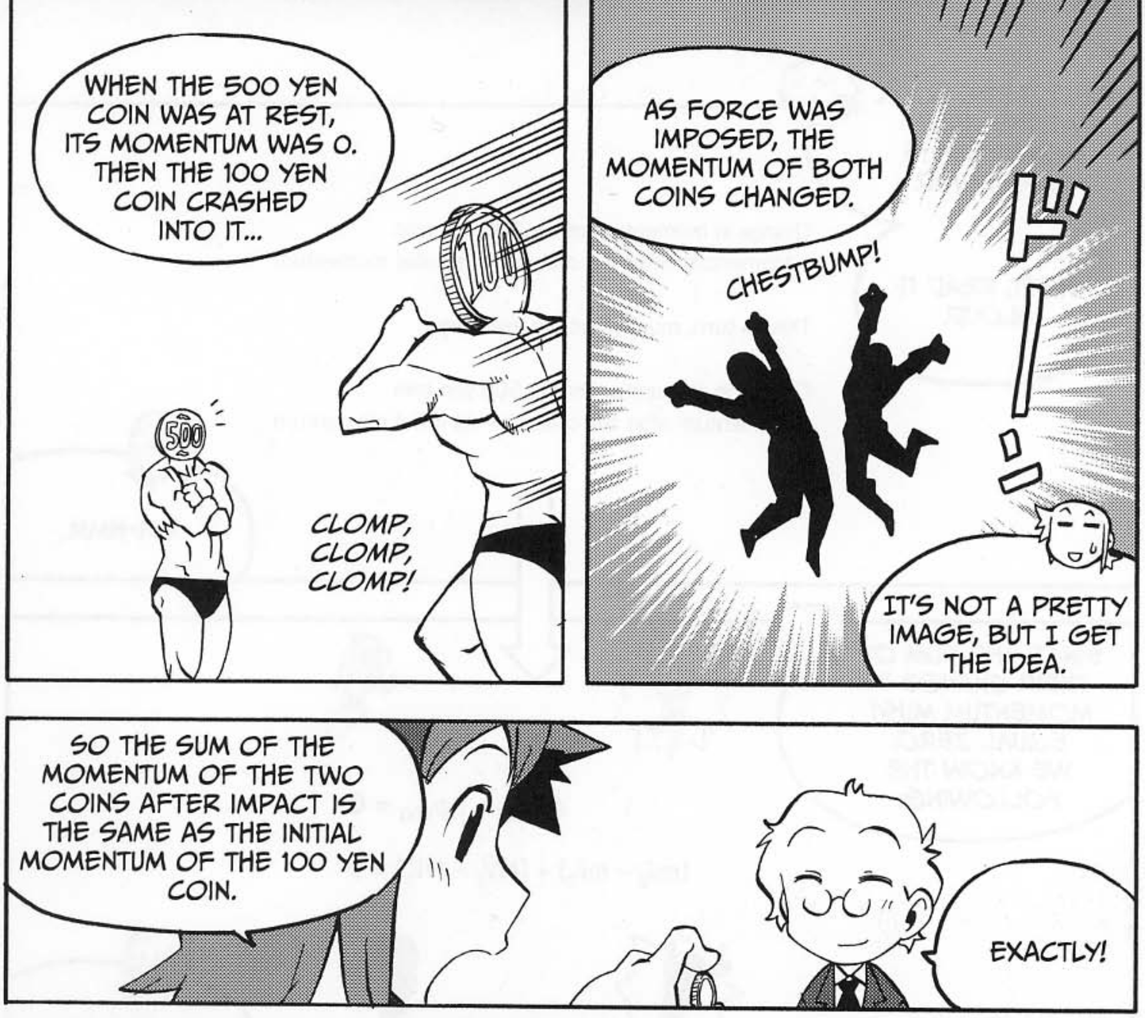
Well, remember, the force from gravity is constant—this is just momentary. And you're using your muscles in a very different way, in a different direction.

THE CONSERVATION OF MOMENTUM



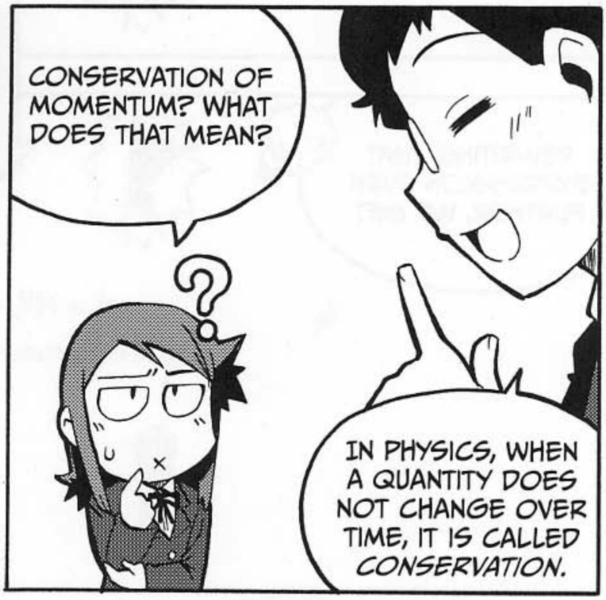

LET'S TALK ABOUT IT USING A SIMPLE EXAMPLE.
HERE ARE A 100 YEN COIN AND A 500 YEN COIN.
PLEASE TRY TO HIT THE 500 YEN COIN WITH THE 100 YEN COIN.
WELL... I'LL TRY.
SHAZAM!
CLINK
FLICK
THE 500 YEN COIN MOVED FORWARD, AND THE 100 YEN COIN'S VELOCITY REVERSED DIRECTION.
THIS HAPPENS BECAUSE THE 100 YEN COIN HAS MOMENTUM WHEN IT HITS THE 500 YEN COIN, RIGHT?


WHEN ONE OBJECT STRIKES ANOTHER, WE KNOW THAT THE TWO FORCES IN PLAY MUST BE EQUAL AND IN OPPOSITE DIRECTIONS.
FORCE FROM THE 100 YEN COIN TO THE 500 YEN COIN
FORCE FROM THE 500 YEN COIN TO THE 100 YEN COIN
THAT'S NEWTON'S THIRD LAW, THE LAW OF ACTION AND REACTION.
AH, NEWTON AGAIN!
AS THE CHANGE IN MOMENTUM IS EQUAL TO THE FORCE MULTIPLIED BY THE TIME ($\Delta p = Ft$), THE CHANGE IN MOMENTUM FOR EACH OBJECT SHOULD BE THE SAME!
IN OTHER WORDS...
THE SUM OF THE CHANGE IN THE MOMENTUM OF THE 100 YEN COIN AND THE CHANGE IN THE MOMENTUM OF THE 500 YEN COIN MUST EQUAL ZERO! ($\Delta p_{100} + \Delta p_{500} = 0$)
+ = 0

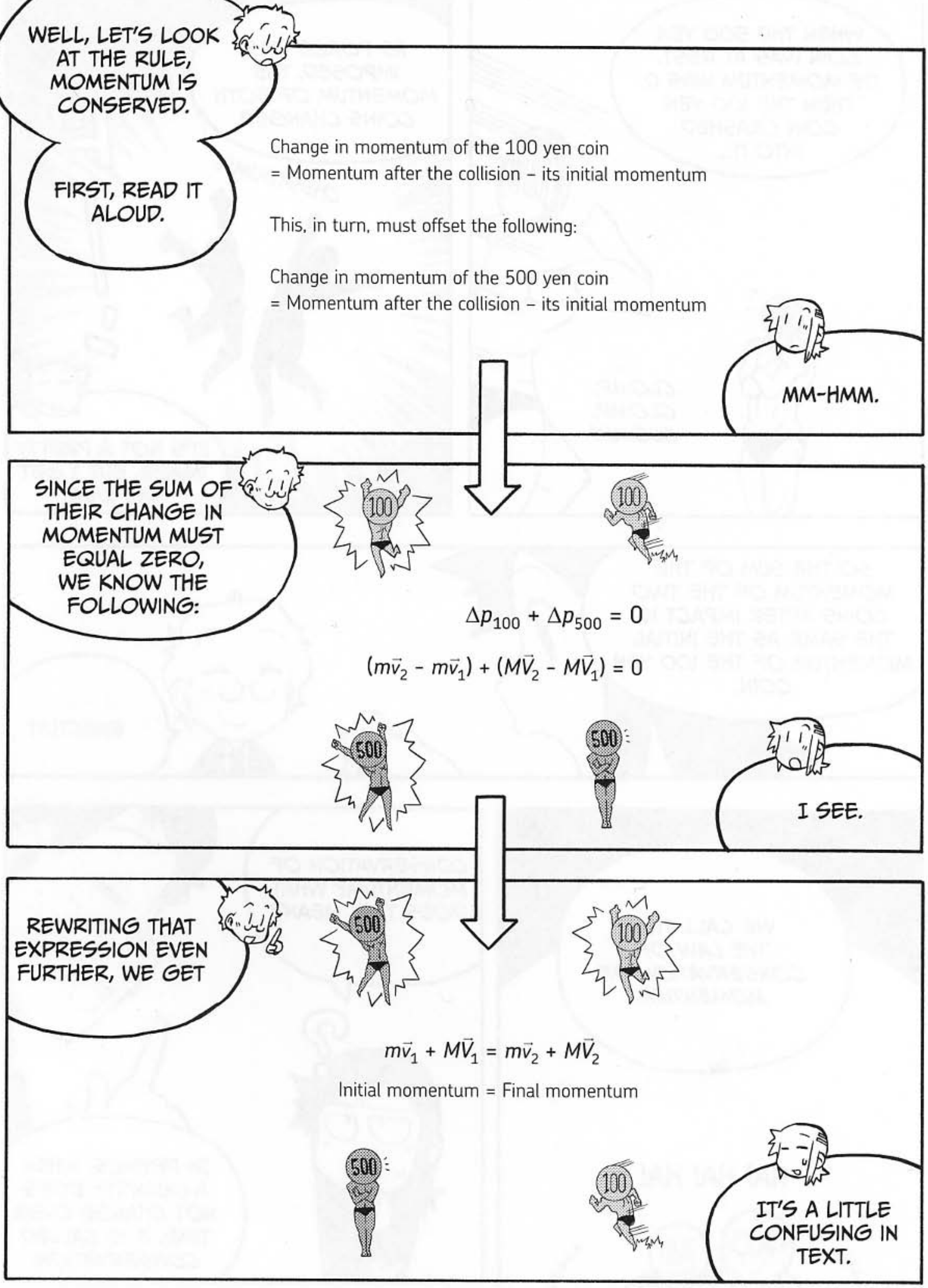


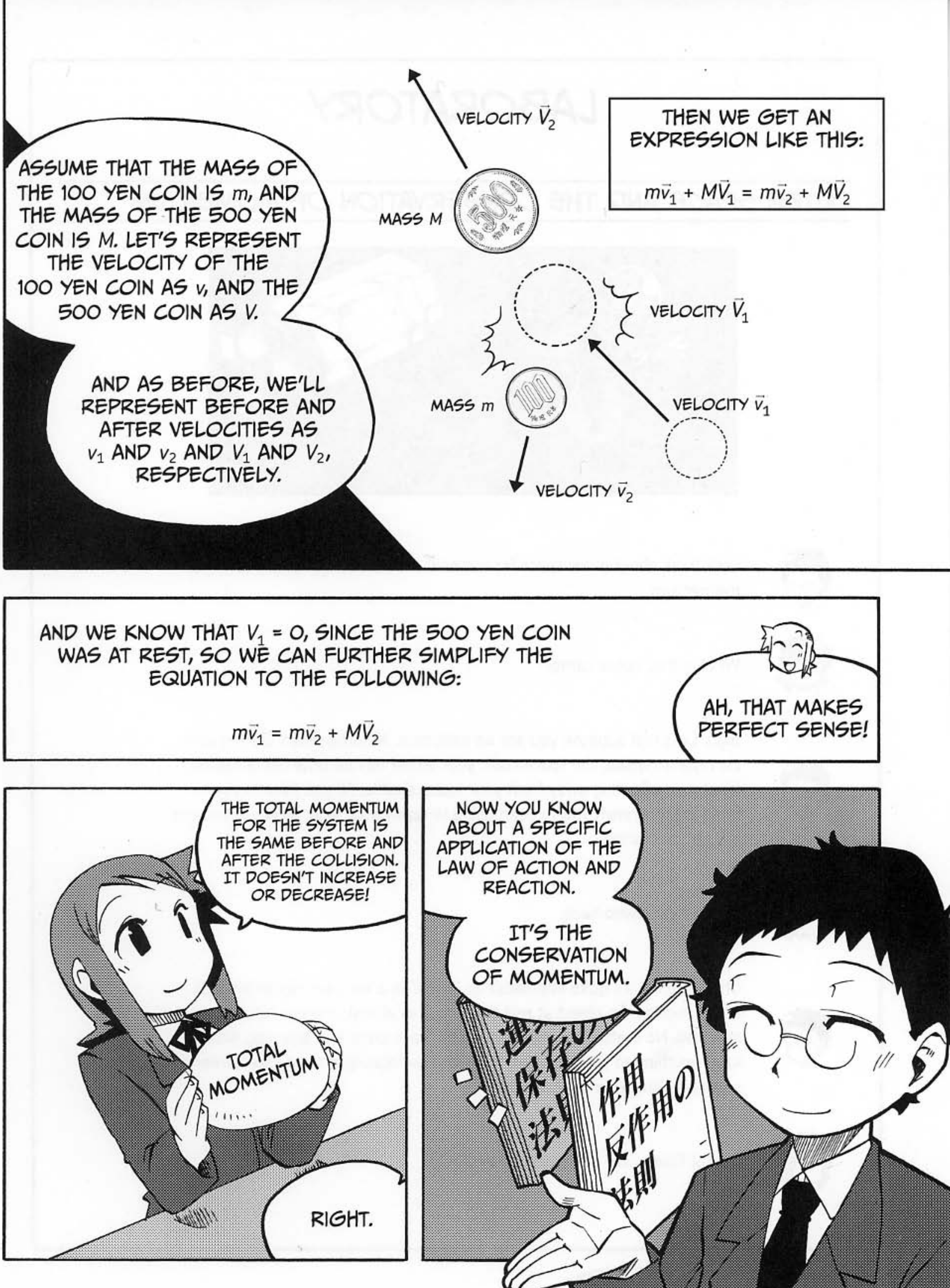
WHEN THE 500 YEN COIN WAS AT REST, ITS MOMENTUM WAS 0. THEN THE 100 YEN COIN CRASHED INTO IT...
CLOMP, CLOMP, CLOMP!
AS FORCE WAS IMPOSED, THE MOMENTUM OF BOTH COINS CHANGED.
CHESTBUMP!
IT'S NOT A PRETTY IMAGE, BUT I GET THE IDEA.
SO THE SUM OF THE MOMENTUM OF THE TWO COINS AFTER IMPACT IS THE SAME AS THE INITIAL MOMENTUM OF THE 100 YEN COIN.
EXACTLY!

WE CALL THIS THE *LAW OF CONSERVATION OF MOMENTUM.*
HA! HA! HA!



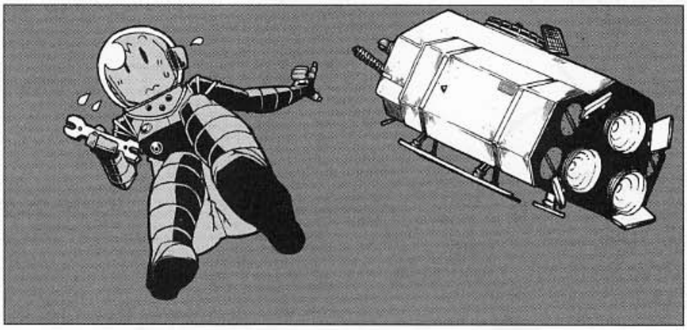
CONSERVATION OF MOMENTUM? WHAT DOES THAT MEAN?
IN PHYSICS, WHEN A QUANTITY DOES NOT CHANGE OVER TIME, IT IS CALLED *CONSERVATION.*


WELL, LET'S LOOK AT THE RULE, MOMENTUM IS CONSERVED.
FIRST, READ IT ALOUD.
Change in momentum of the 100 yen coin
= Momentum after the collision – its initial momentum
This, in turn, must offset the following:
Change in momentum of the 500 yen coin
= Momentum after the collision – its initial momentum
MM-HMM.
SINCE THE SUM OF THEIR CHANGE IN MOMENTUM MUST EQUAL ZERO, WE KNOW THE FOLLOWING:
100
100
$\Delta p_{100} + \Delta p_{500} = 0$
$(m\vec{v}_2 - m\vec{v}_1) + (M\vec{V}_2 - M\vec{V}_1) = 0$
500
500
I SEE.
REWRITING THAT EXPRESSION EVEN FURTHER, WE GET
500
100
$m\vec{v}_1 + M\vec{V}_1 = m\vec{v}_2 + M\vec{V}_2$
Initial momentum = Final momentum
500
100
IT'S A LITTLE CONFUSING IN TEXT.


ASSUME THAT THE MASS OF THE 100 YEN COIN IS m, AND THE MASS OF THE 500 YEN COIN IS M. LET'S REPRESENT THE VELOCITY OF THE 100 YEN COIN AS v, AND THE 500 YEN COIN AS V.
AND AS BEFORE, WE'LL REPRESENT BEFORE AND AFTER VELOCITIES AS v_1 AND v_2 AND V_1 AND V_2, RESPECTIVELY.
VELOCITY $\vec{V}_2$
MASS M
VELOCITY $\vec{V}_1$
MASS m
VELOCITY $\vec{v}_1$
VELOCITY $\vec{v}_2$
THEN WE GET AN EXPRESSION LIKE THIS:
$m\vec{v}_1 + M\vec{V}_1 = m\vec{v}_2 + M\vec{V}_2$
AND WE KNOW THAT $V_1 = 0$, SINCE THE 500 YEN COIN WAS AT REST, SO WE CAN FURTHER SIMPLIFY THE EQUATION TO THE FOLLOWING:
$m\vec{v}_1 = m\vec{v}_2 + M\vec{V}_2$
AH, THAT MAKES PERFECT SENSE!
THE TOTAL MOMENTUM FOR THE SYSTEM IS THE SAME BEFORE AND AFTER THE COLLISION. IT DOESN'T INCREASE OR DECREASE!
TOTAL MOMENTUM
RIGHT.
NOW YOU KNOW ABOUT A SPECIFIC APPLICATION OF THE LAW OF ACTION AND REACTION.
IT'S THE CONSERVATION OF MOMENTUM.
作用反作用の法則

LABORATORY

OUTER SPACE AND THE CONSERVATION OF MOMENTUM



Let's think about outer space for our next example of the conservation of momentum.

What is this, space camp?

Sigh. Let's just suppose you are an astronaut, Ninomiya-san. During vehicle repairs outside the space craft, your tether has become disconnected, leaving you floating away from your space shuttle. All you have in your hand is the wrench you've been using to repair your ship. How can you get back to your ship?

Maybe I can swim back.

Oh, ho ho ho, it's quite impossible to "swim" in a vacuum. Recall the first law of motion: An object at rest tends to stay at rest unless a force is imposed. No matter how hard you move your arms and legs, you won't have anything to push against. You'd just be rotating around your center of gravity, flailing your arms around.

Oh no! Things are really looking bad!

Never give up hope! Your physics knowledge may save your life. You have that wrench, remember? Throw it in the direction opposite to the rocket. Thanks to the conservation of momentum, you will move.

Really? I'm gonna make it?

To confirm that this works, let's assume that you're at rest, in outer space. Then let's set the wrench's mass as m and assume you throw it away from you at velocity v. Your mass and subsequent velocity are represented by M and V.

Since we are starting with no momentum, the momentum of both objects afterward must equal zero, right?

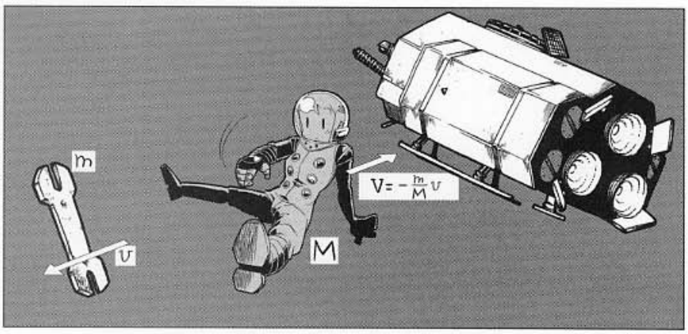
Indeed! Given the law of conservation of momentum, the sum of the momentum of both bodies should equal zero. If we put that in an equation, it looks like this:

$$mv + MV = 0$$

To find V, or your velocity back to your ship, we rearrange the equation:

$$V = -\frac{m}{M} \times v$$

This value is negative because it indicates that your motion is in the opposite direction of the wrench.



Can you see why you'd want to throw the wrench as hard as you could? The faster its v, the faster your V.

Yes, that makes sense.

Let's assign some numeric values and try to predict things. We'll say the wrench has a mass of 1 kg and give you a mass of 60 kg with that heavy space suit on. Assuming that the tool's velocity when thrown is 30 km/h, we get the following:

$$V = -\frac{1\ \text{kg}}{60\ \text{kg}} \times 30\ \text{km/h} = -0.5\ \text{km/h}$$

So that would be your velocity back to the ship.

Let's say I have a whole toolbox. If I throw tools one after another, will I move faster?

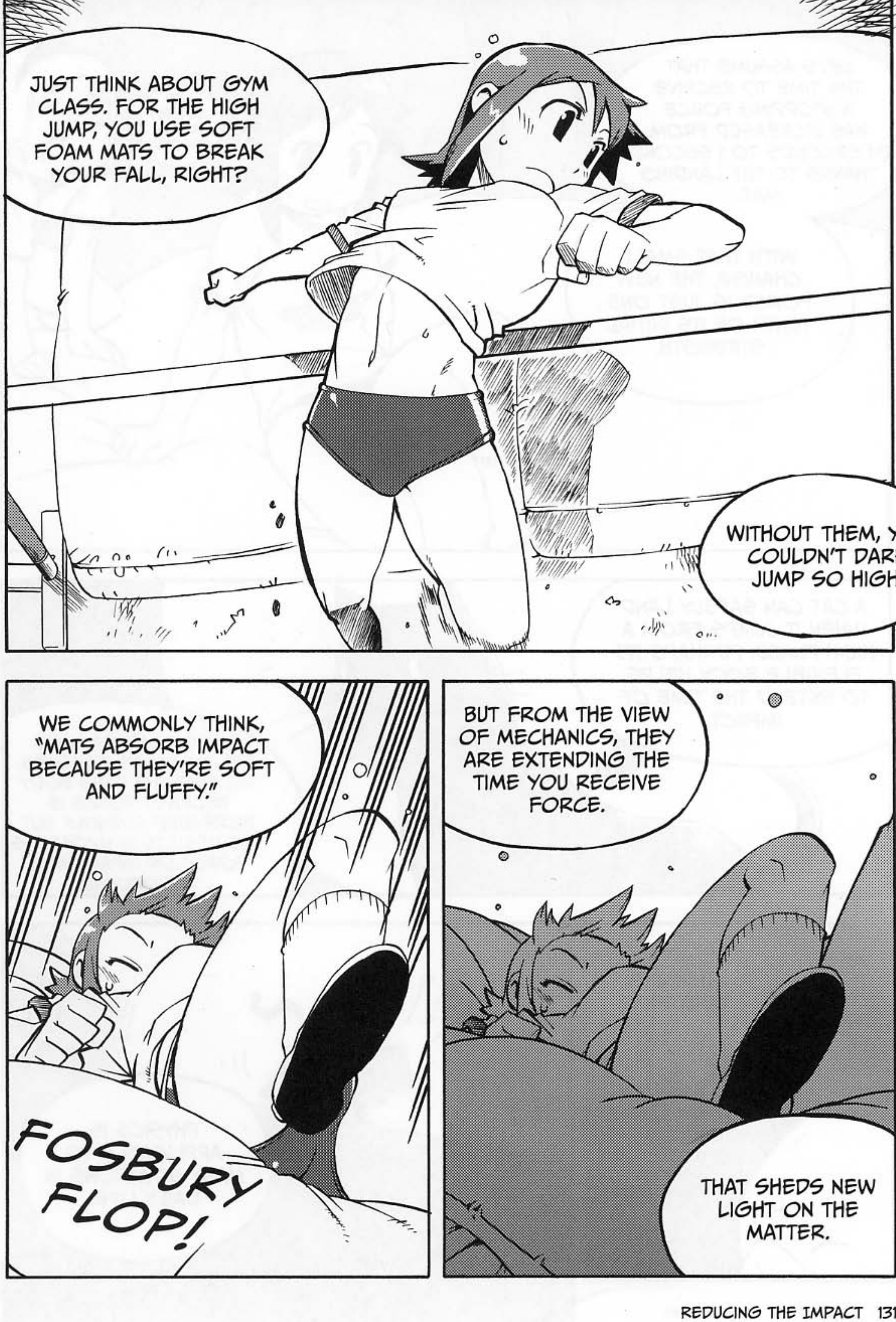
That's a great idea. Yes, you would go faster and faster that way. In fact, that's basically how a rocket moves. The exhaust that is belched out the rear of a rocket is equivalent to an object being thrown.

Gee, I never thought of it that way.

A rocket can continue to accelerate by belching exhaust continuously. As long as fuel continues to discharge, the rocket will accelerate. When the rocket stops discharging exhaust, the rocket's velocity becomes uniform.

REAL-WORLD EXPLORATIONS OF IMPULSE


YOUR CHANGE IN MOMENTUM IS FIXED—YOU CANNOT ALTER IT. HOWEVER, YOU CAN REDUCE THE FORCE ON YOUR BODY FROM THE LANDING.
REALLY? HOW WOULD I DO THAT?
YOU'D MAKE THE TIME THAT YOU RECEIVE THE FORCE FROM THE GROUND AS LARGE AS POSSIBLE.
TIME
THAT SOUNDS PRETTY SIMPLE.
APPLYING THE LAW OF Δp = IMPULSE, WE GET CHANGE IN MOMENTUM ($m \times \Delta v$) EQUALS FORCE MULTIPLIED BY THE TIME. NOW, TIME IN THIS CASE IS THE TIME THAT YOU'RE RECEIVING FORCE.
THIS EQUATION CAN BE REWRITTEN AS: $F = \frac{m \times \Delta v}{t}$
THAT MEANS THE LARGER THE t VALUE, THE SMALLER THE F VALUE YOU RECEIVE.
I SEE!


JUST THINK ABOUT GYM CLASS. FOR THE HIGH JUMP, YOU USE SOFT FOAM MATS TO BREAK YOUR FALL, RIGHT?
WITHOUT THEM, YOU COULDN'T DARE JUMP SO HIGH.
WE COMMONLY THINK, "MATS ABSORB IMPACT BECAUSE THEY'RE SOFT AND FLUFFY."
FOSBURY FLOP!
BUT FROM THE VIEW OF MECHANICS, THEY ARE EXTENDING THE TIME YOU RECEIVE FORCE.
THAT SHEDS NEW LIGHT ON THE MATTER.


LET'S ASSUME THAT THE TIME TO RECEIVE A STOPPING FORCE HAS INCREASED FROM 0.1 SECONDS TO 1 SECOND, THANKS TO THE LANDING MAT.
WITH THAT SMALL CHANGE, THE NEW FORCE IS JUST ONE TENTH OF ITS INITIAL STRENGTH.
YOU JUST SET A NEW RECORD!
A CAT CAN SAFELY LAND WHEN IT JUMPS FROM A HIGH PLACE. PERHAPS ITS FLEXIBLE BODY HELPS TO EXTEND THE TIME OF IMPACT.
THAT'S RIGHT. BECAUSE THE CAT BENDS ITS LIMBS, THE TIME THE CAT'S BODY RECEIVES FORCE IS INCREASED SLIGHTLY. BUT THIS RESULTS IN MUCH LESS FORCE ON IMPACT WITH THE GROUND.
THINKING LIKE THIS...
MROW
PHYSICS IS APPLICABLE TO MANY SITUATIONS IN DAILY LIFE.


NOW...
IMPROVING MEGUMI'S SERVE
WE KNOW ABOUT THE RELATIONSHIP BETWEEN THE CHANGE OF MOMENTUM AND IMPULSE.
YES, I HOPE YOU UNDERSTAND THIS.
THAT MEANS I CAN APPLY IT TO MY TENNIS GAME!
I SEE.
RECALL HOW WE EXAMINED THE MOMENTUM OF A STROKE.
YES!
HERE SHE GOES!
GIVEN THE IMPORTANCE OF CHANGING A BALL'S MOMENTUM, I WANT TO FIND OUT A BETTER WAY TO SERVE!
THE FATAL SERVICE OF MEGUMI NINOMIYA THAT COULD SMASH AN ELEPHANT!
GRRRR
IS THAT REALLY THE KIND OF SERVE YOU WANT TO DELIVER?
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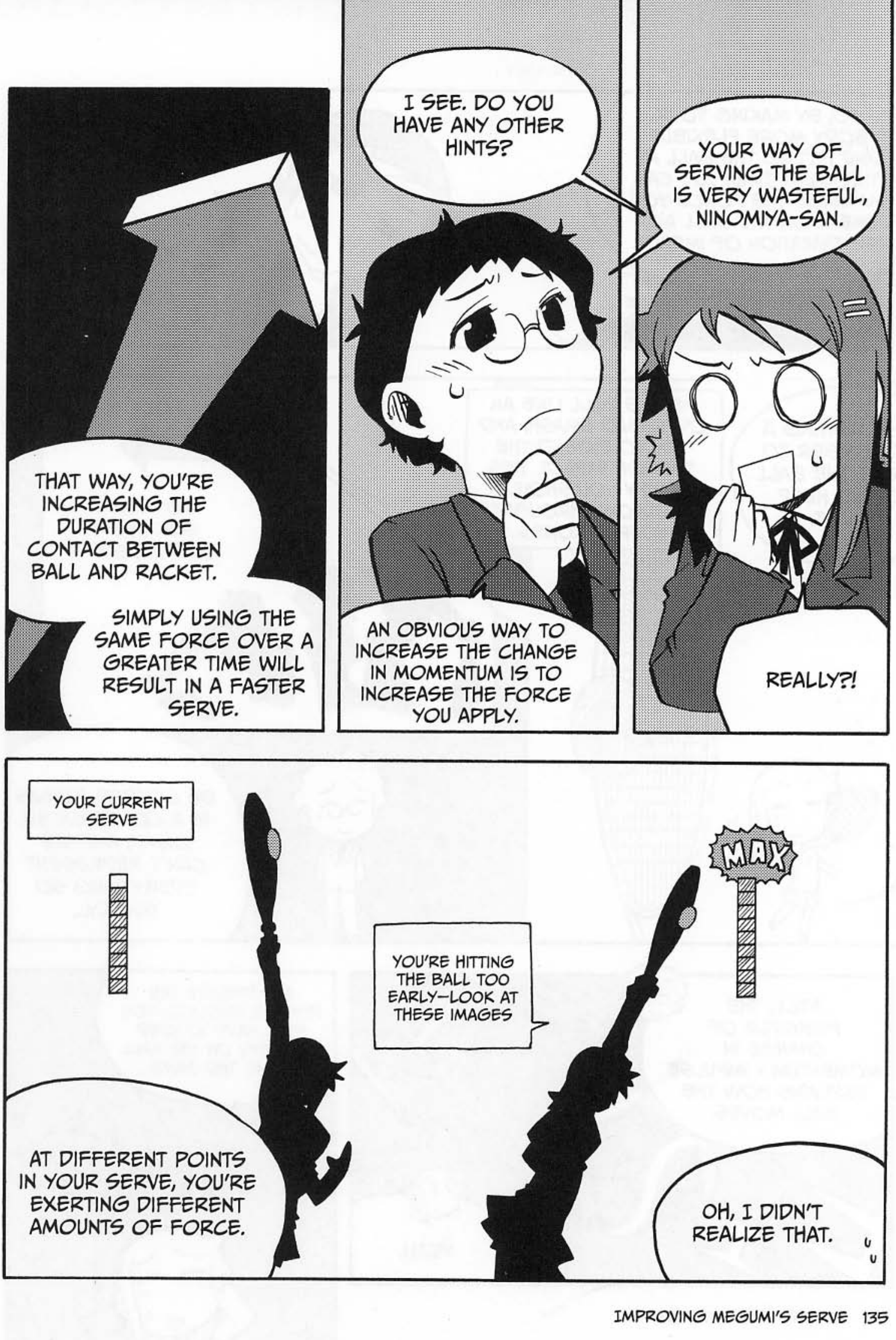
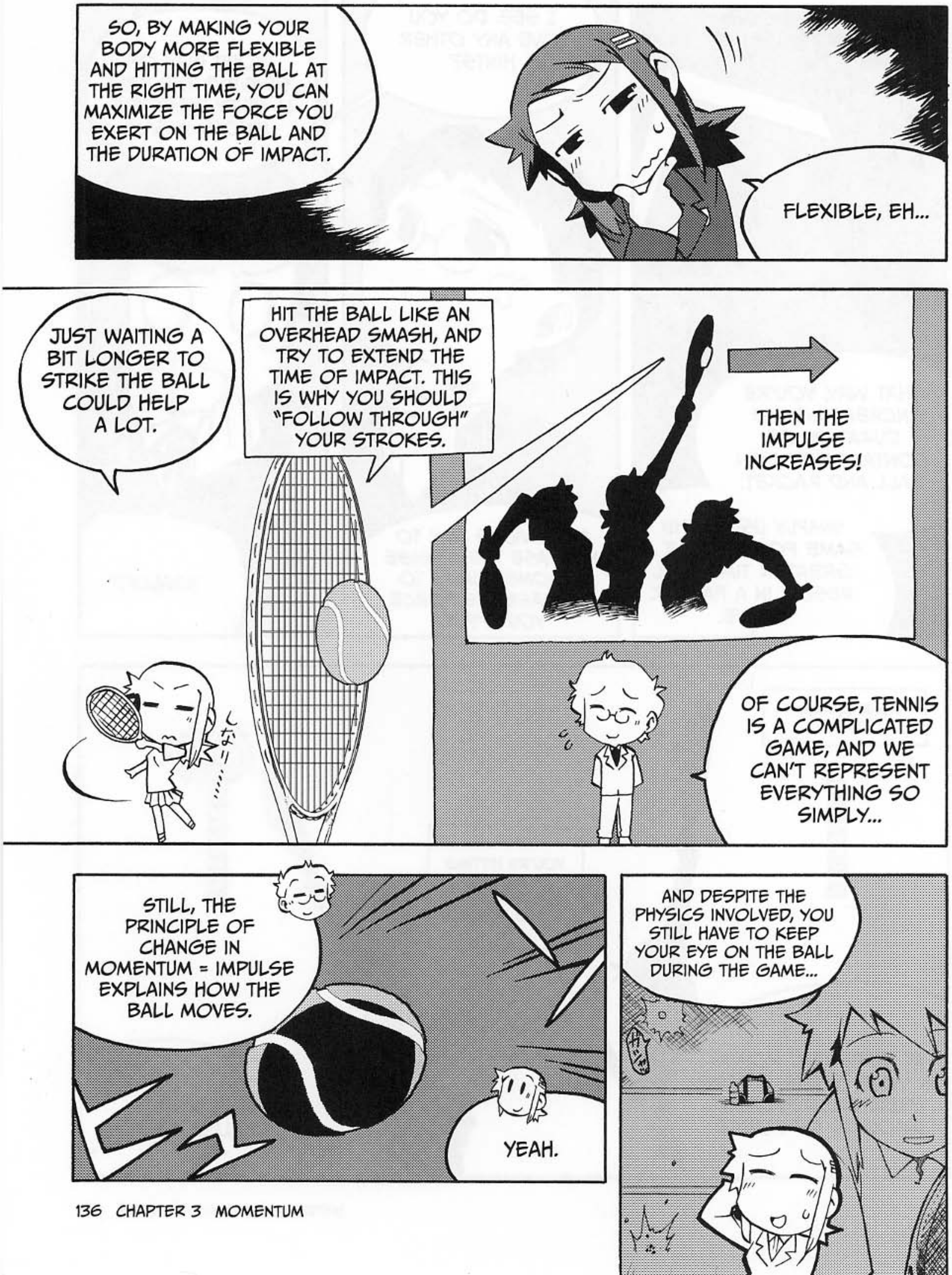
WELL, IF THAT'S THE CASE, WE SHOULD TALK ABOUT YOUR MATCH WITH SAYAKA. YOU TWO ARE EVENLY MATCHED AND SEEM TO HAVE THE SAME PHYSICAL STRENGTH.
BUT KODA-SAN WAS USING THE SPRING OF HER BODY WHILE SHE SERVED. HER SERVE IS MUCH MORE POWERFUL THAN YOUR OWN.
ARE YOU SAYING I'M NOT AS GOOD AS SAYAKA?
I JUST MEAN THAT'S ONE AREA TO IMPROVE. YEOW!
ALL RIGHT THEN. I'LL EXAMINE MY SERVE IN THE CONTEXT OF MECHANICS.
SOUNDS GOOD TO ME.
PUFF
PUFF
PUFF
WELL, WE KNOW THAT CHANGE IN MOMENTUM EQUALS FORCE MULTIPLIED BY TIME, SO ONE IDEA FOR IMPROVING YOUR SERVE...
IS TO IMPOSE A FORCE ON THE BALL FOR AS LONG AS POSSIBLE.
WE'RE OFTEN TOLD TO HIT THE BALL WITH ALL OUR MIGHT!


I SEE. DO YOU HAVE ANY OTHER HINTS?
YOUR WAY OF SERVING THE BALL IS VERY WASTEFUL, NINOMIYA-SAN.
THAT WAY, YOU'RE INCREASING THE DURATION OF CONTACT BETWEEN BALL AND RACKET.
SIMPLY USING THE SAME FORCE OVER A GREATER TIME WILL RESULT IN A FASTER SERVE.
AN OBVIOUS WAY TO INCREASE THE CHANGE IN MOMENTUM IS TO INCREASE THE FORCE YOU APPLY.
REALLY?!
YOUR CURRENT SERVE
MAX
YOU'RE HITTING THE BALL TOO EARLY—LOOK AT THESE IMAGES
AT DIFFERENT POINTS IN YOUR SERVE, YOU'RE EXERTING DIFFERENT AMOUNTS OF FORCE.
OH, I DIDN'T REALIZE THAT.


SO, BY MAKING YOUR BODY MORE FLEXIBLE AND HITTING THE BALL AT THE RIGHT TIME, YOU CAN MAXIMIZE THE FORCE YOU EXERT ON THE BALL AND THE DURATION OF IMPACT.
FLEXIBLE, EH...
JUST WAITING A BIT LONGER TO STRIKE THE BALL COULD HELP A LOT.
HIT THE BALL LIKE AN OVERHEAD SMASH, AND TRY TO EXTEND THE TIME OF IMPACT. THIS IS WHY YOU SHOULD "FOLLOW THROUGH" YOUR STROKES.
THEN THE IMPULSE INCREASES!
OF COURSE, TENNIS IS A COMPLICATED GAME, AND WE CAN'T REPRESENT EVERYTHING SO SIMPLY...
STILL, THE PRINCIPLE OF CHANGE IN MOMENTUM = IMPULSE EXPLAINS HOW THE BALL MOVES.
YEAH.
AND DESPITE THE PHYSICS INVOLVED, YOU STILL HAVE TO KEEP YOUR EYE ON THE BALL DURING THE GAME...


IN MY CASE, I DON'T THINK I HAVE THE COORDINATION TO DO THIS. BUT I THINK YOU CAN, NINOMIYA-SAN...
IT'S NICE TO HEAR THAT! THANK YOU... RYOTA!
RYO—WHAT? YOU... WHAT ON EARTH, ALL OF A SUDDEN?
YOU MUST BE ANGLING FOR SOMETHING AGAIN...!!!
EDGING AWAY
NO, NO, IT'S NOT THAT!
DON'T YOU THINK IT'S TIME WE START CALLING EACH OTHER BY OUR FIRST NAMES?
YOU CAN CALL ME MEGUMI, YOU KNOW.
THAT'S TOO MUCH FOR ME.
COME ON! DON'T BE SO SQUARE.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YOU CAN JUST CALL ME MEGU THEN. IT'S MY NICKNAME, OKAY?
COME ON, RYOTA, PLEASE?
UHHHHHM...
ANYWAY...
AHEM
NEXT SESSION, WE'LL CONCLUDE THE BASICS OF MECHANICS.
I HOPE YOU HANG IN THERE!
YES, I WILL.
...SO THE NEXT LESSON WILL BE OUR LAST.
THAT'S RIGHT.