

THE MANGA GUIDE™ TO

COMICS  
INSIDE!

# ELECTRICITY

KAZUHIRO FUJITAKI  
MATSUDA  
TREND-PRO CO., LTD.



THE MANGA GUIDE™ TO  
**ELECTRICITY**

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# CONTENTS

PREFACE.....	xi
--------------	----

## PROLOGUE

FROM ELECTOPIA, THE LAND OF ELECTRICITY.....	1
--	---

## 1

WHAT IS ELECTRICITY?.....	13
---------------------------	----

Electricity and Everyday Life.....	14
------------------------------------	----

Electrical Units .....	15
------------------------	----

Electricity in the Home .....	19
-------------------------------	----

How Electricity Works.....	25
----------------------------	----

The True Nature of Electricity.....	26
-------------------------------------	----

Current and Electrical Discharge.....	30
---------------------------------------	----

Atomic Structure and Conductivity.....	34
--	----

Static Electricity .....	36
--------------------------	----

The Triboelectric Series.....	40
-------------------------------	----

Uses of Static Electricity .....	43
----------------------------------	----

Tags on Consumer Electric Products .....	45
--	----

Voltage and Potential .....	46
-----------------------------	----

Atoms and Electrons.....	47
--------------------------	----

Static Electricity .....	49
--------------------------	----

Electrostatic Force.....	49
--------------------------	----

The Triboelectric Series.....	51
-------------------------------	----

Movement of Charge and Direction of Current.....	51
--	----

## 2

WHAT ARE ELECTRIC CIRCUITS?.....	55
----------------------------------	----

Electric Circuits in Everyday Devices .....	56
---	----

A Flashlight's Circuit .....	59
------------------------------	----

Parts of an Electric Circuit .....	61
------------------------------------	----

Ohm's Law and Methods of Connecting Electrical Components.....	67
--	----

Electric Circuits and Ohm's Law .....	68
---------------------------------------	----

Series and Parallel Connections .....	69
---------------------------------------	----

Electric Circuits and Current.....	73
------------------------------------	----

Graphical Symbols .....	73
-------------------------	----

Direct Current Circuit and Alternating Current Circuit .....	74
--	----

Ohm's Law .....	76
-----------------	----

Resistivity and Conductivity .....	77
------------------------------------	----

Effective Resistance .....	78
----------------------------	----

### 3

<b>HOW DOES ELECTRICITY WORK?</b> .....	81
Why Does Electricity Produce Heat? .....	82
Electricity and Joule Heat .....	85
How Is Heat Generated by Current?.....	87
Thermal Emission and Luminescence .....	90
Current and Magnetic Fields.....	94
Fleming's Left-Hand Rule (For DC Motors).....	98
Fleming's Right-Hand Rule (For Generators) .....	100
Joule Heat .....	104
Thermal Vibration.....	104
Electromagnetic Waves.....	106
Electricity and Magnetism .....	107
Fleming's Left-Hand Rule and Motors .....	109
Fleming's Right-Hand Rule and Electric Generators .....	110
Electricity and Coils.....	111
Coils and Electromagnetic Induction.....	111
Coils and Inductance.....	112
Coils and Alternating Current .....	113
Coils and Transformers .....	114
Capacitors.....	115
Capacitors and Alternating Current.....	115

### 4

<b>HOW DO YOU CREATE ELECTRICITY?</b> .....	117
Generators .....	118
How Does a Power Generator Create Electricity? .....	121
Batteries and Other Sources of Electricity .....	124
Chemical Cells.....	126
What Happens in a Dry Cell Battery?.....	132
Water and Fuel Cells.....	135
Anodes and Cathodes .....	138
Creating Your Own Coin Battery.....	140
Thermopiles .....	141
Electricity Created by a Power Plant.....	147
Thermal Power Generation.....	149
Nuclear Power Generation .....	151
Hydroelectric Power Generation.....	152
Wind Power Generation .....	154

<b>5</b>	
<b>HOW CAN YOU CONVENIENTLY USE ELECTRICITY?</b>	<b>155</b>
What are Semiconductors?	161
Diodes and Transistors	169
Diodes That Emit Light	174
Transistors	176
Diodes	186
Transistors	188
Field-Effect Transistor	188
Converters and Inverters	189
Sensors	190
Temperature Sensors	190
Optical Sensors	192
<b>EPILOGUE</b>	<b>197</b>
<b>INDEX</b>	<b>201</b>



# PREFACE

Our current lifestyle necessitates the use of electricity. Electric current is often explained by comparing it to flowing water, but since electricity cannot be seen by the naked eye, this metaphor can be difficult to understand. What can we do to better understand electricity?

Electricity is very helpful in almost every facet of our lives; it produces light, heat, and power. Even though we can see these benefits, we are usually unaware of electricity itself. However, if we simply learn the basics, we can get a clear picture of how electricity works.

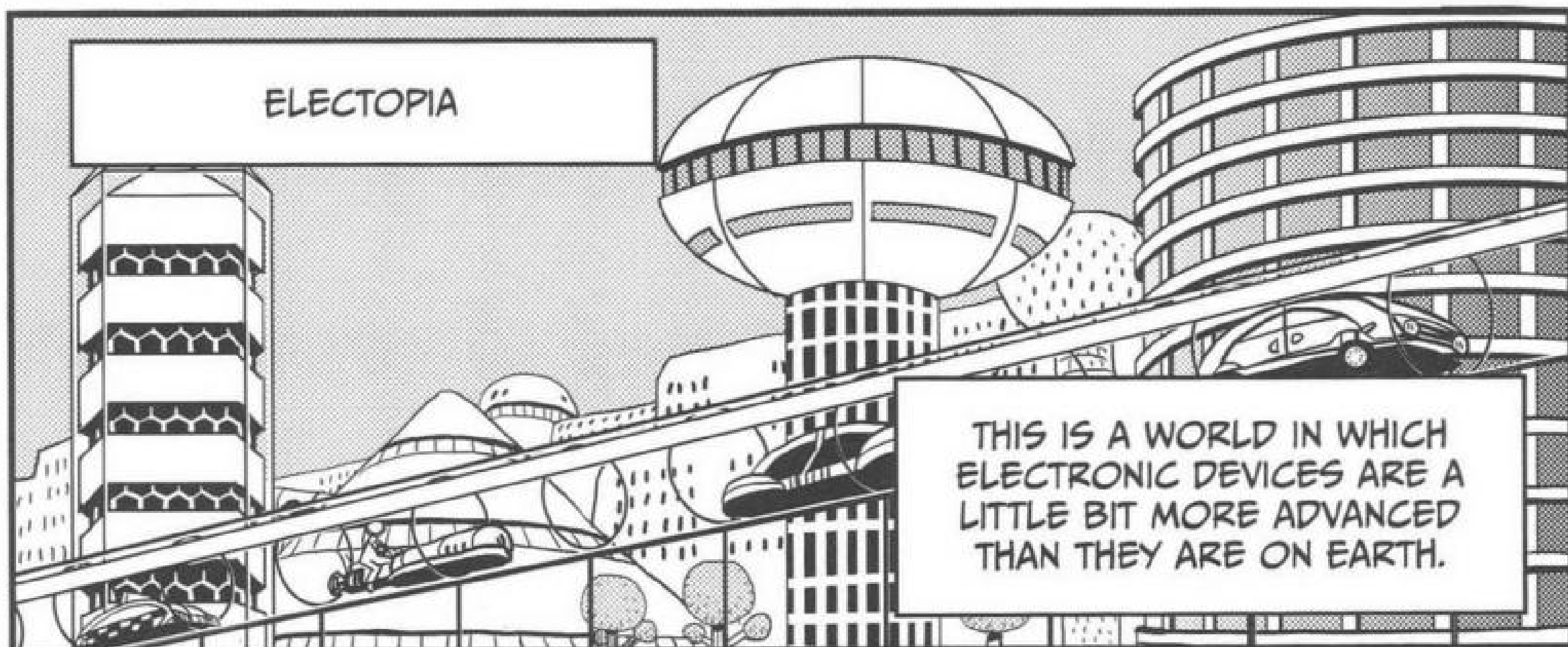
This book explains fundamental electrical concepts using a story told through manga followed by further explanations in written text. There are no complicated explanations—readers simply listen along with the heroine Rereko as her teacher Hikaru explains concepts. Even people who have had a hard time understanding electricity will find Hikaru's explanations easy to comprehend.

I am extremely grateful to Matsuda, who provided the artwork, and to everyone at TREND-PRO, who produced the book. I would also like to give my sincere thanks to Professor Masaaki Mitani for checking my work. I am also very thankful to Ohmsha, Ltd. for giving me the opportunity to write this book.

I hope that in reading this book you will learn about electricity and gain a familiarity with it.

KAZUHIRO FUJITAKI  
DECEMBER 2006





ELECTOPIA

THIS IS A WORLD IN WHICH  
ELECTRONIC DEVICES ARE A  
LITTLE BIT MORE ADVANCED  
THAN THEY ARE ON EARTH.



HOWEVER, STUDENTS  
ON ELECTOPIA HAVE  
THE SAME KINDS OF  
PROBLEMS THAT  
STUDENTS ON EARTH DO.

中央電子教育学校

\*CENTRAL  
ELECTRICAL  
TRAINING  
SCHOOL



REREKO...

DO YOU KNOW  
WHY I CALLED  
YOU IN?

中等部  
職員室

\* HIGH SCHOOL  
TEACHER'S ROOM

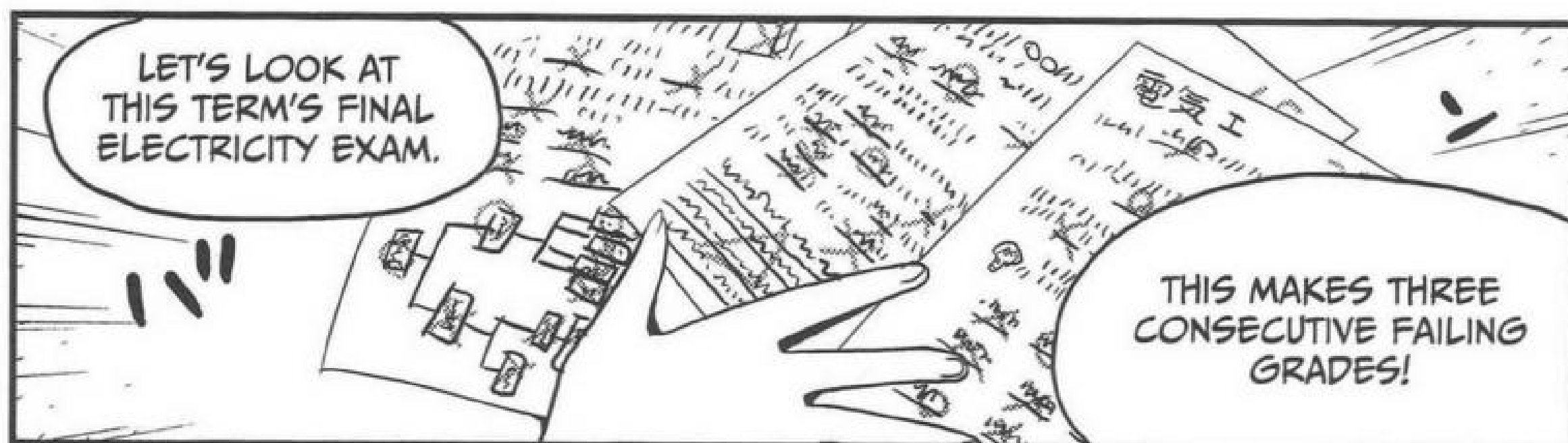
UH...UM...



WELL, I'VE NEVER  
BEEN VERY SMART...  
BUT I HONESTLY  
DON'T KNOW.

THAT'S OKAY. YOU  
ALMOST HAVE THE  
RIGHT ANSWER.





B...B...BUT...IF I SUDDENLY  
SHOW UP, IT'LL PROBABLY  
BE INCONVENIENT FOR THE  
TEACHER THERE.

B...B...BUT, BUT...MY PARENTS  
HAVEN'T GIVEN PERMISSION  
FOR ME TO GO YET, RIGHT?

I ALREADY SENT  
A LETTER, SO  
IT'LL BE FINE.

THEY SAID,  
"GO FOR IT!"

YOU! A SMART WOMAN  
LIKE YOU NEVER MAKES  
A MISTAKE, DO YOU?

WHAT IS IT?  
A ROBOT?

IT'S  
YONOSUKE, A  
TRANSDIMENSIONAL  
WALKIE-TALKIE AND  
OBSERVATION ROBOT!

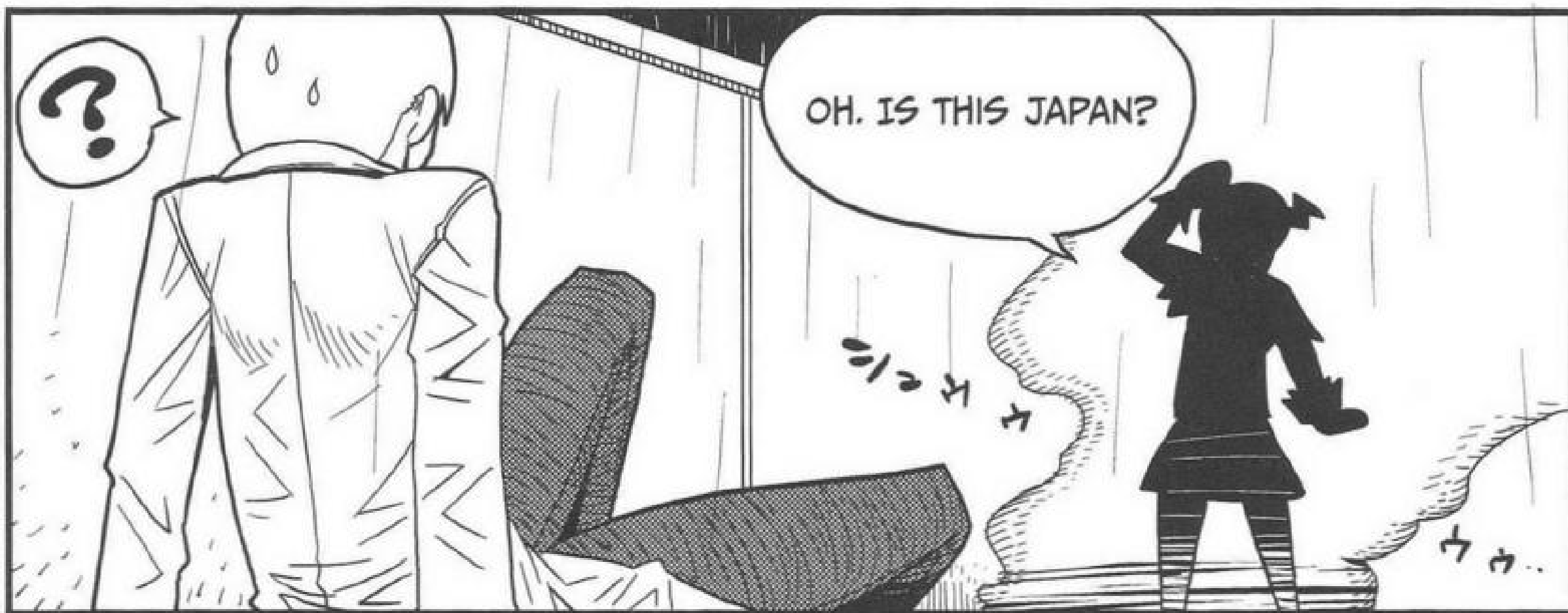
TAKE GOOD CARE OF HIM! YOU'LL  
ALSO USE HIM INSTEAD OF A  
PASSPORT WHEN GOING BACK  
AND FORTH TO EARTH.

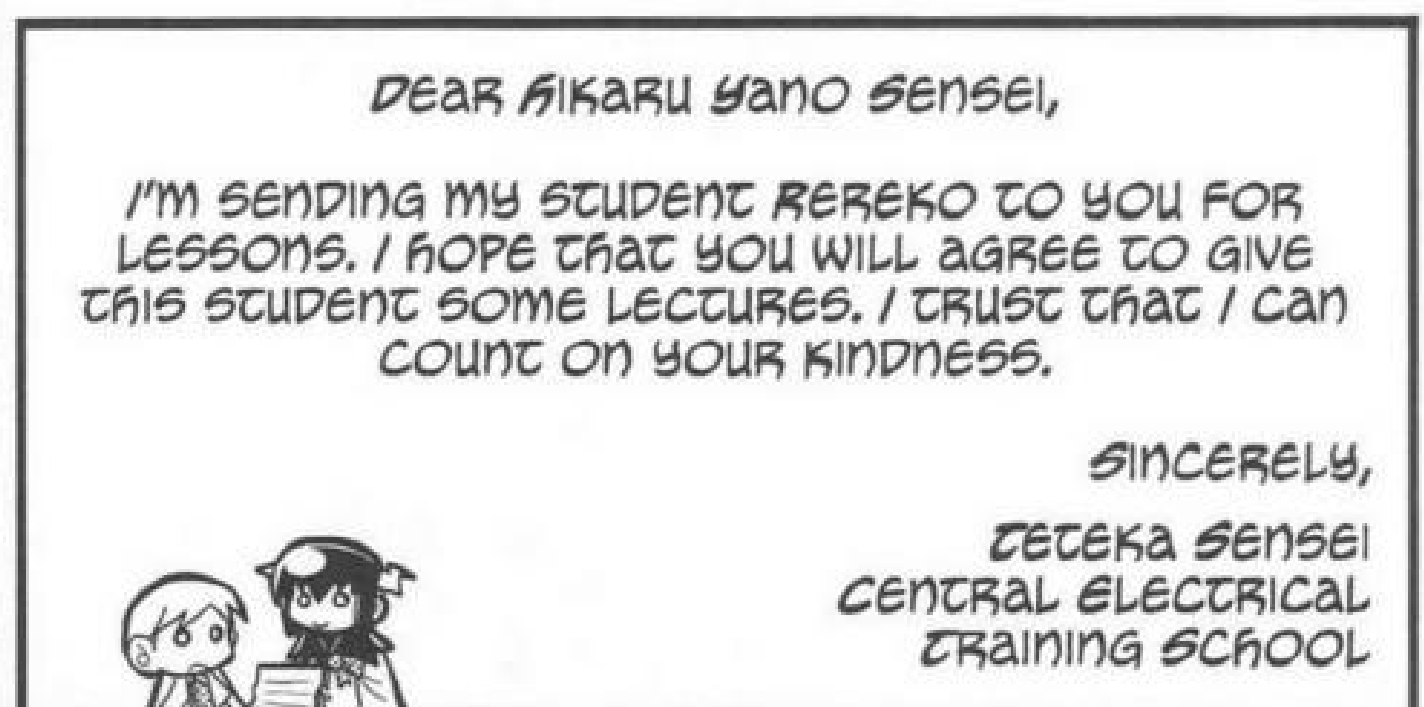
NICE TO  
MEET YOU.

TAKE THIS  
WITH YOU FOR  
LATER.







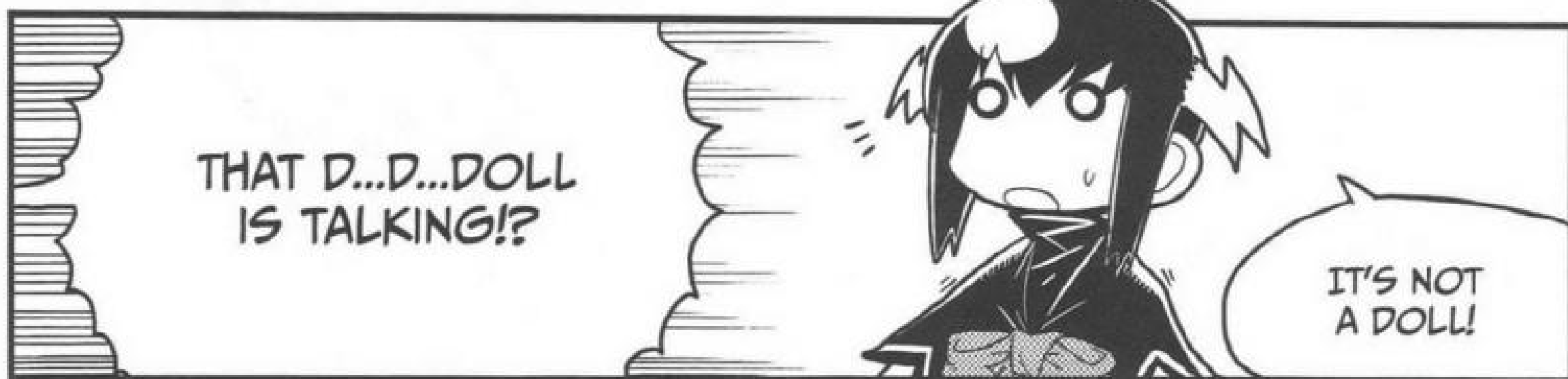
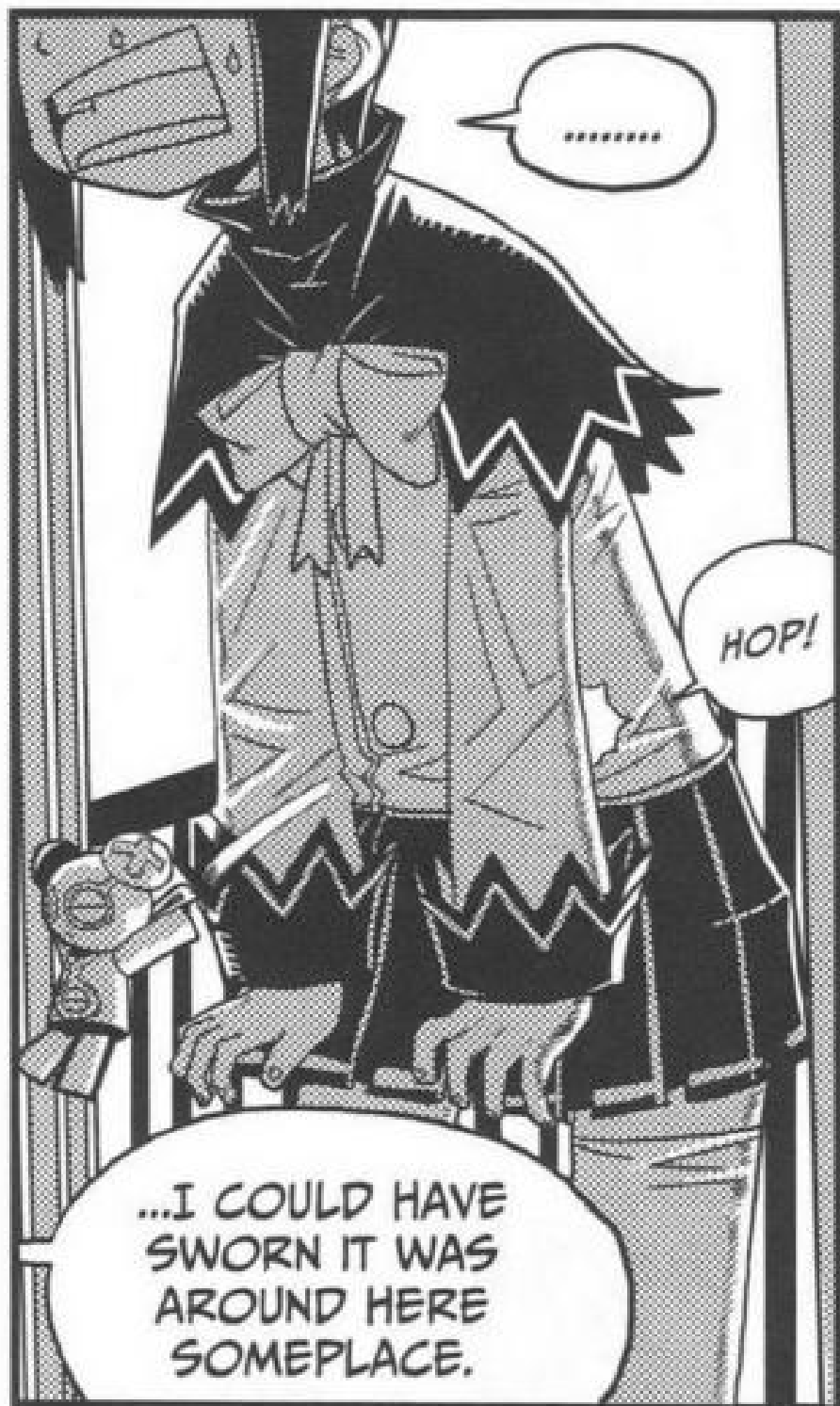




...AT HIKARU'S APARTMENT







30  
MINUTES  
LATER...

YOU CAME  
HERE TO STUDY  
FROM ANOTHER  
WORLD.

SINCE THE STUDY OF  
ELECTRICITY IS THOUGHT  
TO BE SO IMPORTANT,  
EVEN KIDS IN MY GRADE  
MUST KNOW THE BASICS.  
BUT ACTUALLY, I'M...  
WHAT CAN I SAY? I'M...

A LOSER!!

네= 네= 네=

**FWAP!**

SO, BY TAKING  
EXTRA CLASSES  
HERE, YOU'LL TRY  
TO MAKE UP FOR  
THE AMOUNT YOU'VE  
FALLEN BEHIND?

TETKA SENSEI IS VERY KNOWLEDGEABLE ABOUT THIS WORLD.

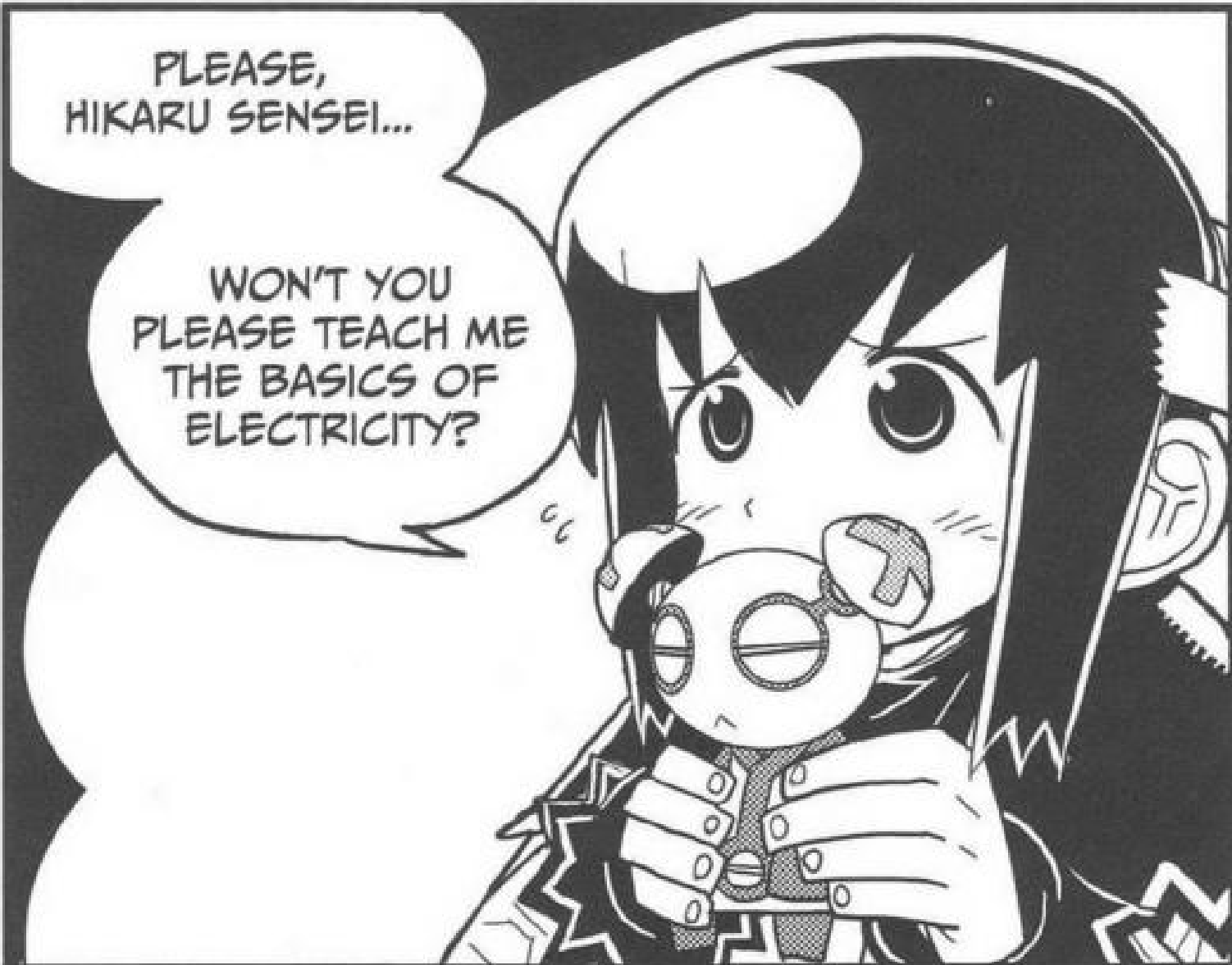
THEREFORE, I'M SURE  
THAT YOU ARE WELL  
QUALIFIED TO TEACH ME,  
SENSEI.



I WOULDN'T BE  
SO SURE ABOUT  
THAT...

PLEASE,  
HIKARU SENSEI...

WON'T YOU  
PLEASE TEACH ME  
THE BASICS OF  
ELECTRICITY?



SINCE I GAVE UP MY  
SUMMER VACATION TO  
COME HERE, I WON'T BE  
ABLE TO RETURN UNLESS  
I FINISH THESE EXTRA  
CLASSES...



I KNOW, BUT...  
I'VE GOT RESEARCH  
TO DO, AND...



WELL, HOW  
ABOUT THIS—



AS YOU CAN SEE, MY  
ROOM IS A LITTLE  
MESSY, RIGHT?



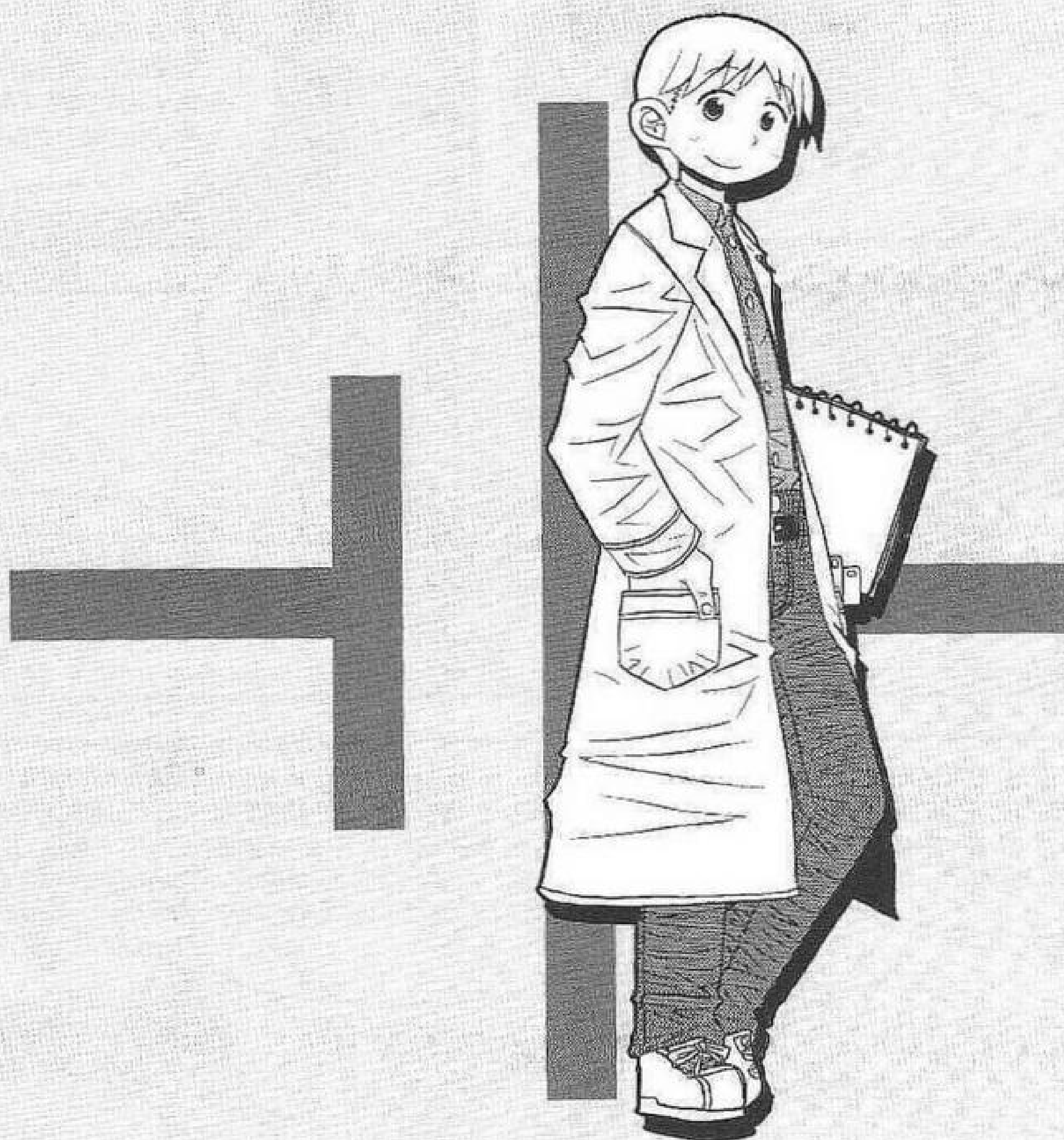
A LITTLE!?

QUI...QUITE MESSY,  
OKAY?



1

# WHAT IS ELECTRICITY?

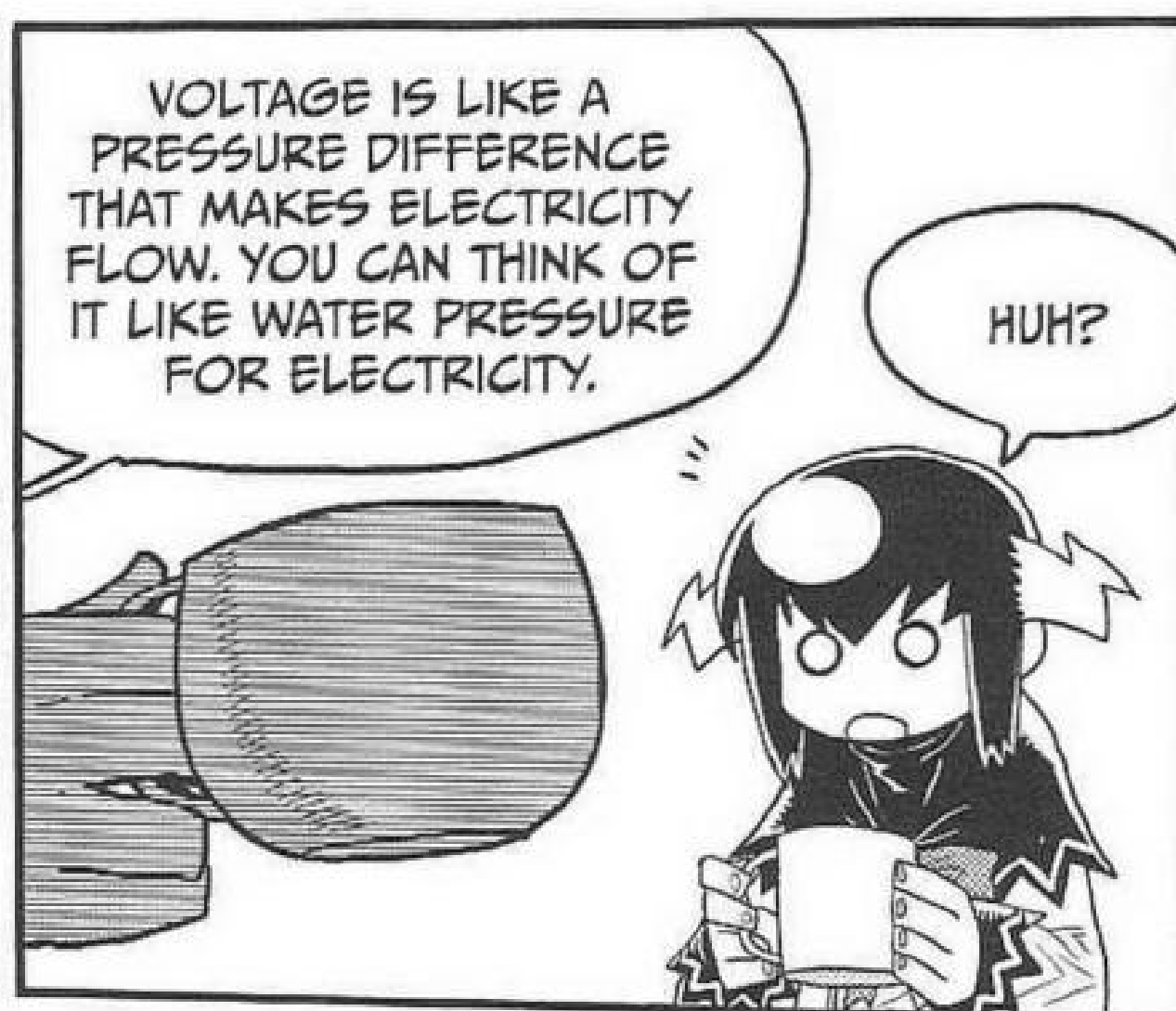
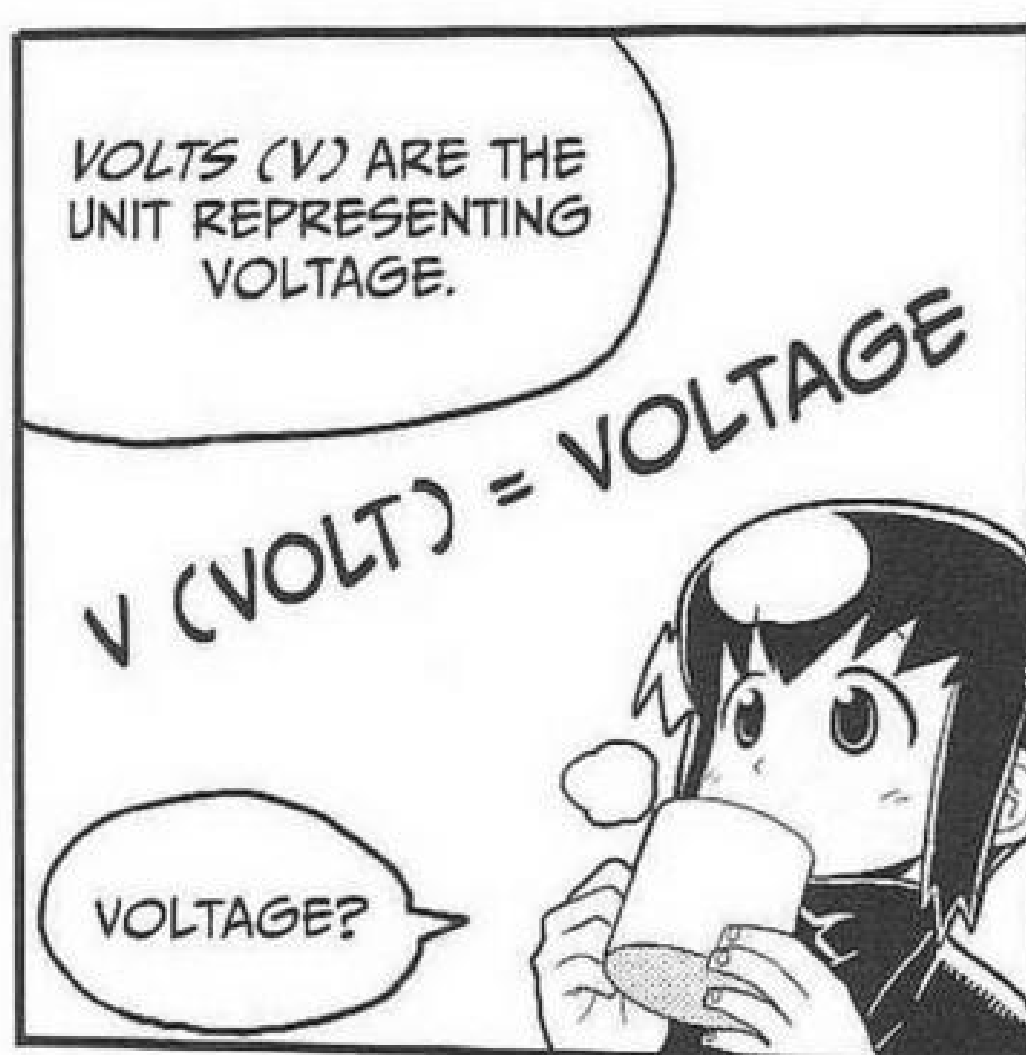
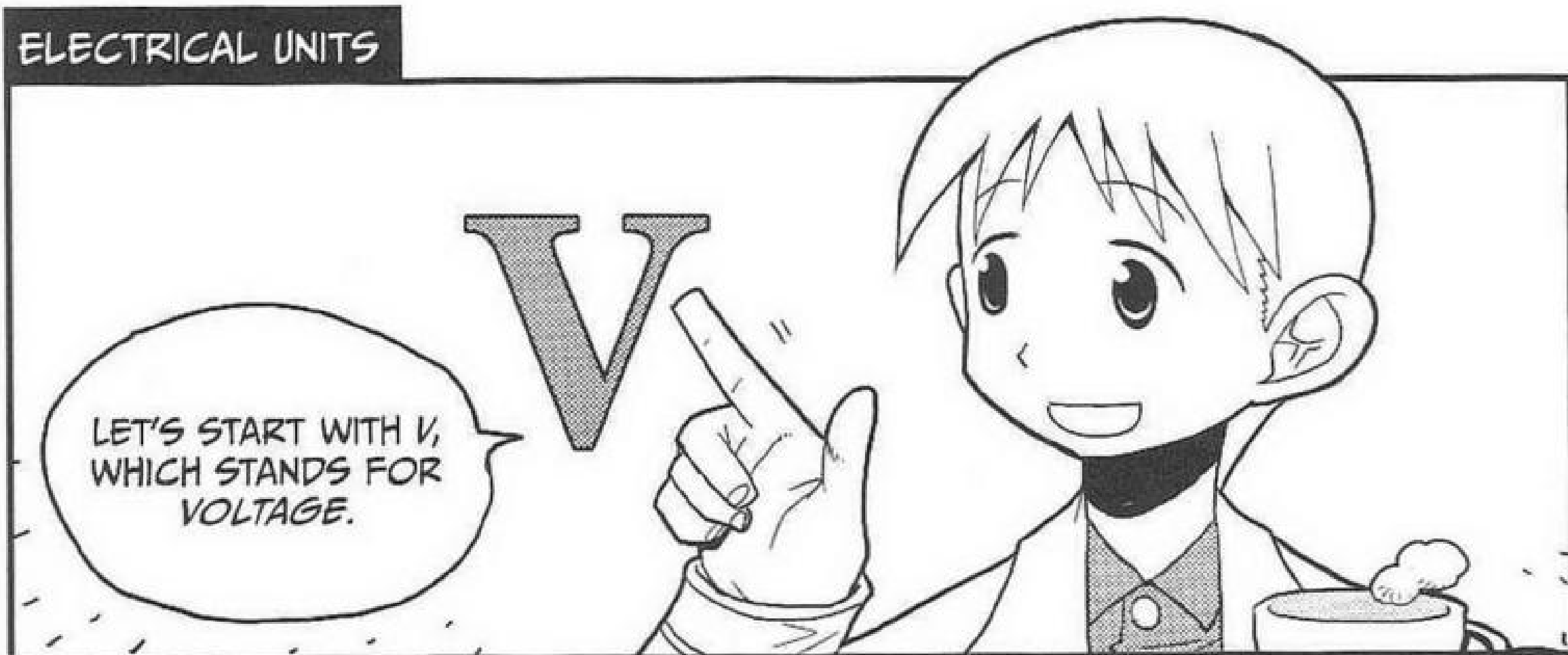


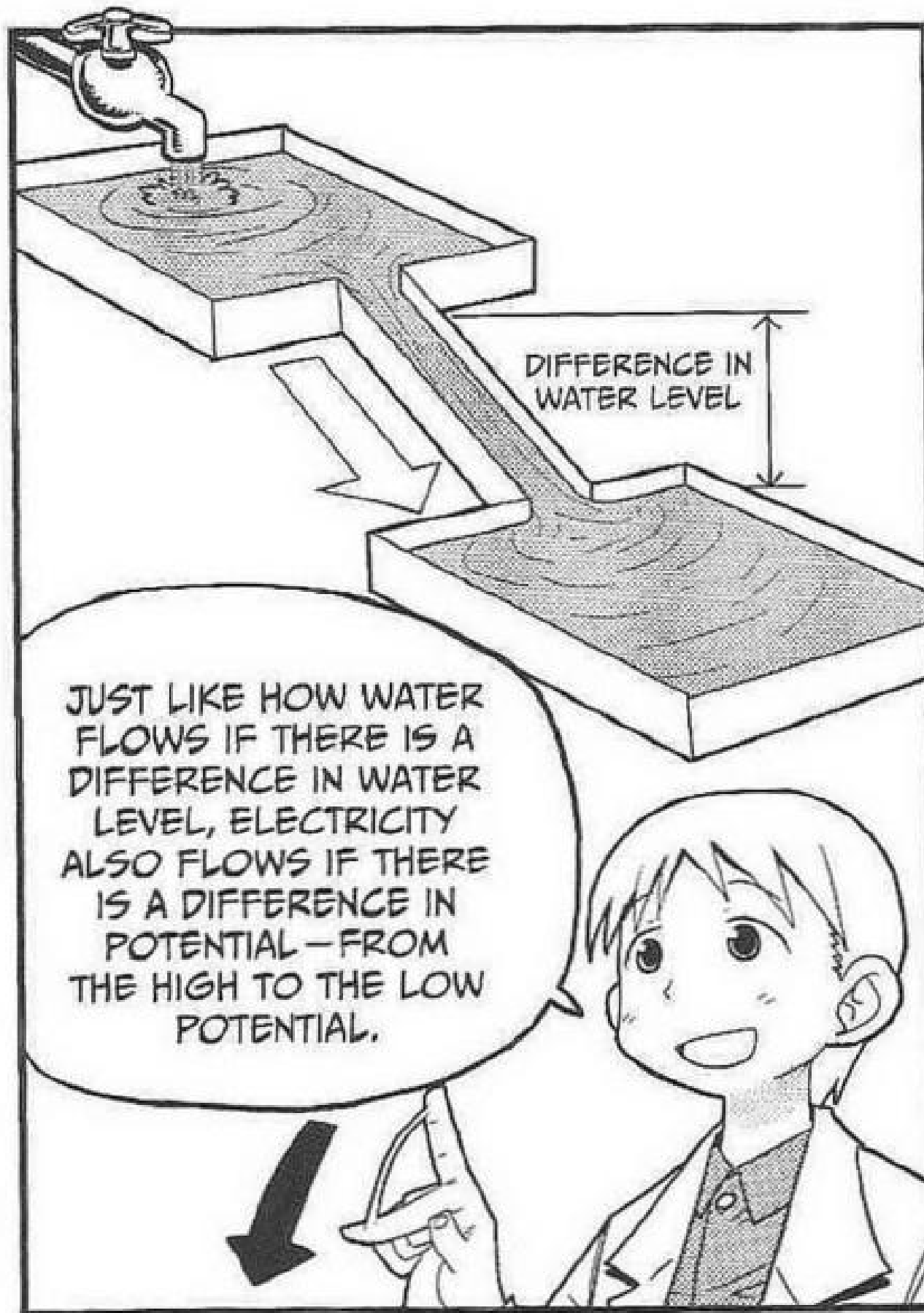


# ELECTRICITY AND EVERYDAY LIFE









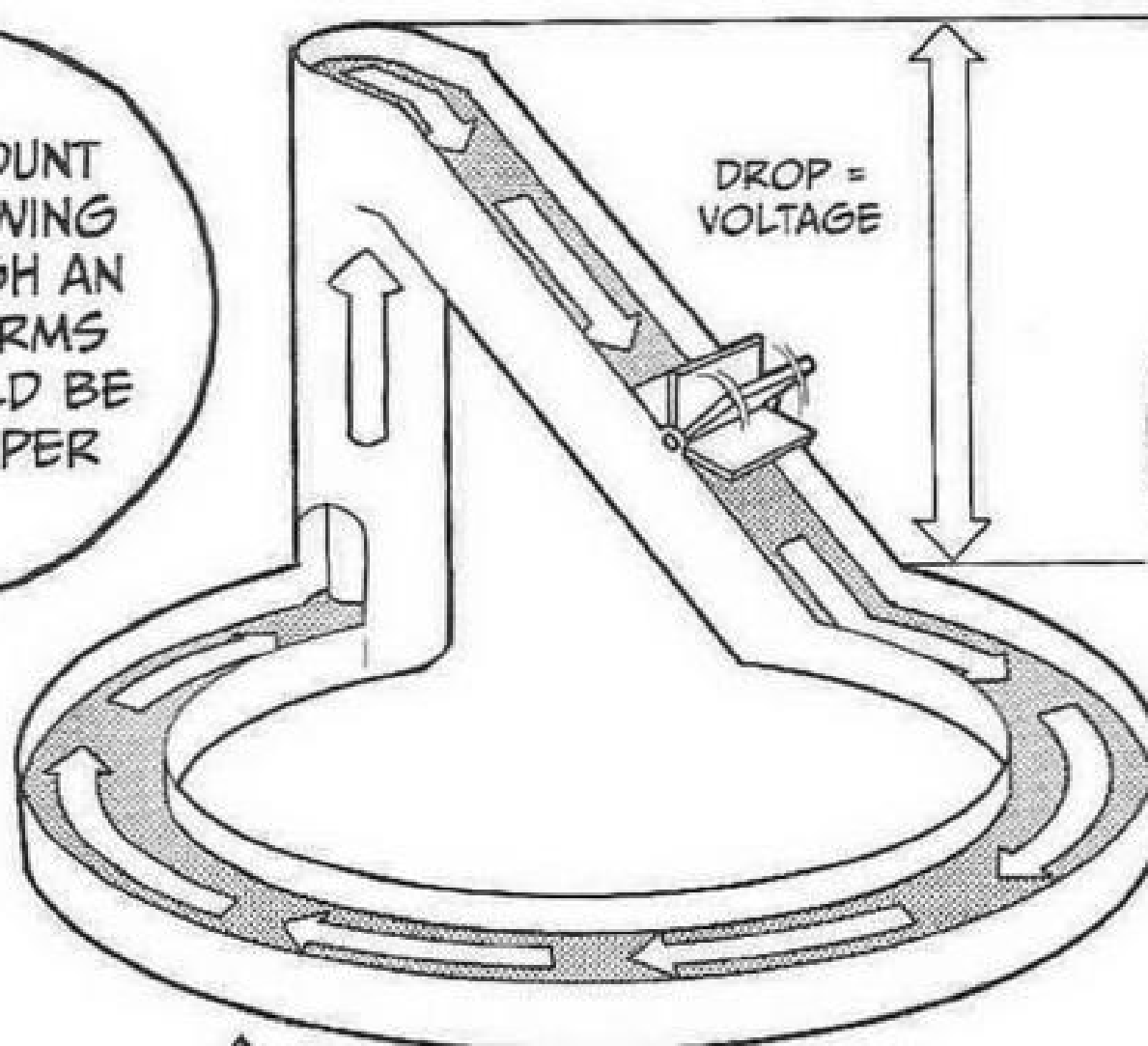
VOLTAGE IS THE DIFFERENCE IN POTENTIAL BETWEEN TWO POINTS.

DIFFERENCE IN WATER LEVEL =  
DIFFERENCE IN POTENTIAL =  
VOLTAGE

ON THE OTHER HAND, A (AMPERE OR AMP FOR SHORT) IS THE UNIT REPRESENTING ELECTRIC CURRENT.

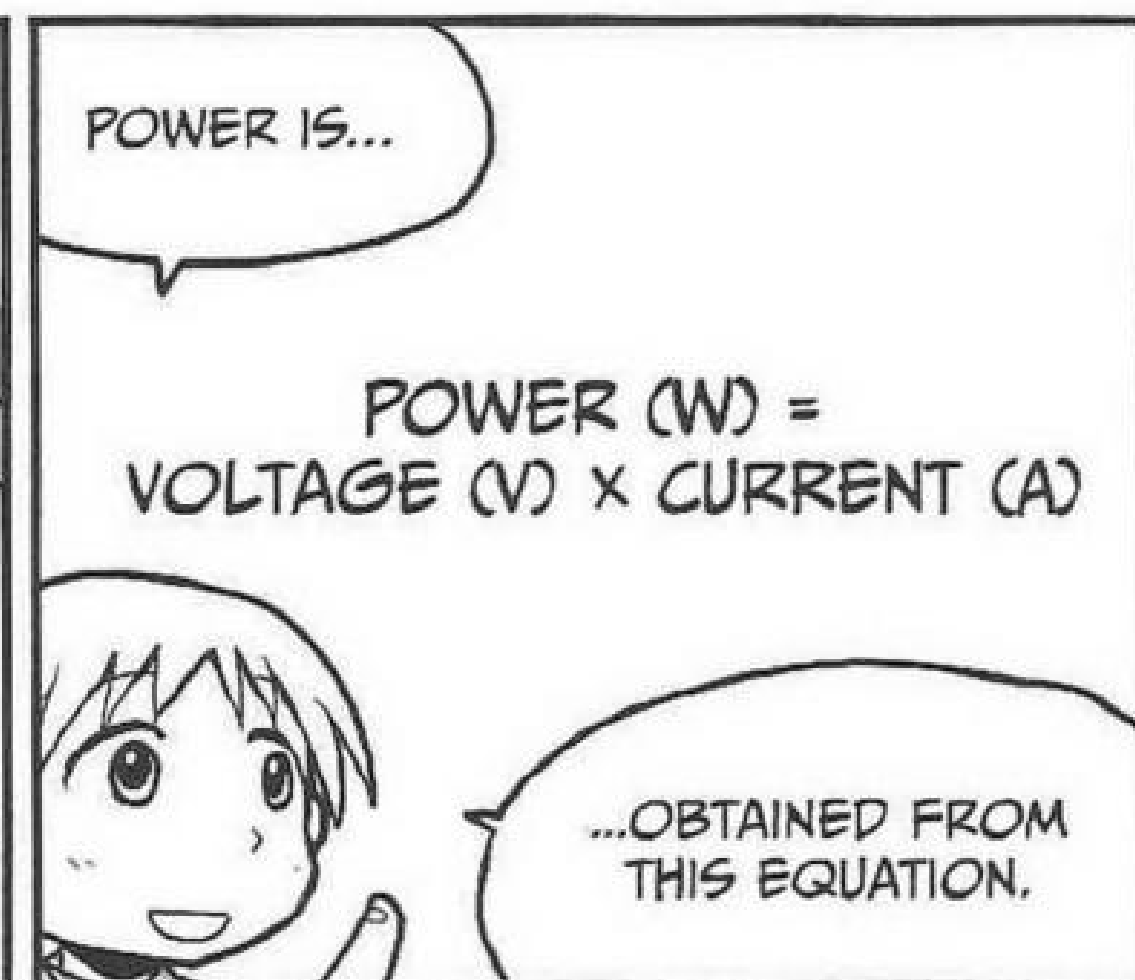
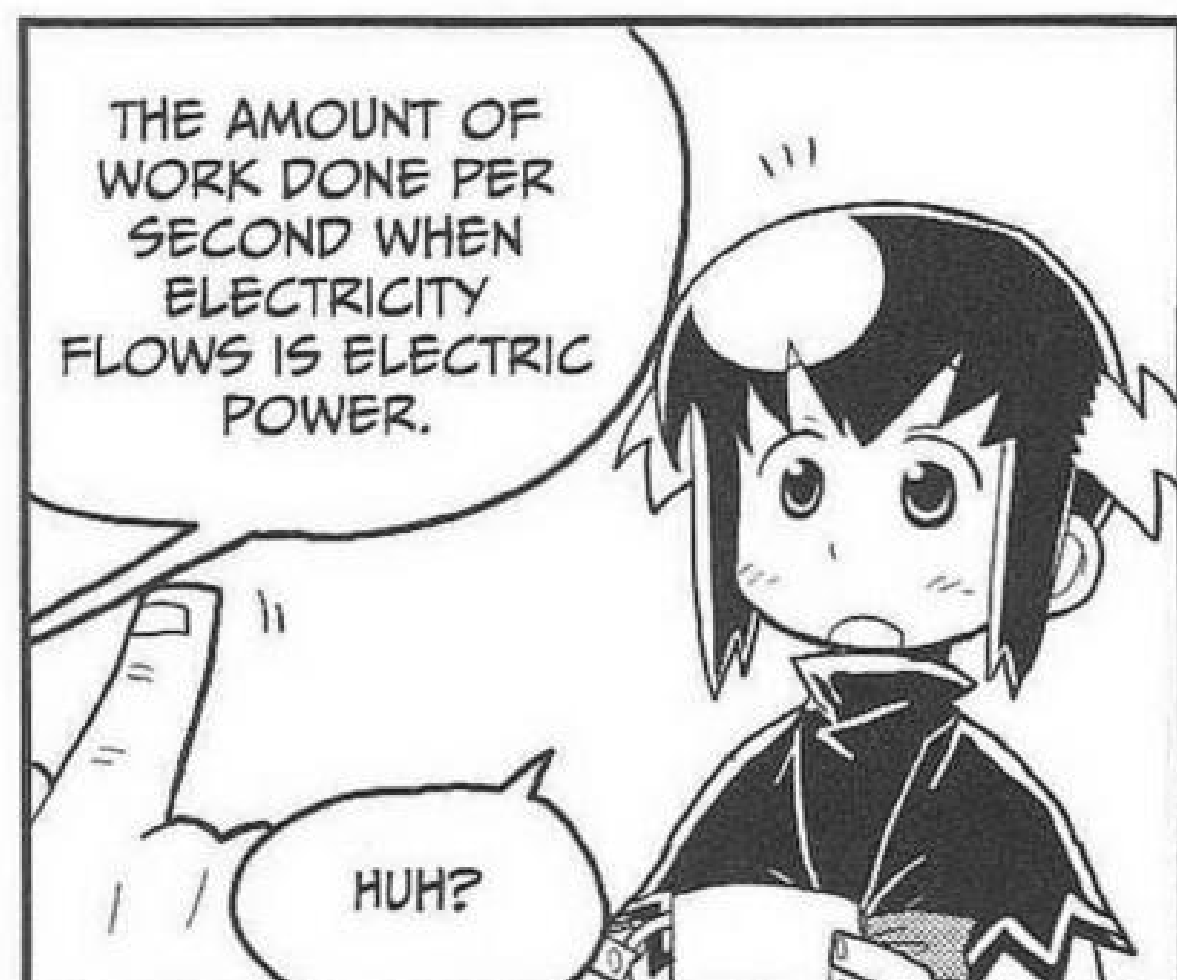
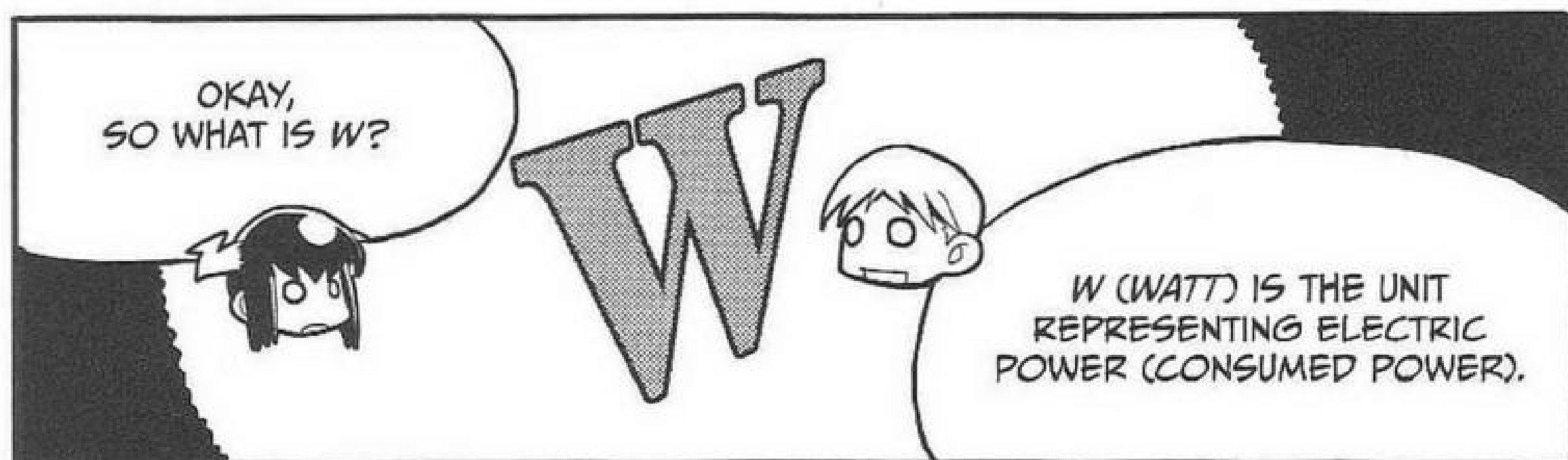
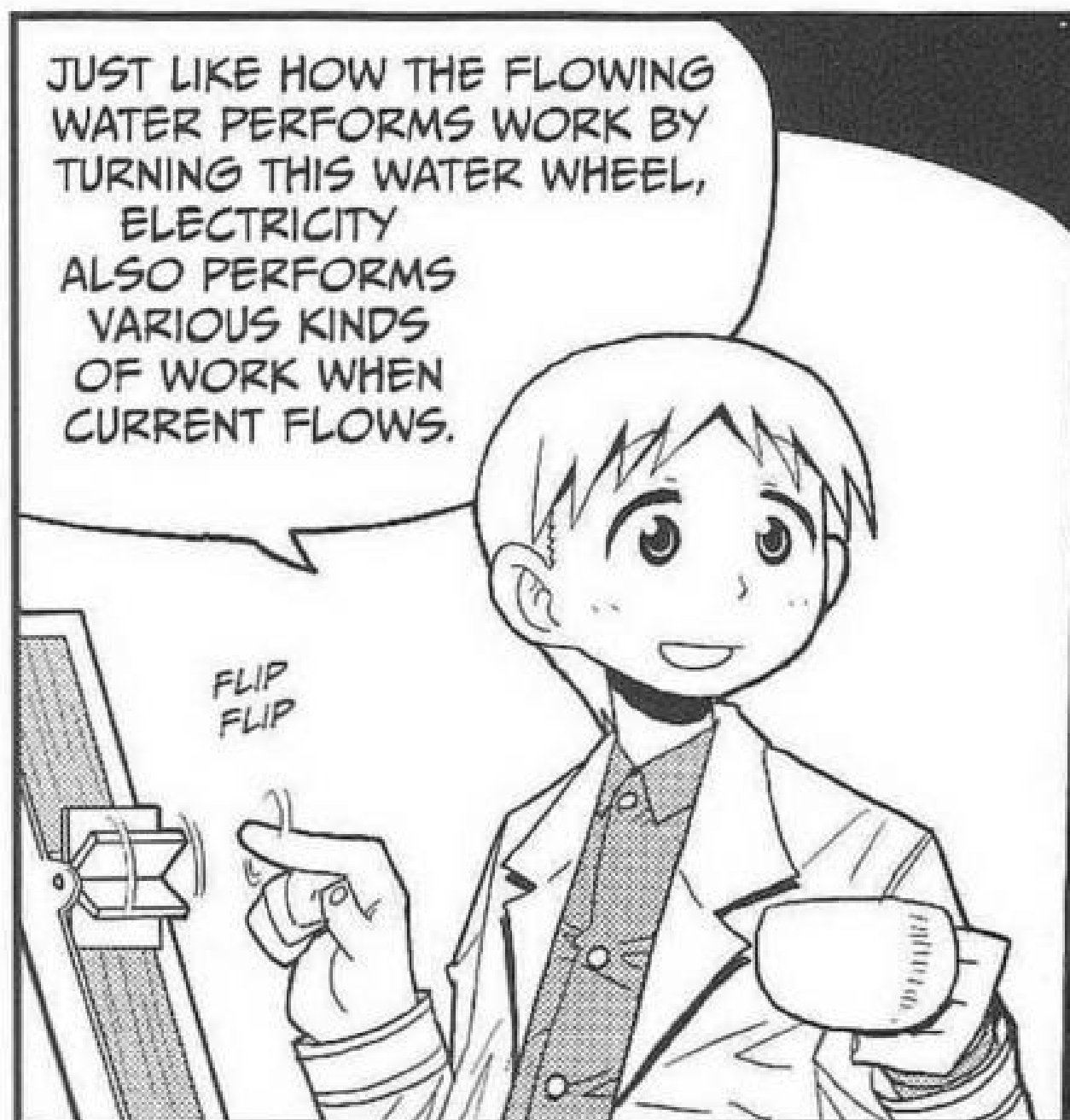
A

CURRENT IS THE AMOUNT OF ELECTRICITY FLOWING PER SECOND THROUGH AN ELECTRIC LINE. IN TERMS OF WATER, THIS WOULD BE THE WATER VOLUME PER SECOND.



THIS MAKES ME WANT TO EAT NAGASHI SOMEN—FLOWING NOODLES!





SINCE WE CAN REWRITE  
THIS EQUATION AS

$$\text{CURRENT (A)} = \frac{\text{POWER (W)}}{\text{VOLTAGE (V)}}$$

...WE CAN ALSO EASILY  
FIND THE CURRENT.

FOR THIS  
ELECTRIC TEA  
KETTLE...

...WE HAVE

$$\frac{1000\text{W}}{100\text{V}} = 10\text{A}$$

DON'T WE?

THAT'S RIGHT!

電気使用量のお知らせ

〒100-0001 東京都千代田区千代田

0年0月分

ご使用量 310kWh

請求予定金額 58円

基本料金	1.70円
電圧1段料金	1.70円
電力2段料金	3.50円
電力3段料金	2.10円
11kV料金調整	5.00円
電化所用住宅割引額	16.00円
口座振替手数料	5.00円
消費税等相当額	3.07円
グリーン電力料金	5.00円

契約種別 従量電灯B

契約 30A

当月基本料金 14.21円

前月基本料金 11.11円

当月基本料金 3.00円

当月基本料金 3.00円

00000-00000-000

NOW LET'S LOOK AT ENERGY.  
THE MONTHLY ELECTRIC BILL HAS  
THE UNIT KWH (KILOWATT HOUR)  
REPRESENTING THE AMOUNT OF  
ELECTRIC ENERGY A HOUSEHOLD  
USES...

YUP...  
I SEE IT!

THIS CAN BE OBTAINED BY  
MULTIPLYING POWER AND  
USAGE TIME.



FOR EXAMPLE, IF A  
1200W APPLIANCE IS  
USED FOR 2 HOURS,  
HOW MANY KILOWATT  
HOURS WOULD  
THAT BE?



UM...1200 TIMES 2

IS 2400, ISN'T IT?

$1200W \times 2 \text{ HOURS} = 2400WH = 2.4KWH$

RIGHT, IT'S 2400WH (WATT HOURS).  
SO THAT'S 2.4KWH.

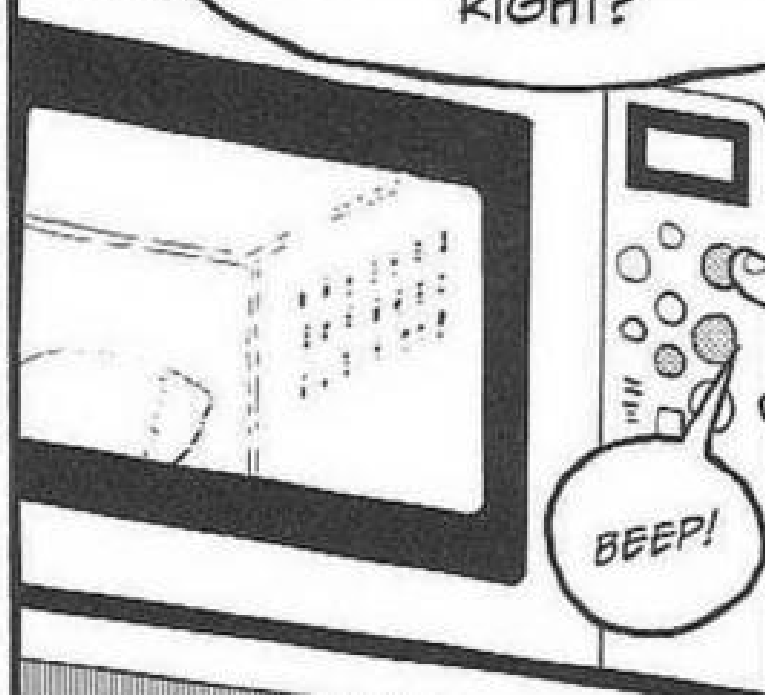
IF YOU KNOW THIS, YOU  
CAN FIGURE OUT THE  
ELECTRICAL UTILITY  
CHARGES FOR ANY  
APPLIANCE.



IF 1KWH COSTS 20 YEN,  
RUNNING THE TEA KETTLE  
FOR 2 HOURS (2.4KWH)  
WILL COST 48 YEN!

## ELECTRICITY IN THE HOME

YOU KNOW  
THAT IF SEVERAL ELECTRONIC  
APPLIANCES THAT CONSUME  
A LARGE AMOUNT OF POWER  
ARE USED AT THE SAME TIME,  
THE CIRCUIT BREAKER MAY  
TRIP AND "BLOW A FUSE,"  
RIGHT?



YEAH!



WELL, WHY DOES THE  
BREAKER TRIP, AND WHAT  
CAN WE DO TO PREVENT IT  
FROM HAPPENING?

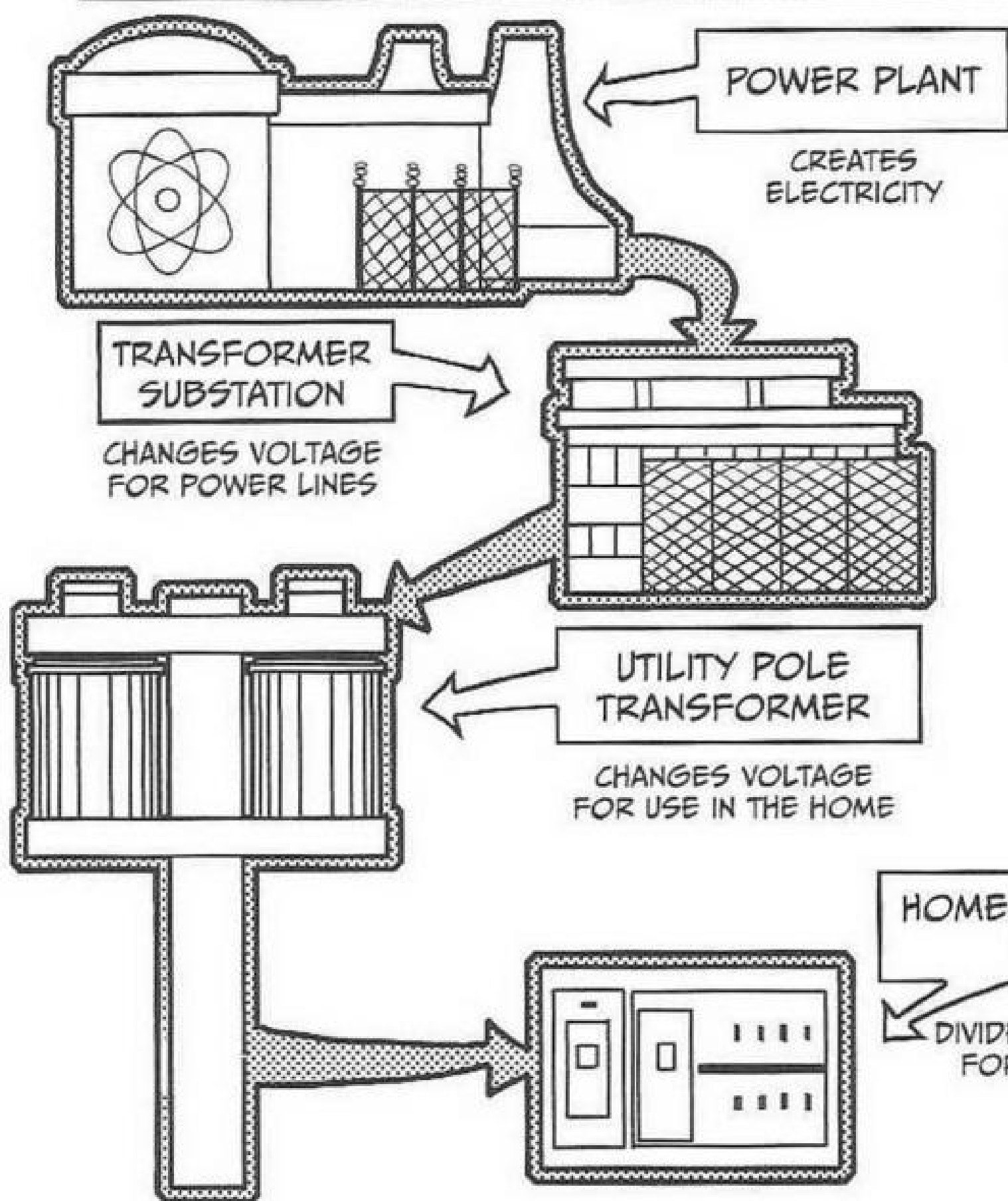
LET'S THINK  
ABOUT THIS  
TOGETHER.

OKAY.

FIRST, LET'S TALK  
ABOUT THE FLOW OF  
ELECTRICITY COMING  
TO THE HOUSE.

CLICK!

ALL RIGHT!

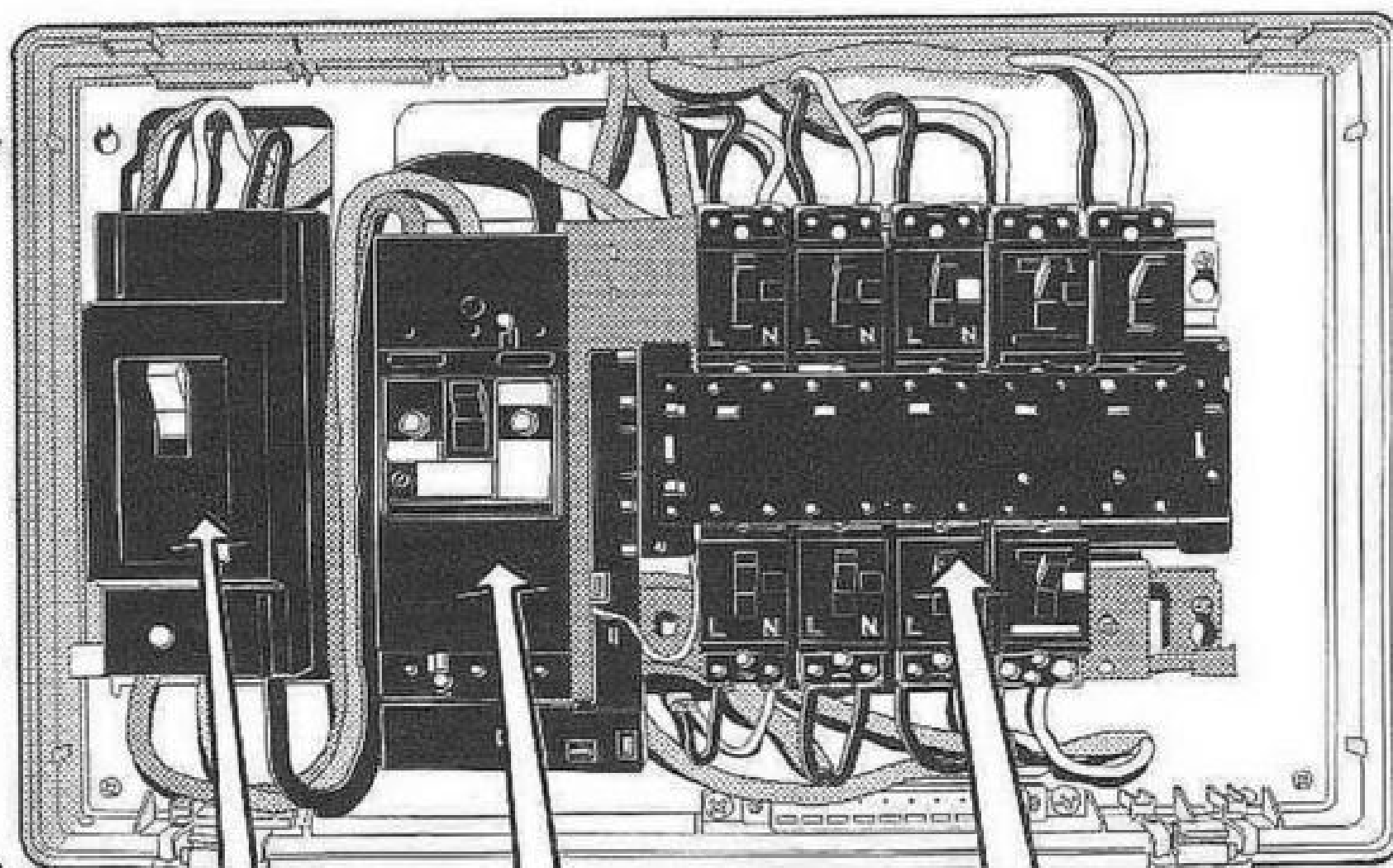


THE ELECTRICITY USED  
IN AN ORDINARY HOME IS  
CREATED AT A POWER PLANT  
AND DELIVERED TO EACH  
HOME BY ELECTRIC LINES,  
AFTER IT PASSES THROUGH  
TRANSFORMER SUBSTATIONS  
OR TRANSFORMERS ON  
UTILITY POLES.



A DISTRIBUTION BOARD DIVIDES ELECTRICITY FOR EACH ROOM IN THE HOUSE. THE ELECTRICITY THAT ENTERS THE DISTRIBUTION BOARD

PASSES THROUGH A CURRENT LIMITER, ENTERS A LEAKAGE CIRCUIT BREAKER, AND IS DIVIDED AMONG MULTIPLE SAFETY BREAKERS.



LEAKAGE CIRCUIT BREAKER

CURRENT LIMITER

SAFETY BREAKERS

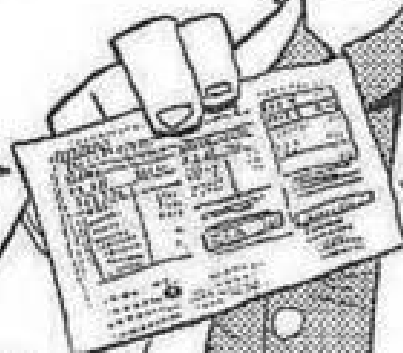
THE INSIDE OF A DISTRIBUTION BOARD LOOKS LIKE THIS.

HUH.

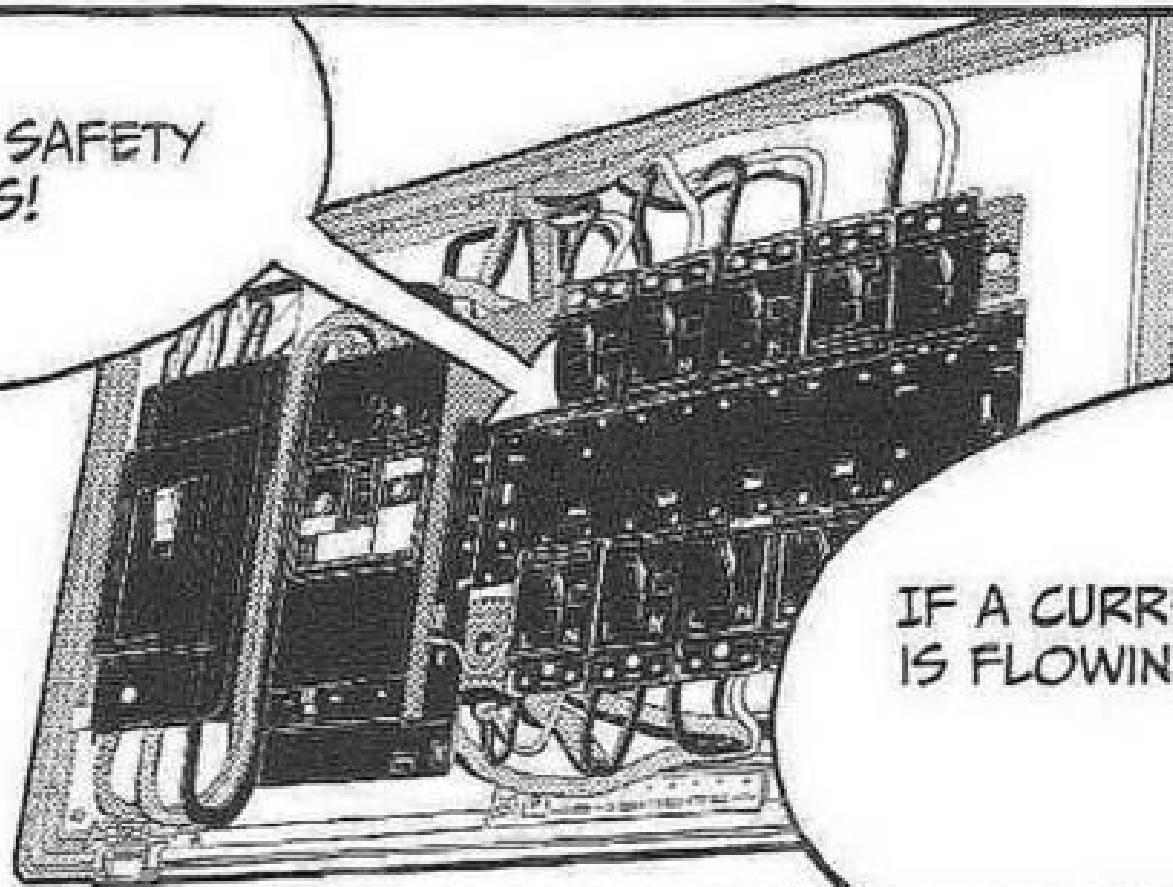
IF THE TOTAL CURRENT FLOWING THROUGH MULTIPLE SAFETY BREAKERS EXCEEDS THE MAXIMUM CURRENT VALUE, THE CURRENT LIMITER WILL TRIP.

SO IF THE CURRENT IS MORE THAN 20A, IT WILL TRIP FOR SAFETY, RIGHT?

IN MY HOUSE, THE MAXIMUM CURRENT VALUE ALLOWED IS 20A.



THESE ARE THE SAFETY BREAKERS!



IF A CURRENT OF 20A OR MORE IS FLOWING, THIS WILL TRIP FOR SAFETY.

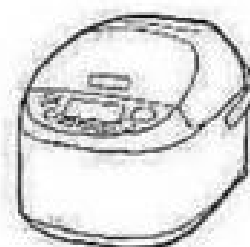
SO, IF THE TOTAL ELECTRICITY USED BY THE ELECTRONIC APPLIANCES CONNECTED TO ONE SAFETY BREAKER DOES NOT EXCEED 20A...

SINCE THE VOLTAGE OF A HOUSEHOLD ELECTRICAL OUTLET IS ALWAYS 120V, LET'S TRY CALCULATING THE TOTAL POWER USED BY THE APPLIANCES CONNECTED TO ONE SAFETY BREAKER AND SEE IF IT EXCEEDS THE LIMIT.

FOR EXAMPLE, IF WE TRY USING THE ELECTRIC KETTLE AND THE RICE COOKER...



ELECTRIC TEA KETTLE  
 $840W / 120V = 7.0A$



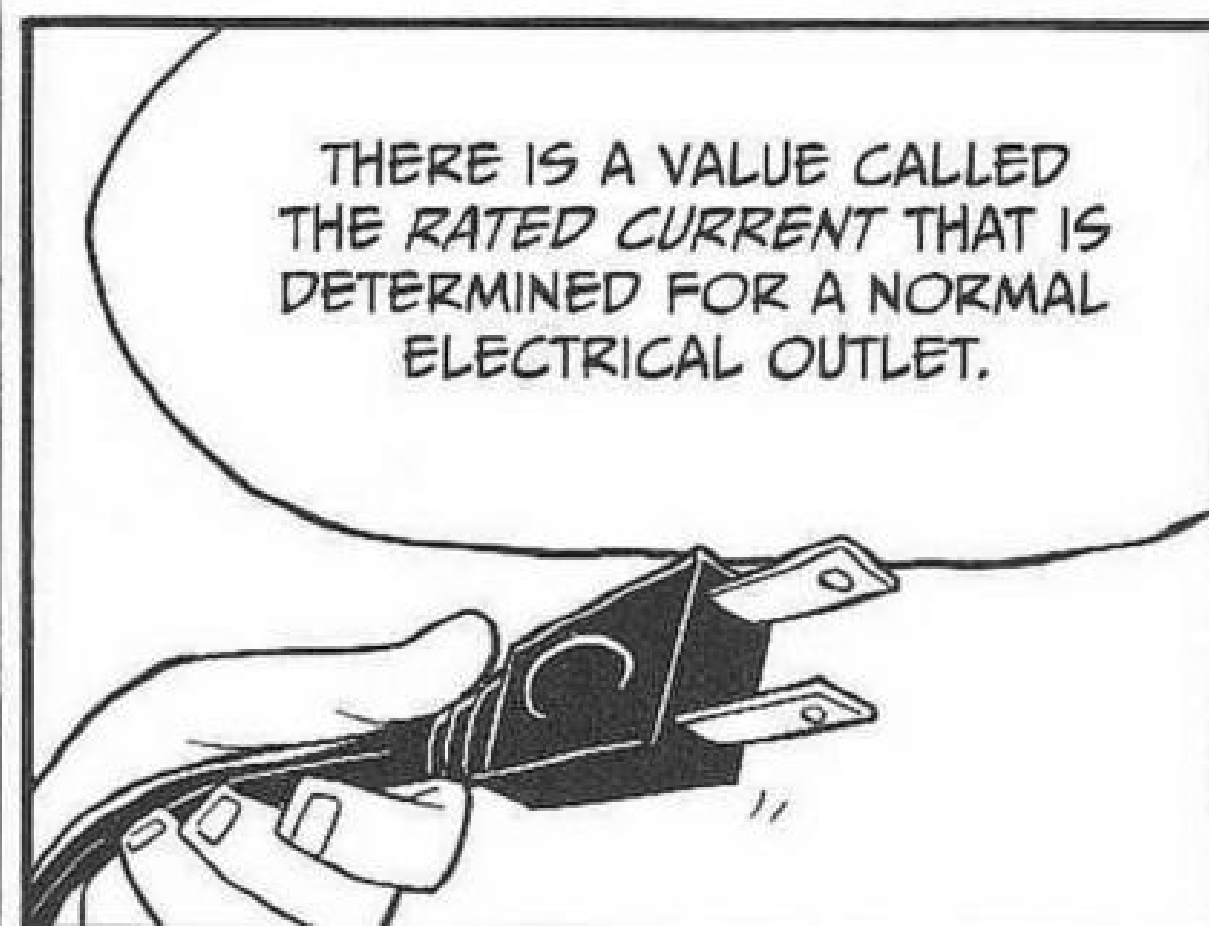
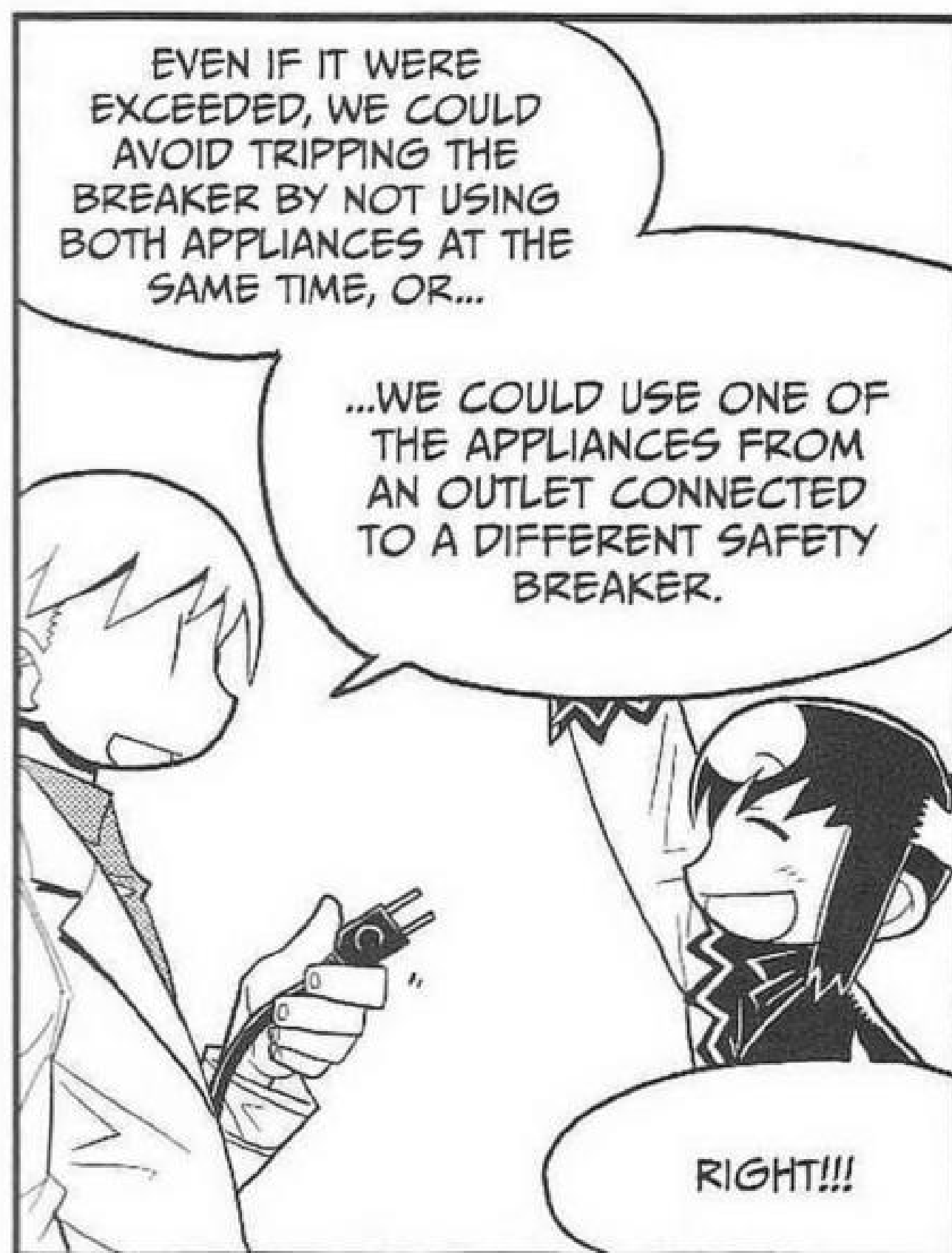
RICE COOKER  
 $1500W / 120V = 12.5A$

$$7.0A + 12.5A = 19.5A$$

...THE SAFETY BREAKER WILL NOT TRIP.

THIS COMBINATION JUST MAKES IT BY A WHISKER...

20A HAS NOT BEEN EXCEEDED.





AROUND 600 BC, THE GREEK PHILOSOPHER THALES DISCOVERED THAT WHEN AN AMBER ORNAMENT WAS RUBBED WITH A CLOTH, IT ATTRACTED FEATHERS OR PIECES OF LINT.



THALES



AH! IS THIS, BY ANY CHANCE...

...DUE TO STATIC ELECTRICITY!?

YEP!

BUT, IN THOSE DAYS, THEY DIDN'T KNOW ABOUT STATIC ELECTRICITY.

INCIDENTALLY, THE WORD *ELECTRICITY* COMES FROM THE WORD *ELECTRON*, WHICH MEANS AMBER IN GREEK.

**electron**

HUH!

THE MYSTERIOUS FORCE THAT ATTRACTS TINY OBJECTS TOGETHER CAN NOW BE EXPLAINED WITH ELECTRICITY.

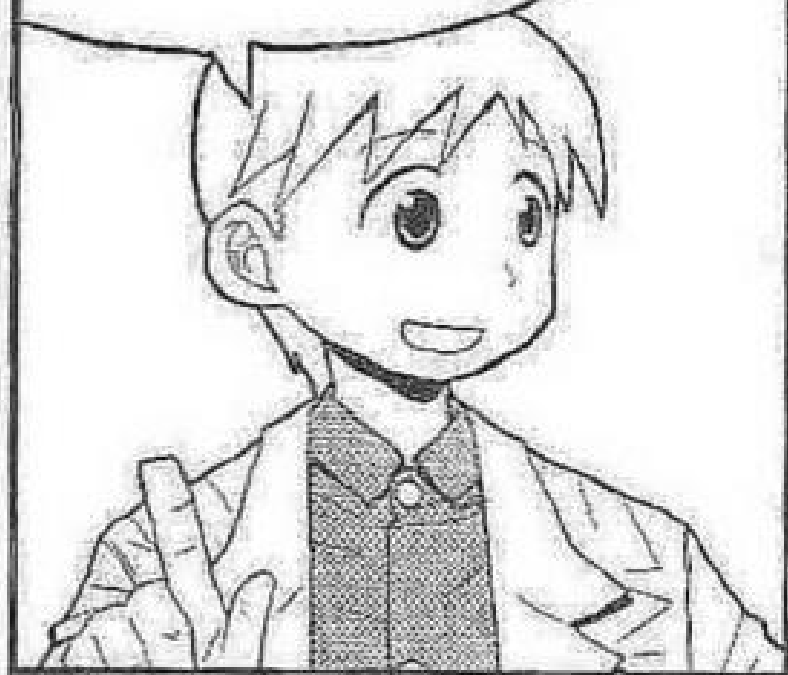
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# THE TRUE NATURE OF ELECTRICITY

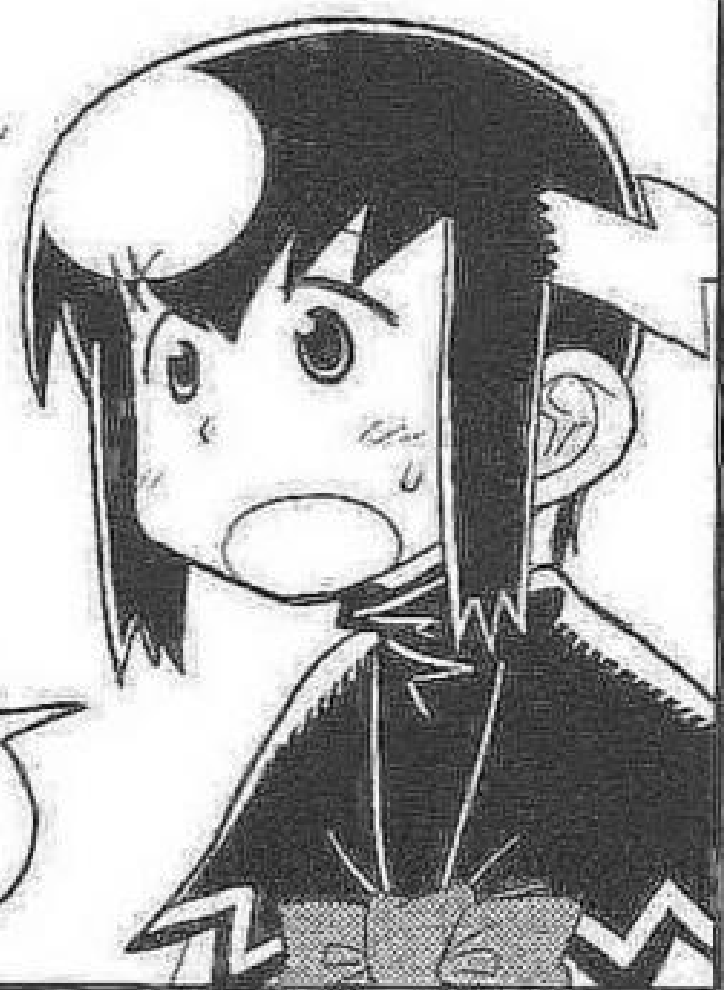
SO LET'S TRY TO  
CLOSE IN ON THE  
TRUE NATURE OF  
ELECTRICITY!



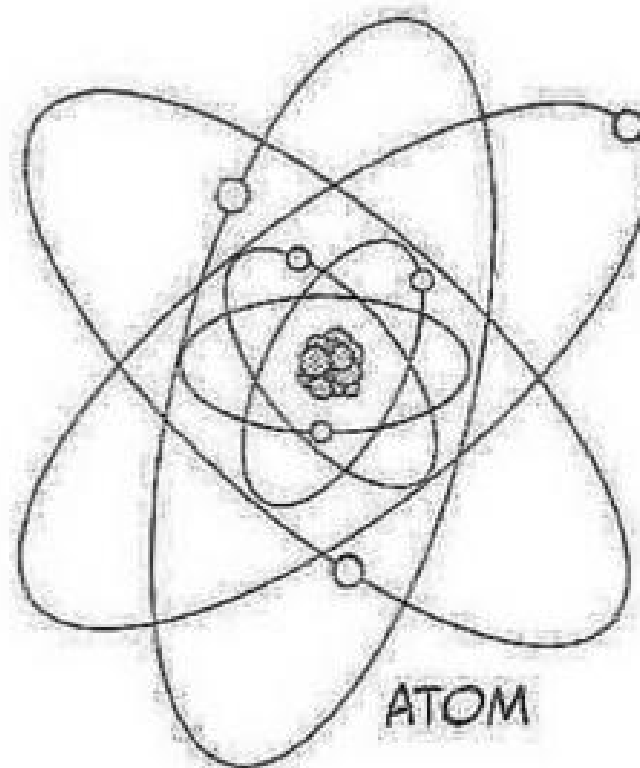
ACTUALLY, THE  
TRUE NATURE OF  
ELECTRICITY COMES  
FROM TINY THINGS  
INSIDE EVERY  
SUBSTANCE.

HUH?

EVEN IN YOU  
AND ME?



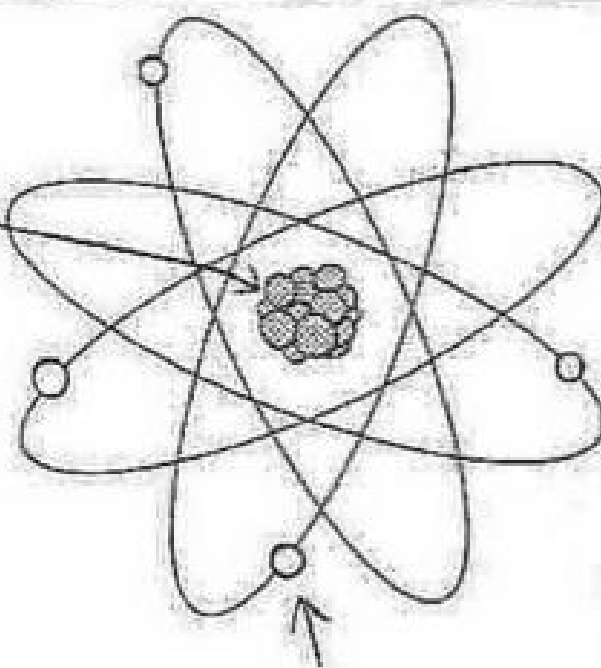
THAT'S RIGHT!  
IT'S IN BOTH YOU AND ME.  
ALL SUBSTANCES ARE MADE UP OF  
COLLECTIONS OF TEENSY LITTLE  
PARTICLES CALLED ATOMS.



HMM.



NUCLEUS

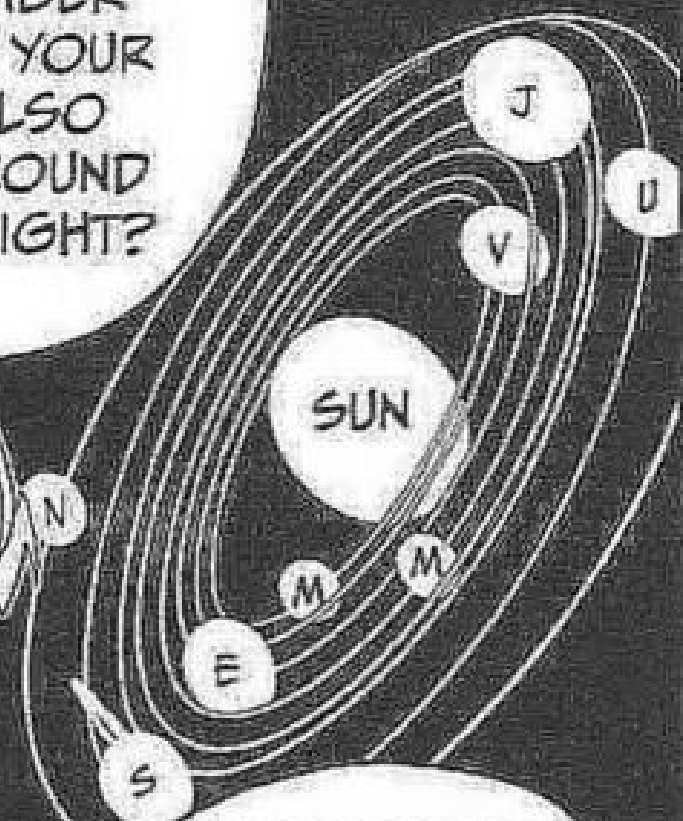


ELECTRON

AN ATOM HAS  
SOMETHING CALLED  
A NUCLEUS AT ITS  
CENTER, AND THINGS  
CALLED ELECTRONS  
REVOLVE AROUND IT.

THESE EVEN TINIER  
PARTICLES ARE  
THE CAUSE OF  
ELECTRICITY.

IF I REMEMBER  
CORRECTLY, YOUR  
PLANETS ALSO  
REVOLVE AROUND  
YOUR SUN, RIGHT?



IS IT SIMILAR  
TO THAT  
RELATIONSHIP?



IT IS! THE NUCLEUS, WHICH CORRESPONDS TO THE SUN, CONSISTS OF PROTONS, WHICH HAVE AN ELECTRICALLY POSITIVE PROPERTY, AND NEUTRONS, WHICH HAVE NO ELECTRICAL PROPERTY.

PROTON  
(+)

NEUTRON  
(NEUTRAL)

THE ELECTRONS THAT REVOLVE AROUND THE OUTSIDE HAVE A NEGATIVE PROPERTY.

ELECTRON  
(-)

IF AN ATOM CONTAINS BOTH POSITIVES AND NEGATIVES, IS THE ATOM ITSELF POSITIVE OR NEGATIVE?

SINCE THE NUMBER OF PROTONS IS USUALLY THE SAME AS THE NUMBER OF ELECTRONS, THE ATOM ITSELF IS ELECTRICALLY NEUTRAL.

NOW, IF EXTERNAL HEAT OR LIGHT IS ADDED TO AN ATOM...

HEAT

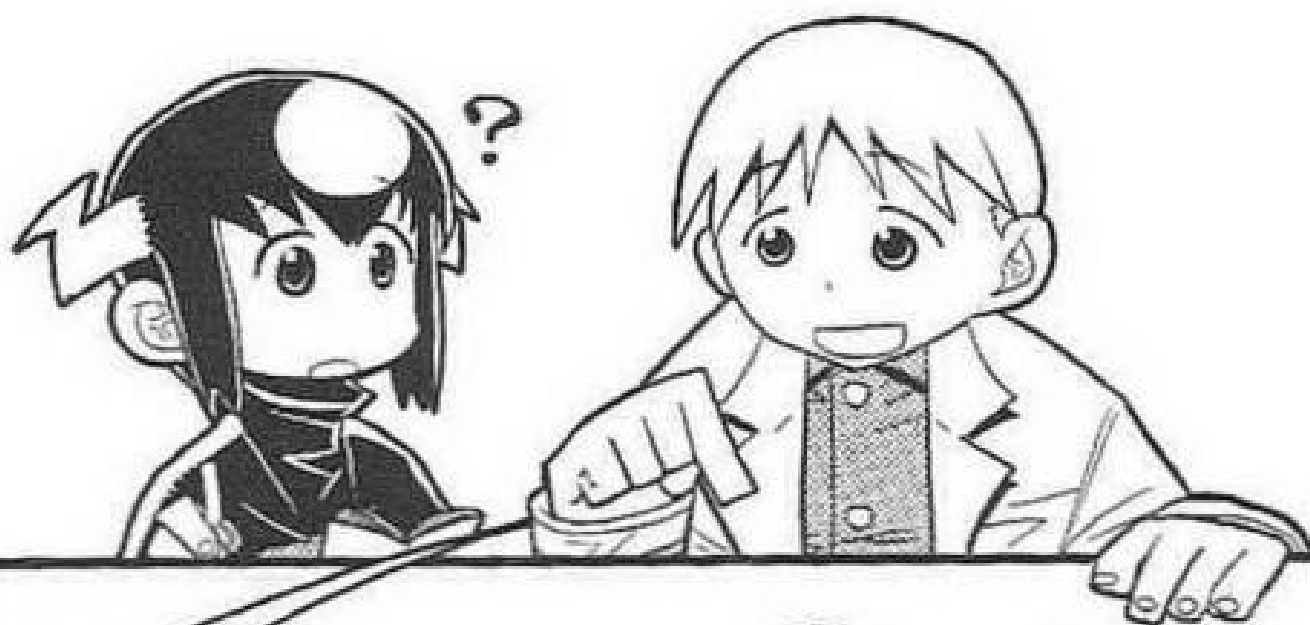
LIGHT

ZIP!

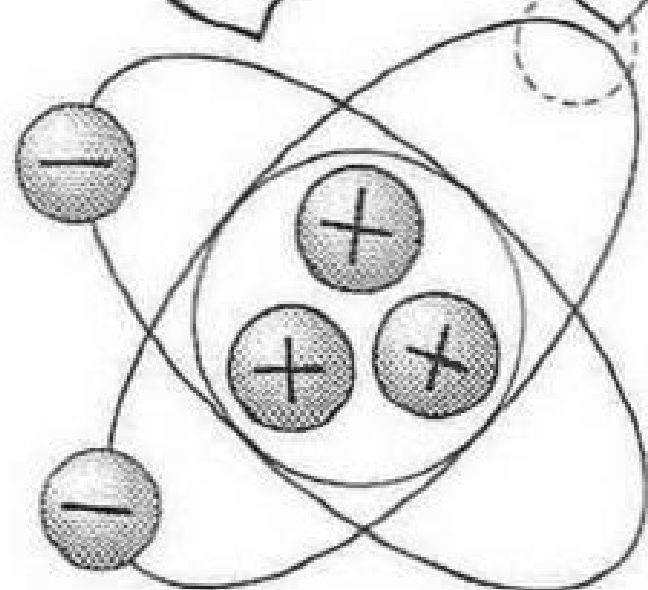
YOW!

AN ELECTRON MAY ESCAPE FROM THE ATOM. THIS IS CALLED A FREE ELECTRON.

WHAT HAPPENS IF IT ESCAPES?



IF AN ELECTRON ESCAPES, THE NEGATIVES ARE REDUCED, AND THE ATOM BECOMES ELECTRICALLY POSITIVE.



THE NUMBER OF ELECTRONS DECREASES, AND THE ATOM BECOMES ELECTRICALLY POSITIVE.

HEAT

LIGHT

THE NUMBER OF ELECTRONS INCREASES, AND THE ATOM BECOMES ELECTRICALLY NEGATIVE.

IF AN ESCAPED ELECTRON PLUNGES INTO ANOTHER ATOM, THE NEGATIVES IN THAT ATOM INCREASE, AND IT BECOMES ELECTRICALLY NEGATIVE.



AHA! THE ESCAPED ELECTRON MOVES TO ANOTHER ATOM!

AN ATOM THAT HAS THIS KIND OF ELECTRICAL PROPERTY IS SAID TO BE CHARGED.

SO AN ATOM IS CHARGED WHEN ONE OF ITS ELECTRONS ESCAPES OR WHEN IT RECEIVES ANOTHER ELECTRON.

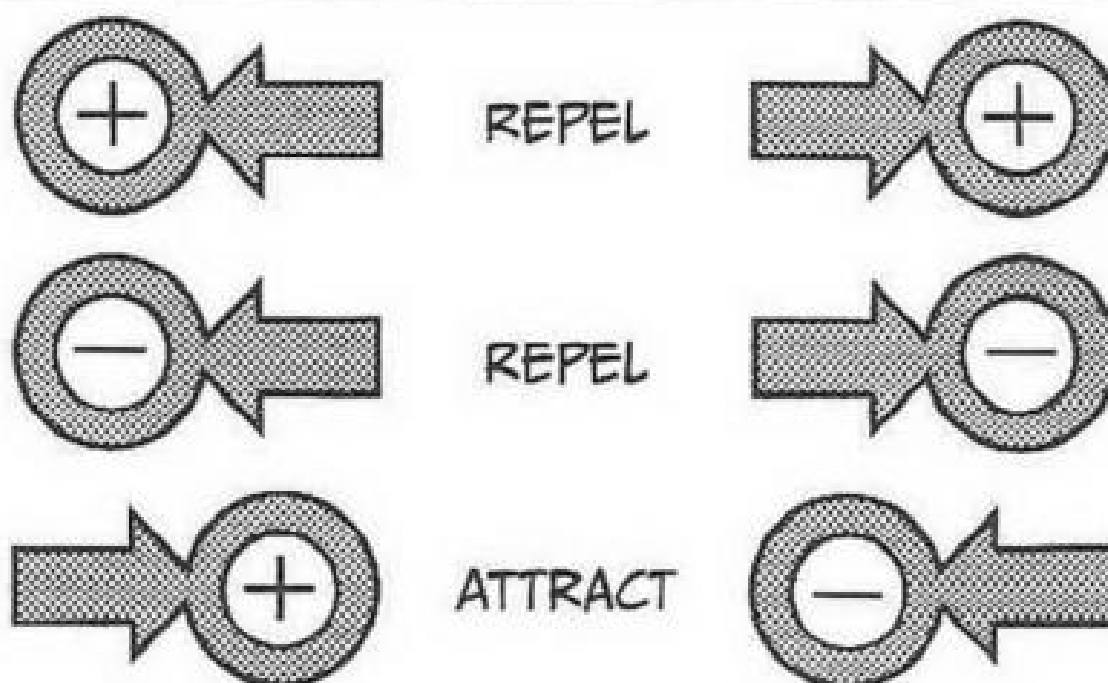


CHARGE IS THE POSITIVE OR NEGATIVE ELECTRICAL PROPERTY. A PROTON IS SAID TO HAVE POSITIVE CHARGE AND AN ELECTRON NEGATIVE CHARGE.



CHARGE...??

TWO POSITIVE CHARGES OR TWO NEGATIVE CHARGES REPEL EACH OTHER, WHILE A POSITIVE AND A NEGATIVE ATTRACT EACH OTHER.



IT'S LIKE THE NORTH AND SOUTH POLES OF A MAGNET, ISN'T IT?



YEP! THIS FORCE IS CALLED THE **ELECTROSTATIC FORCE** OR **COULOMB'S FORCE**.



**STATIC ELECTRICITY** OCCURS WHEN A MATERIAL HAS A POSITIVE OR NEGATIVE ELECTRIC CHARGE THAT IS NOT MOVING.

## CURRENT AND ELECTRICAL DISCHARGE

IF A SUBSTANCE IS POSITIVELY OR NEGATIVELY CHARGED, IT TRIES TO BECOME NEUTRAL AGAIN BY RECEIVING OR LOSING ELECTRONS.

IT TRIES TO GET BACK TO ITS NATURAL STATE, DOESN'T IT?

BY THE WAY, OBJECTS CAN BE *CONDUCTORS*, THROUGH WHICH ELECTRICITY EASILY FLOWS (LIKE METAL)...

...*INSULATORS*, THROUGH WHICH ELECTRICITY HAS DIFFICULTY FLOWING (LIKE GLASS OR RUBBER)...

...AND *SEMICONDUCTORS*, WHICH ARE MIDWAY BETWEEN CONDUCTORS AND INSULATORS.

HMMM.

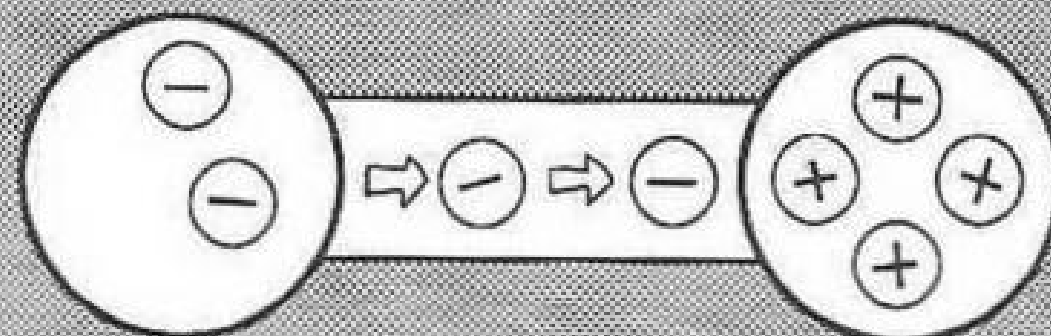
IF THERE IS AN INSULATOR BETWEEN A POSITIVE AND A NEGATIVE CHARGE, THE ELECTRONS CANNOT MOVE.

INSULATOR

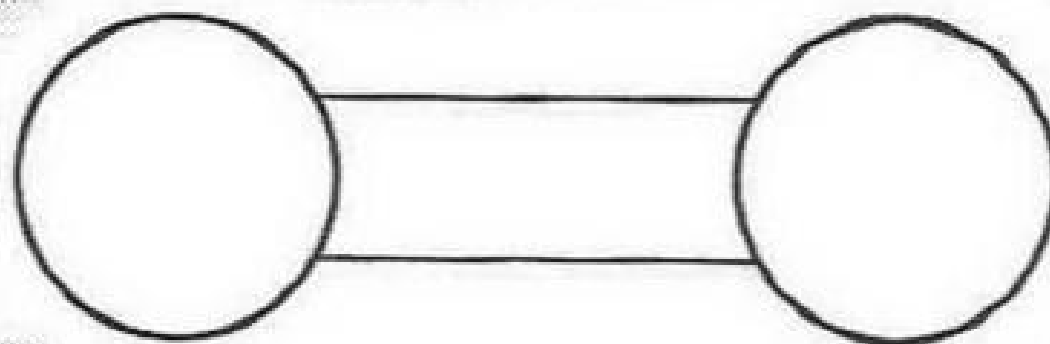
BECAUSE THE ELECTRICITY HAS DIFFICULTY FLOWING, RIGHT?

IF OBJECTS HAVING A CHARGE ARE CONNECTED BY A CONDUCTOR LIKE A COPPER WIRE...

...THE NEGATIVE ELECTRONS MOVE TO THE POSITIVE SIDE.



THEN THE POSITIVES AND NEGATIVES UNITE TO CANCEL EACH OTHER OUT, AND THE CHARGED STATE NO LONGER EXISTS.



THIS PHENOMENON IS CALLED ELECTRICAL DISCHARGE.

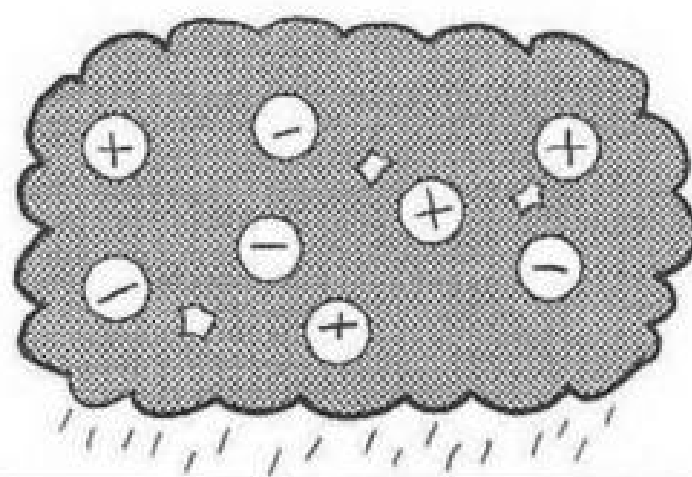
ELECTRICAL DISCHARGE ALSO OCCURS IN THE AIR OR IN A VACUUM.

A DISCHARGE CAN EVEN OCCUR IN THE AIR?

HMMM.



THIS IS WHAT LIGHTNING IS!  
LIGHTNING OCCURS WHEN TINY  
WATER DROPLETS IN CLOUDS  
RUB AGAINST EACH OTHER, AND  
THE STATIC ELECTRICITY THAT  
WAS PRODUCED DISCHARGES  
TO THE GROUND.

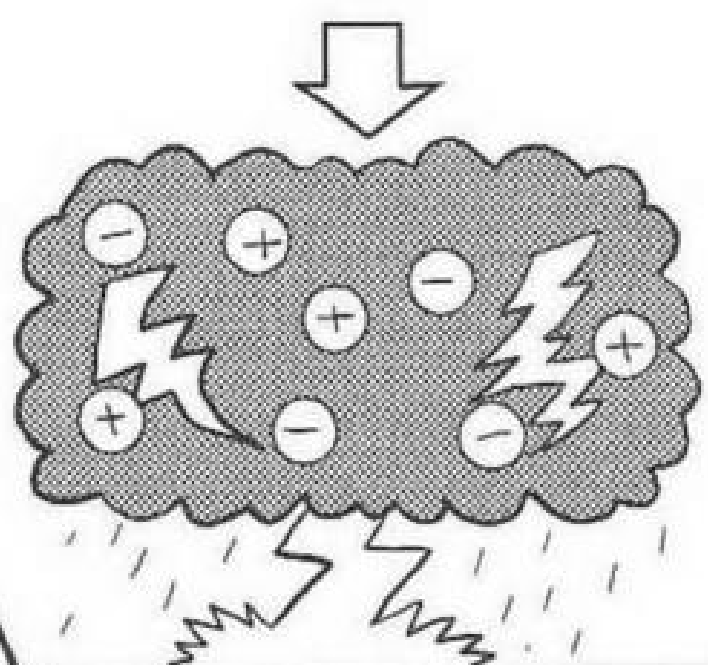


HAIL AND ICE PARTICLES IN  
CUMULONIMBUS CLOUDS  
COLLIDE WITH EACH OTHER,  
AND ELECTRIC CHARGE  
ACCUMULATES.

SINCE AIR IS AN  
INSULATOR, A  
DISCHARGE DOES  
NOT OCCUR EASILY.



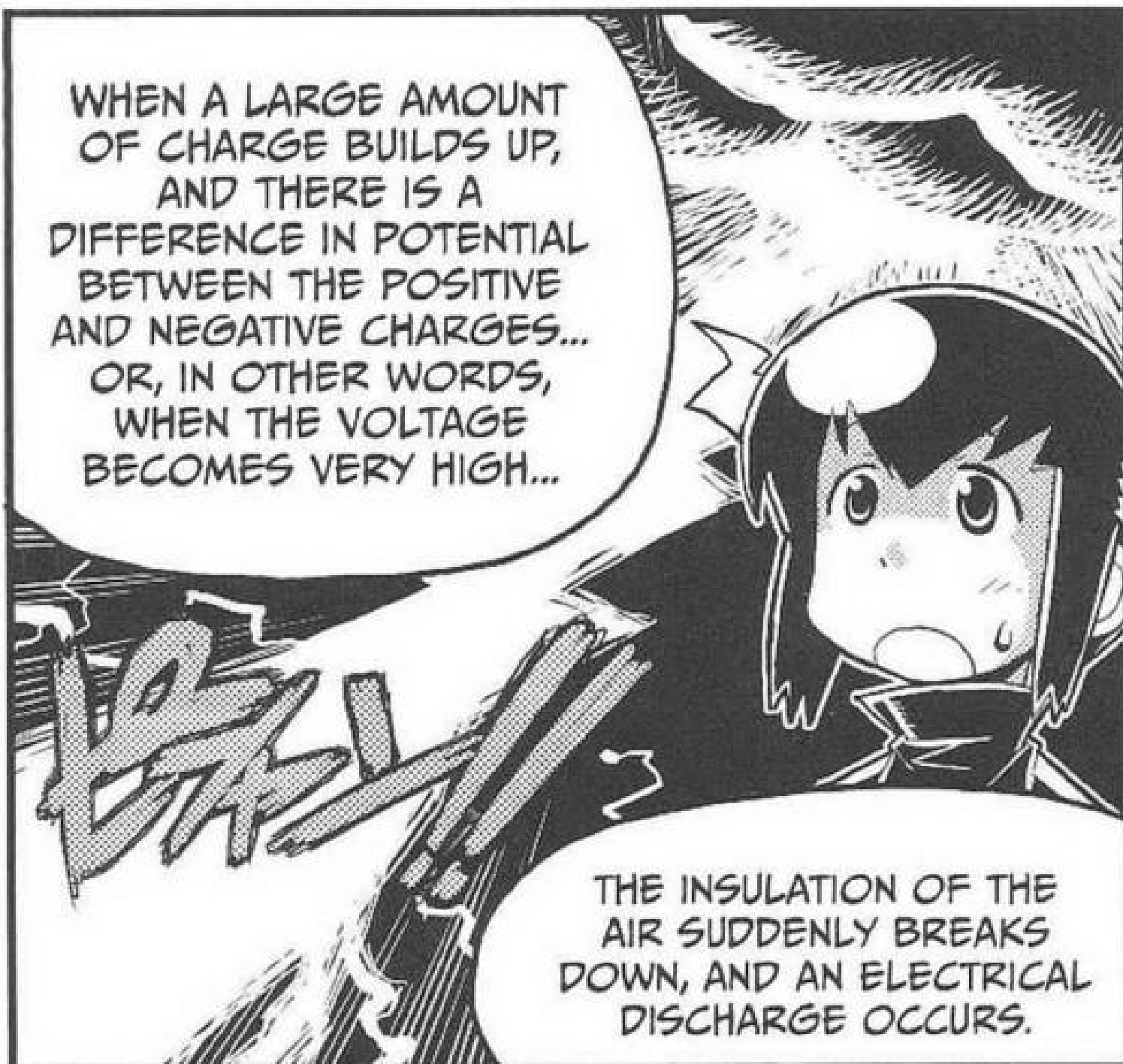
THEN AN  
ENORMOUS  
DISCHARGE  
OCCURS!



AN ELECTRICAL DISCHARGE  
OCCURS, EITHER WITHIN THE  
CLOUD ITSELF OR IN THE  
FORM OF LIGHTNING TO  
THE GROUND.



WHEN A LARGE AMOUNT  
OF CHARGE BUILDS UP,  
AND THERE IS A  
DIFFERENCE IN POTENTIAL  
BETWEEN THE POSITIVE  
AND NEGATIVE CHARGES...  
OR, IN OTHER WORDS,  
WHEN THE VOLTAGE  
BECOMES VERY HIGH...



THE INSULATION OF THE  
AIR SUDDENLY BREAKS  
DOWN, AND AN ELECTRICAL  
DISCHARGE OCCURS.

THE BREAKDOWN  
OF THE INSULATION  
CREATES AWESOME  
POWER, RIGHT?



IT DOES!  
BUT IT HAPPENS  
IN AN INSTANT.





## ATOMIC STRUCTURE AND CONDUCTIVITY

THERE ARE VARIOUS KINDS OF ATOMS, AND A NUMBER IS ASSIGNED TO EACH ONE.

THIS IS CALLED THE ATOMIC NUMBER.

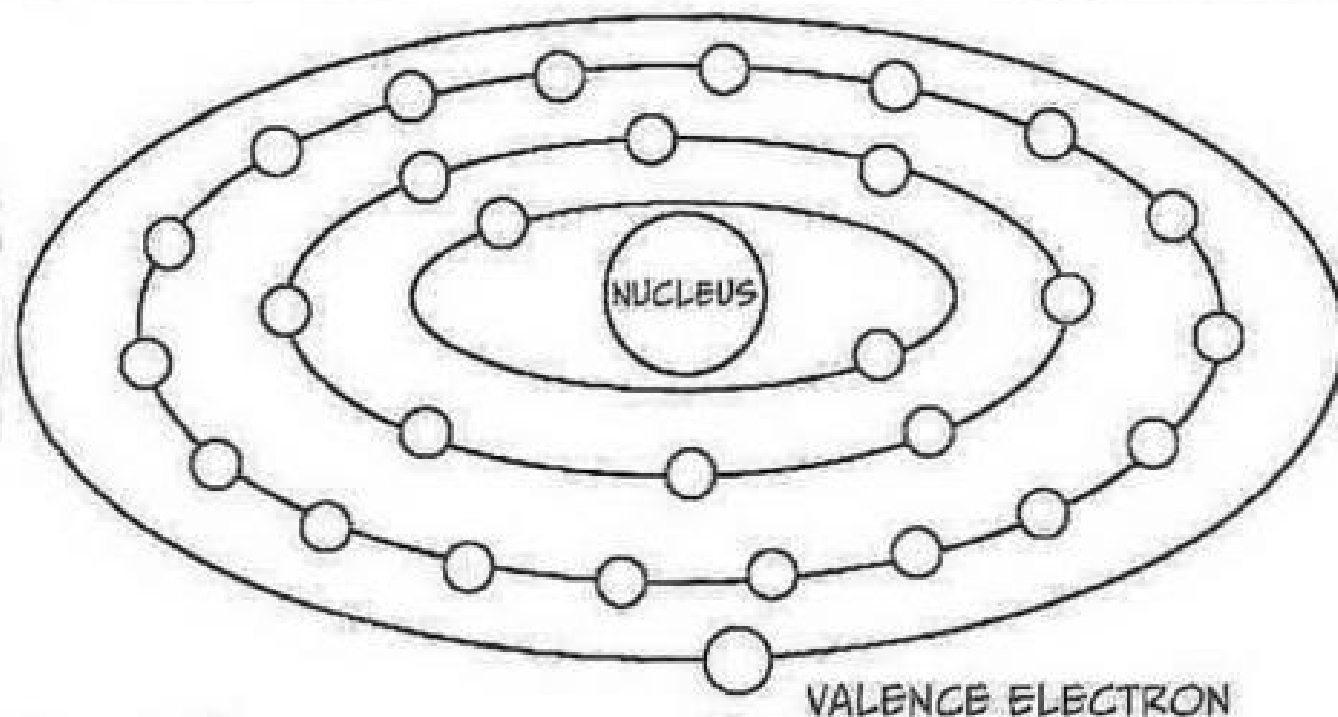
FOR EXAMPLE, THE ATOMIC NUMBER OF COPPER, WHICH IS OFTEN USED IN ELECTRIC LINES, IS 29.

WHY IS COPPER NUMBER 29?

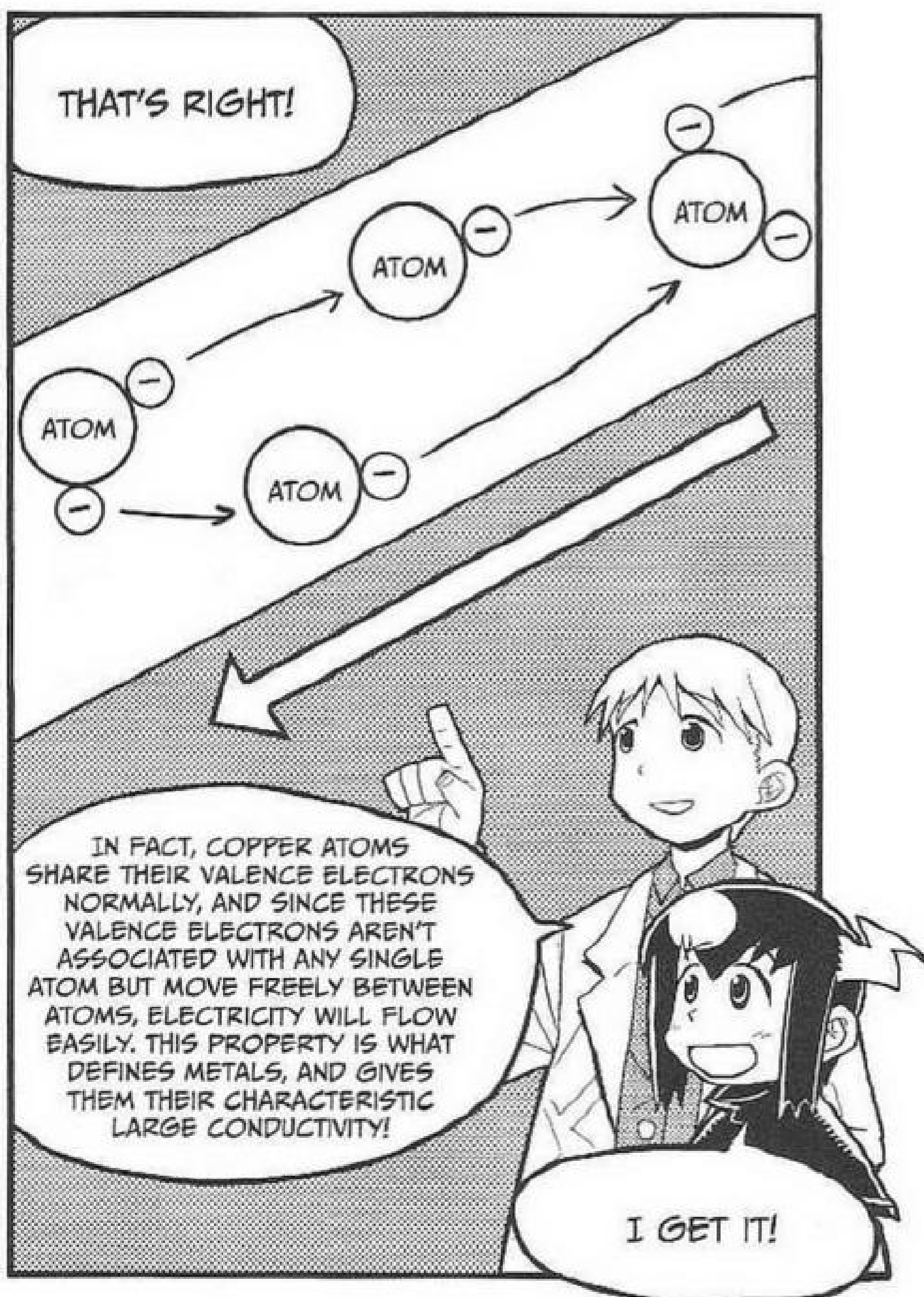
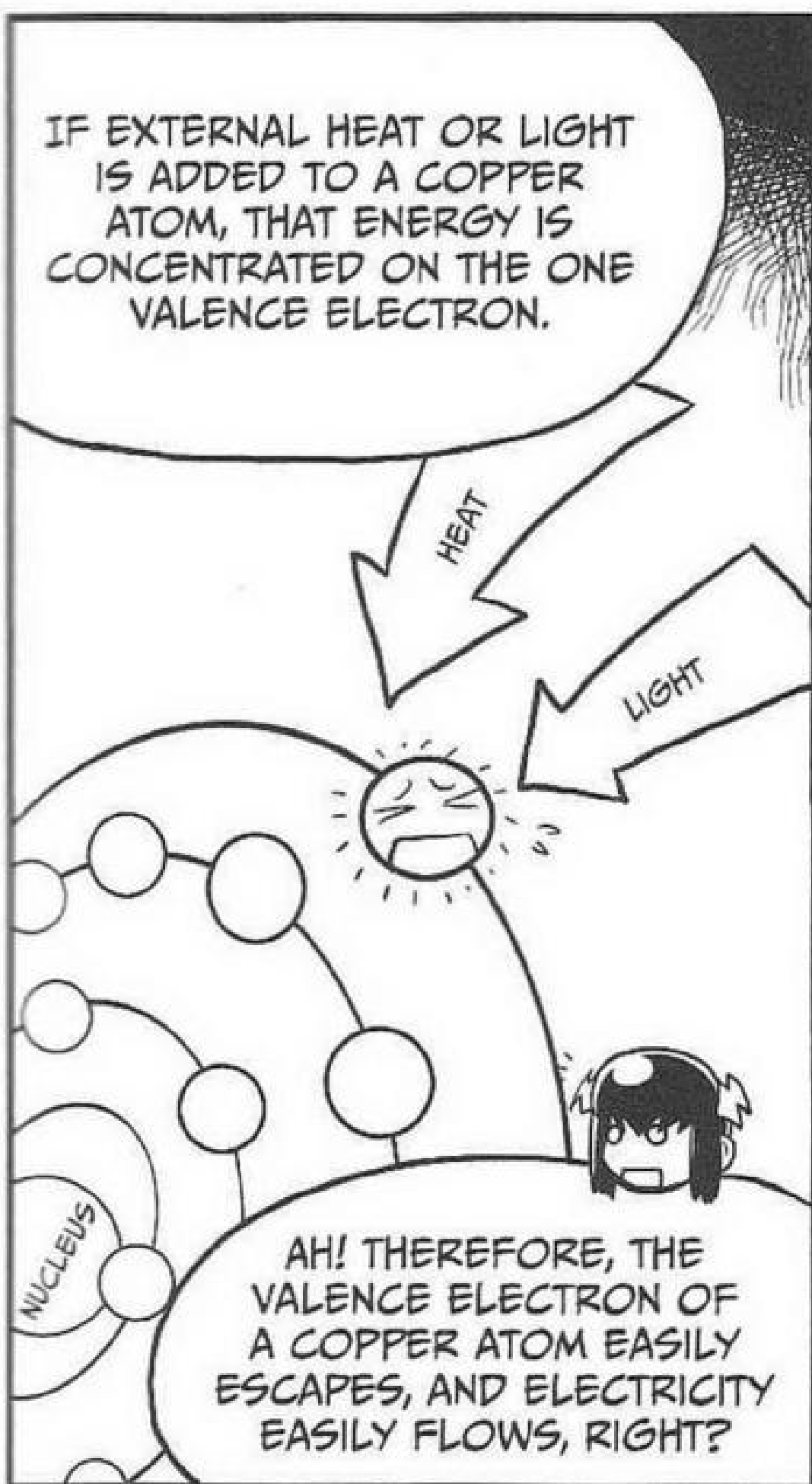
THE ATOMIC NUMBER IS THE SAME AS THE NUMBER OF PROTONS THAT THE ATOM HAS.

AND SINCE THERE ARE THE SAME NUMBER OF PROTONS AS ELECTRONS, COPPER MUST ALSO HAVE 29 ELECTRONS.

THERE ARE FOUR ORBITS CALLED *ELECTRON SHELLS* AROUND THE NUCLEUS OF A COPPER ATOM. STARTING FROM THE INNERMOST SHELL, THESE CONTAIN 2, 8, 18, AND 1 ELECTRON, RESPECTIVELY, FOR A TOTAL OF 29 ELECTRONS.



AN ELECTRON IN THE OUTERMOST SHELL IS CALLED A VALENCE ELECTRON.



## STATIC ELECTRICITY

EARLIER I TOLD YOU THAT STATIC ELECTRICITY OCCURS WHEN AN OBJECT HAS AN ELECTRICALLY POSITIVE OR NEGATIVE CHARGE. *STATIC* MEANS THAT NOTHING IS MOVING—NO CURRENT FLOWS.

NOW LET'S TALK ABOUT STATIC ELECTRICITY IN A LITTLE MORE DETAIL.

OKAY!

YOU KNOW, WE ALSO HAVE FOUR SEASONS IN ELECTOPIA, AND IN WINTER, IT SEEMS TO CAUSE LITTLE SHOCKS EVERYWHERE... IT'S JUST AWFUL.

ZAP

WITH SWEATERS

ZAP

OW!

OW!

ZAP

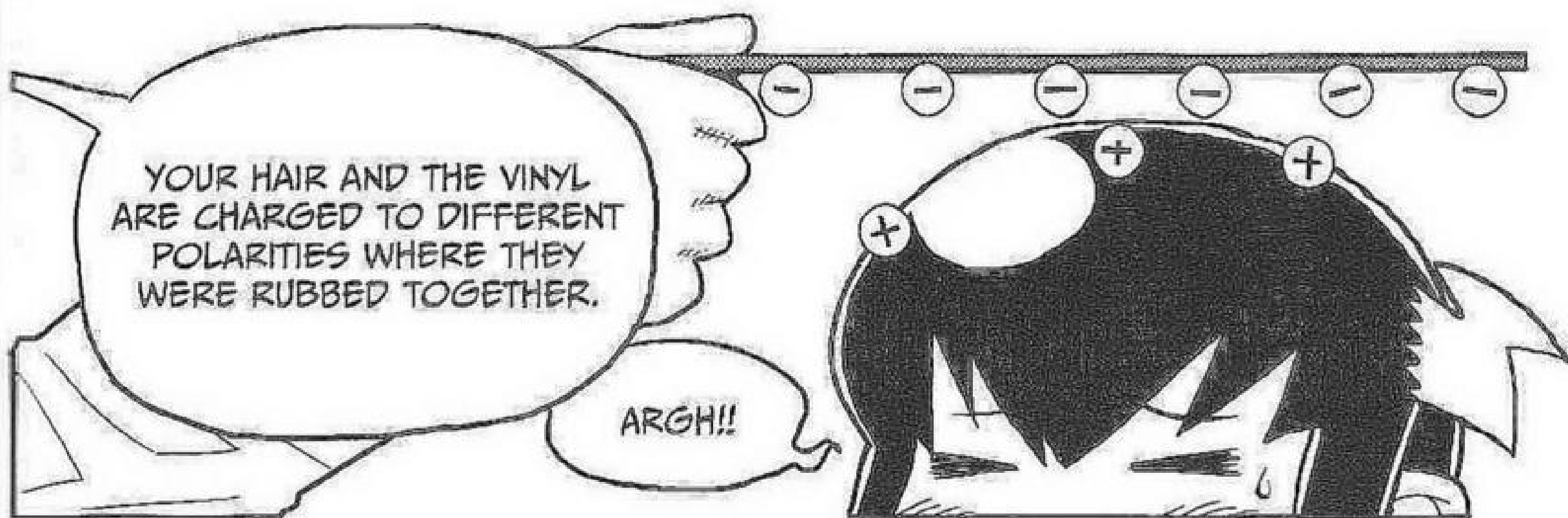
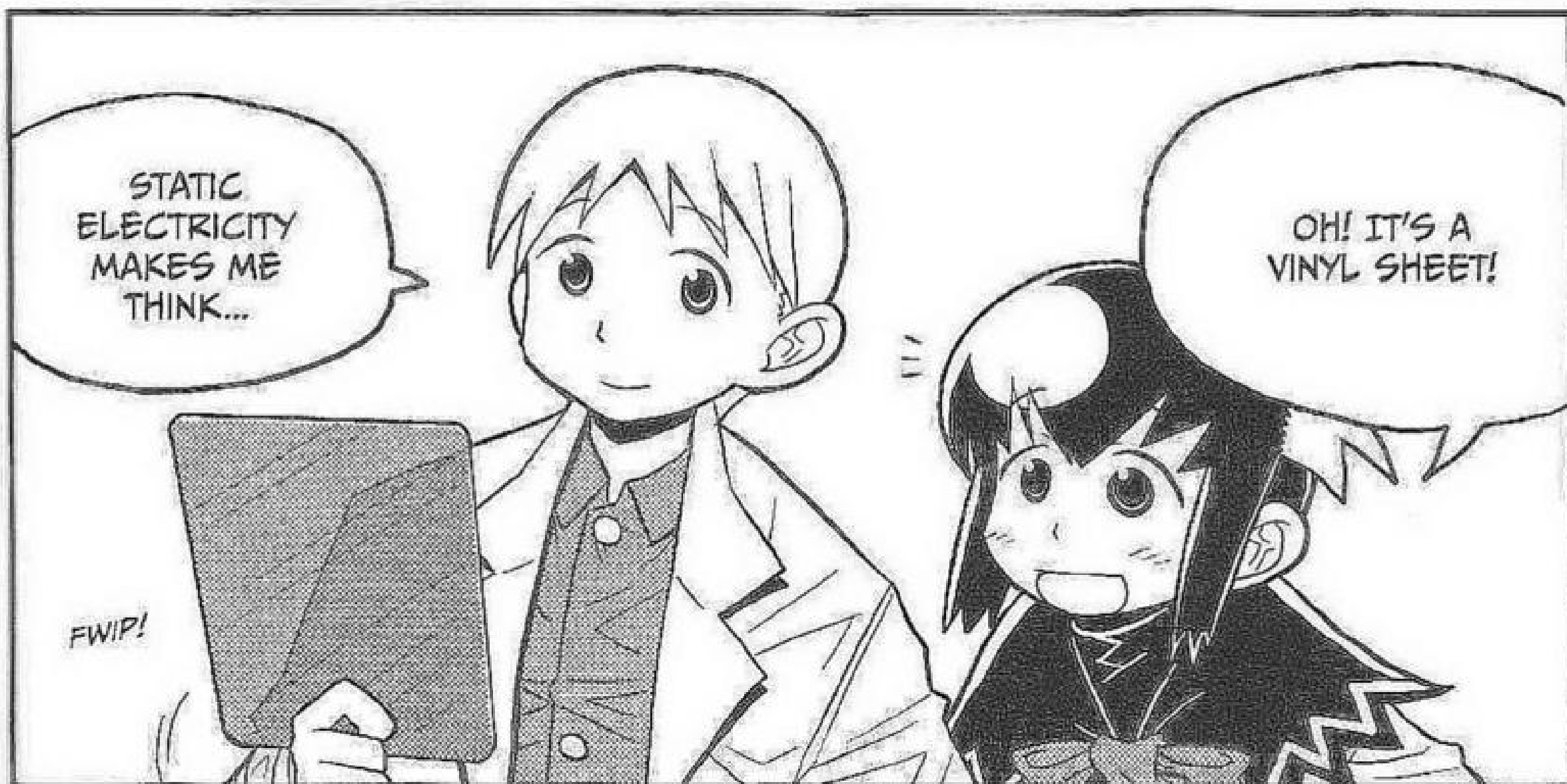
WITH DOOR KNOBS

WELL, IN THAT SENSE, STATIC ELECTRICITY IS SOMETHING WE'RE RELATIVELY FAMILIAR WITH. BUT DO YOU KNOW HOW IT IS PRODUCED AND WHAT PROPERTIES IT HAS?

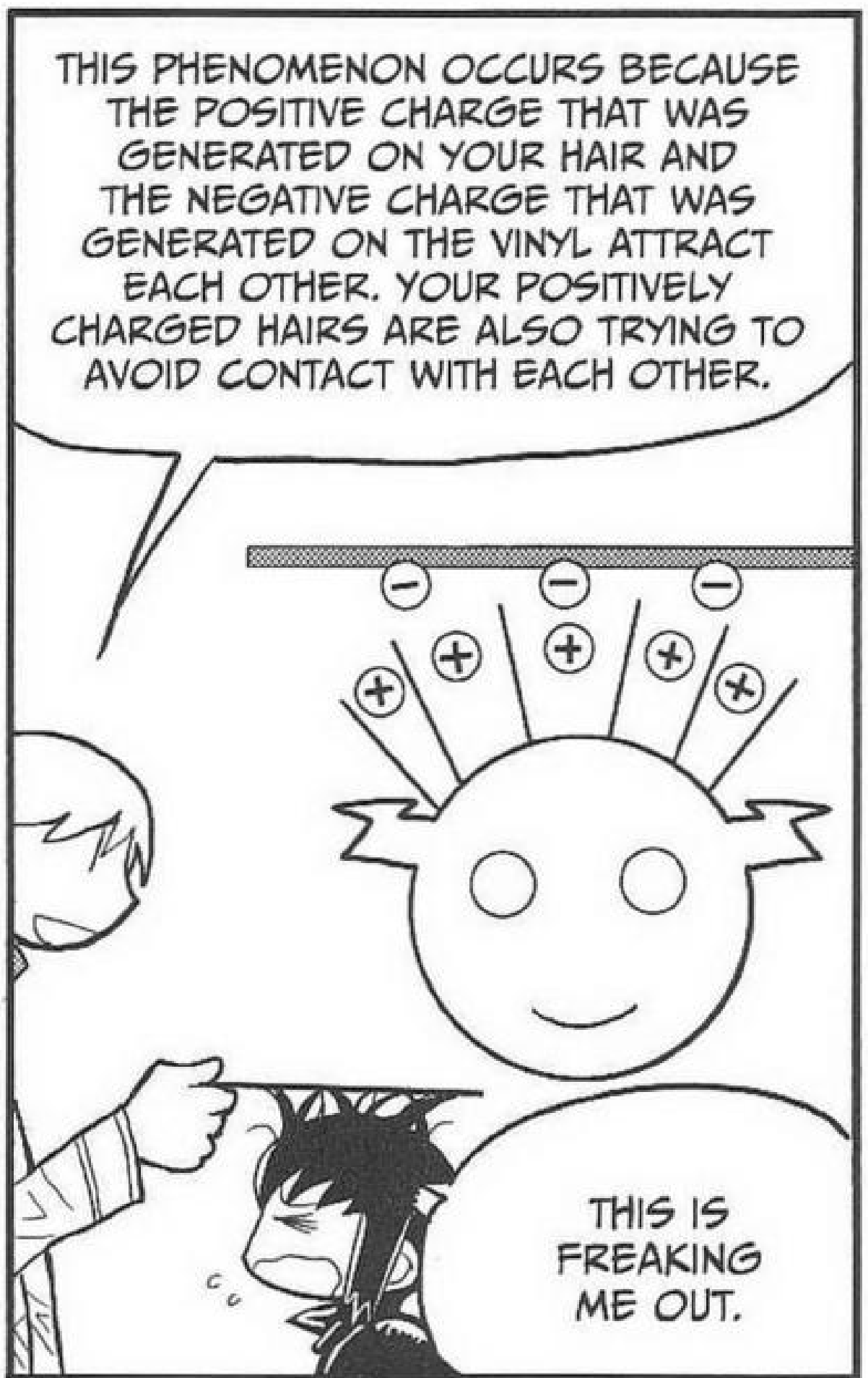
WELL...

UM...IT'S...

THAT'S WHAT I THOUGHT!







STATIC ELECTRICITY IS  
GENERATED BY THE  
CONTACT OR RUBBING OF  
TWO OBJECTS LIKE THIS.



IF I BRING THE CHARGED  
VINYL TO MY HEAD...

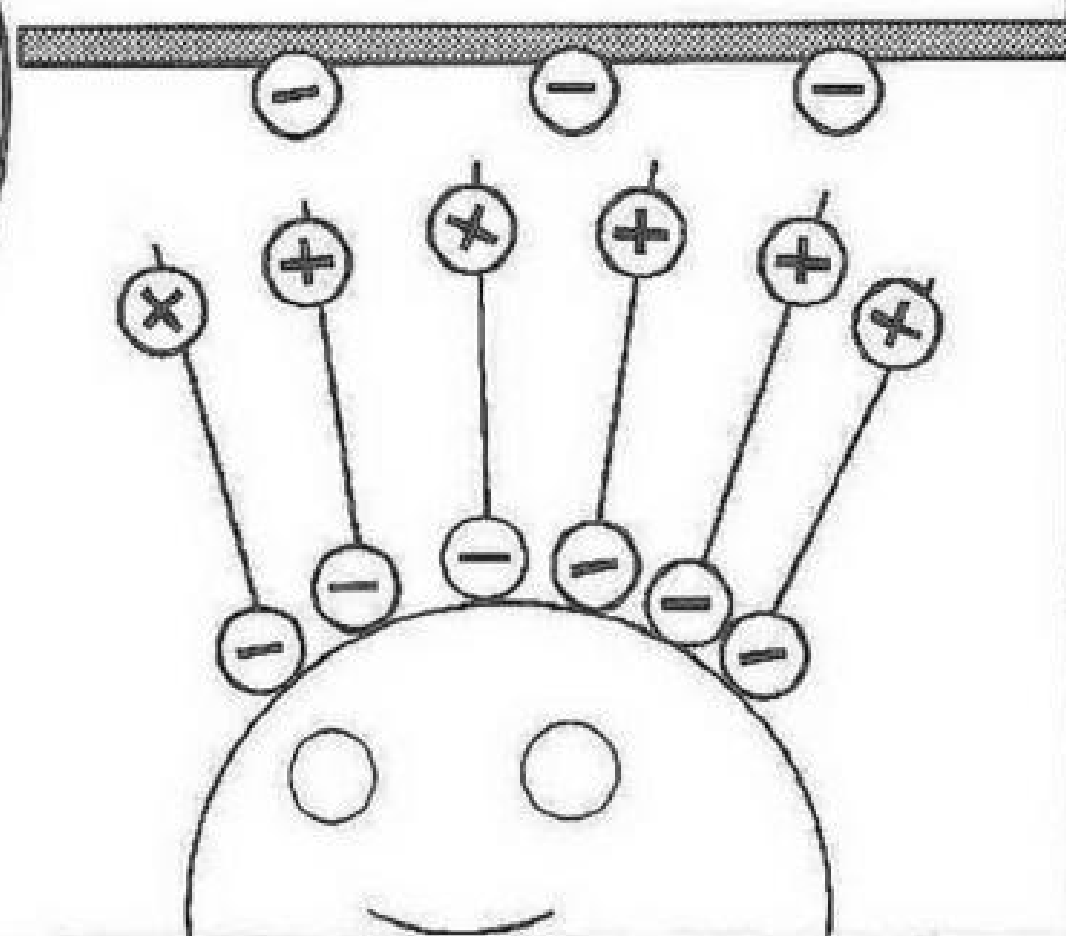


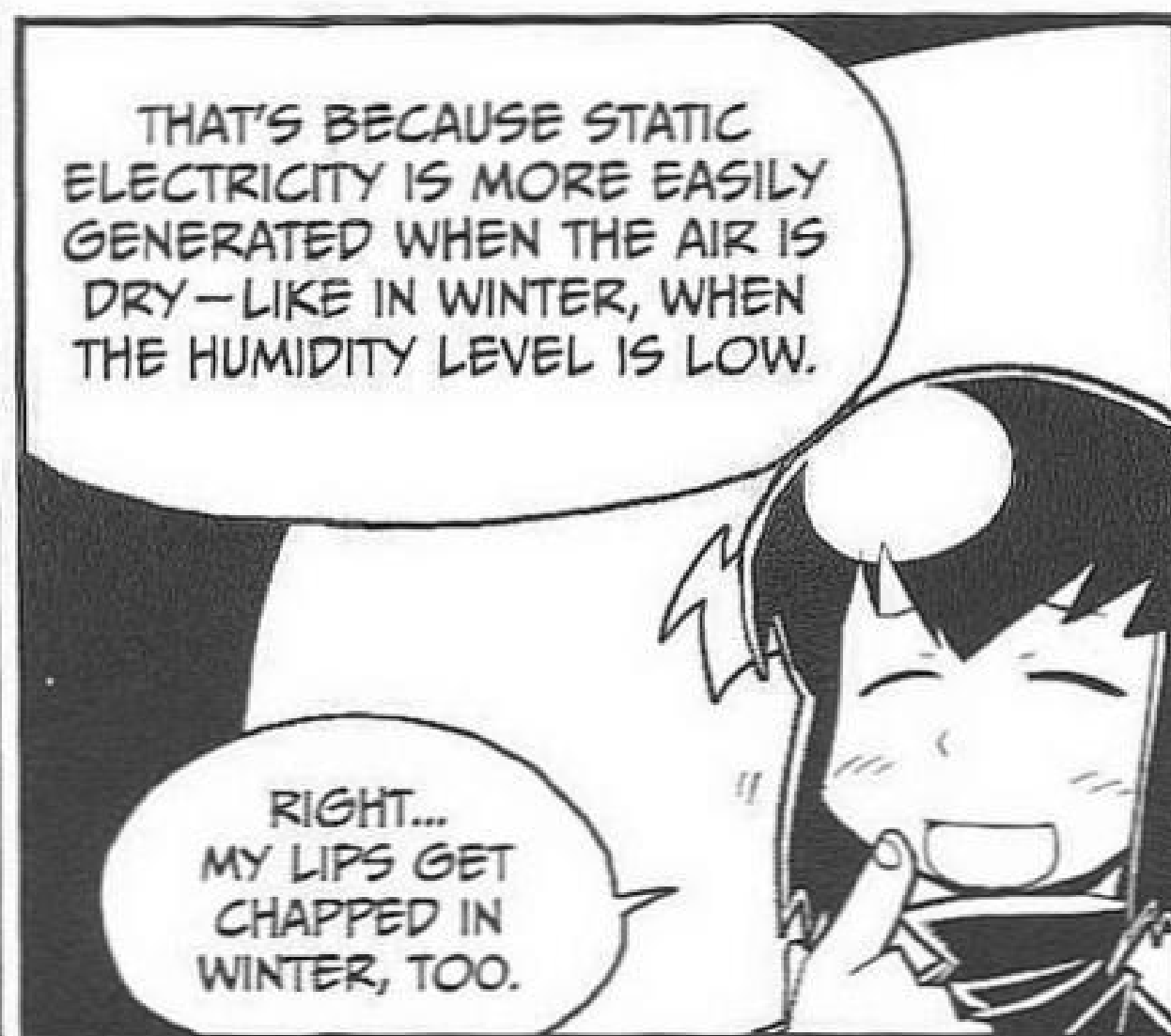
TA-DA!

...MY HAIR STANDS  
ON END NOW,  
RIGHT?

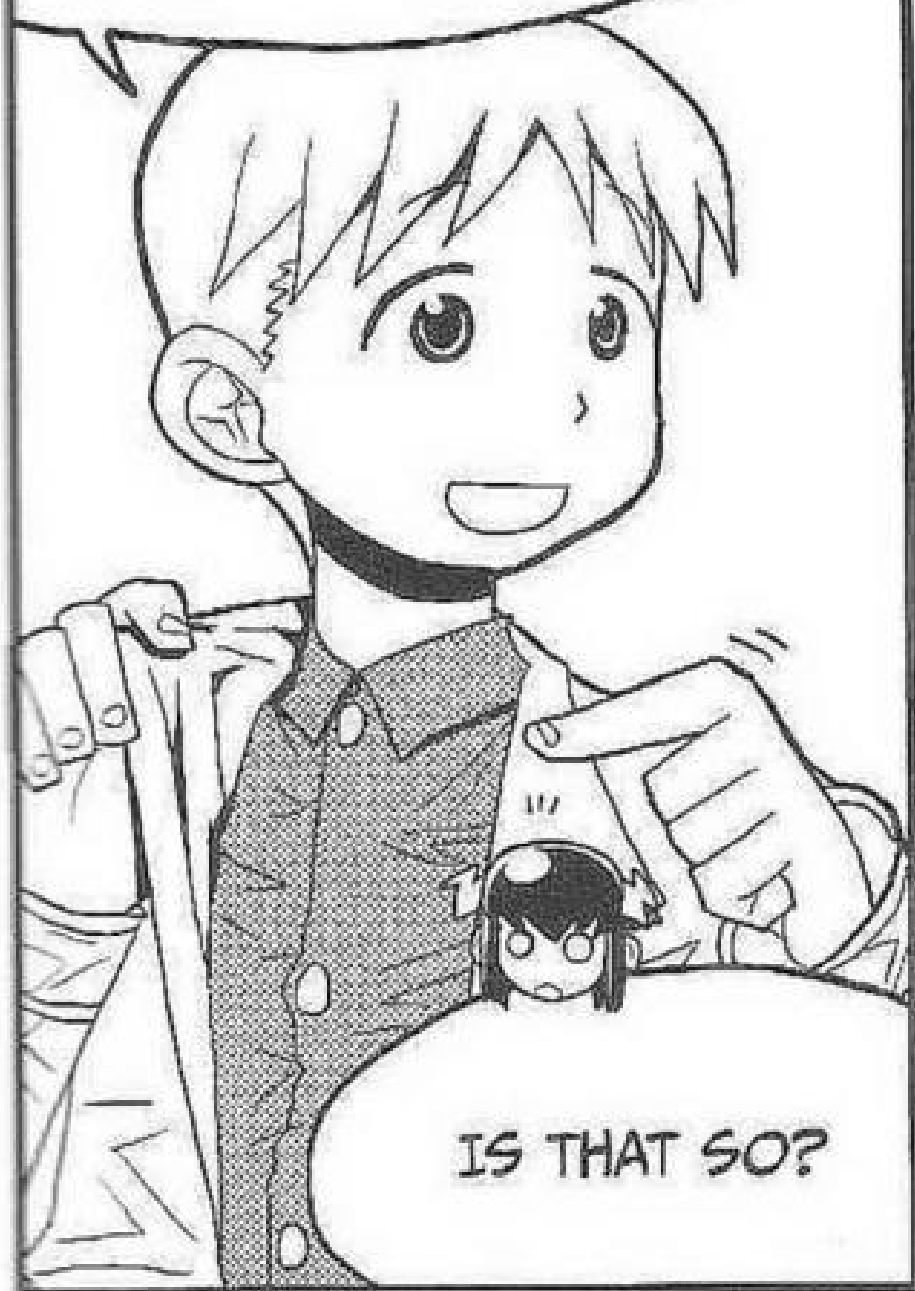


BRINGING THE CHARGED VINYL TO MY HAIR  
CAUSES CHARGE TO BE REDISTRIBUTED IN  
MY BODY - THE NEGATIVE CHARGE IN THE  
VINYL PUSHES ELECTRONS AWAY IN MY HAIR,  
GIVING IT A POSITIVE CHARGE. NOTE THAT  
THE OVERALL CHARGE IN MY BODY IS STILL  
NEUTRAL, AS THERE HAS BEEN NO EXCHANGE  
OF CHARGE BETWEEN ME AND THE VINYL.

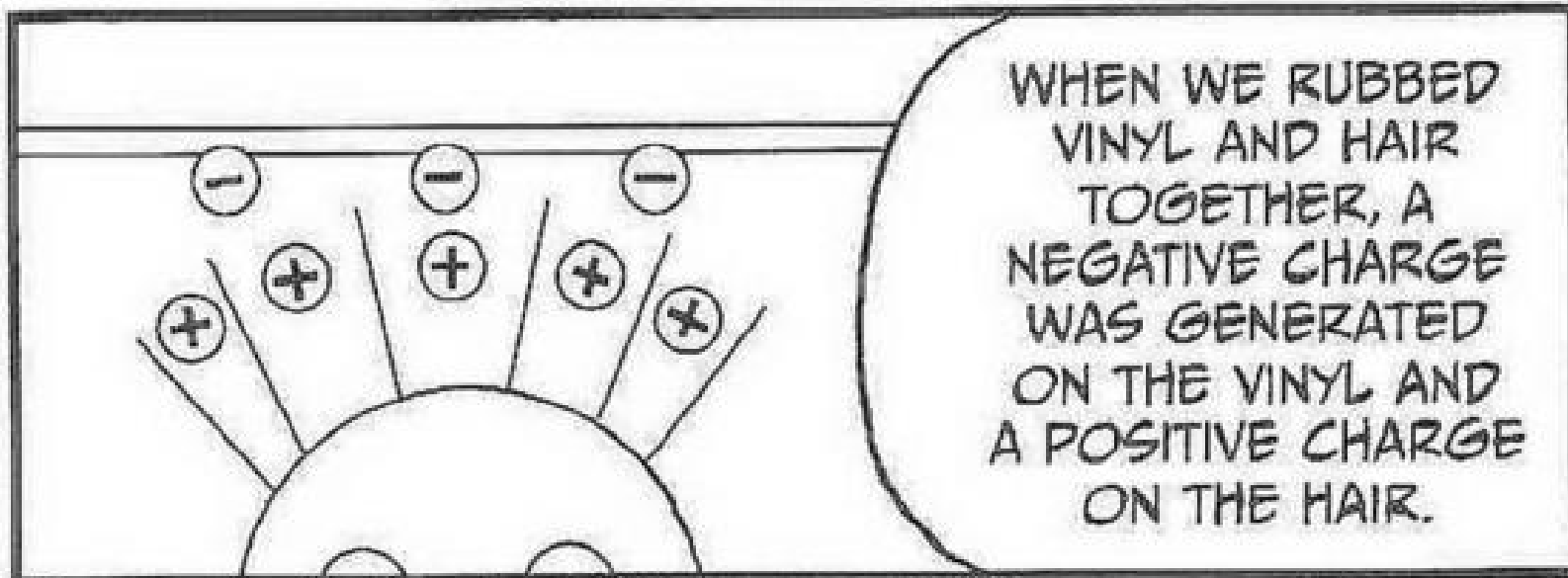
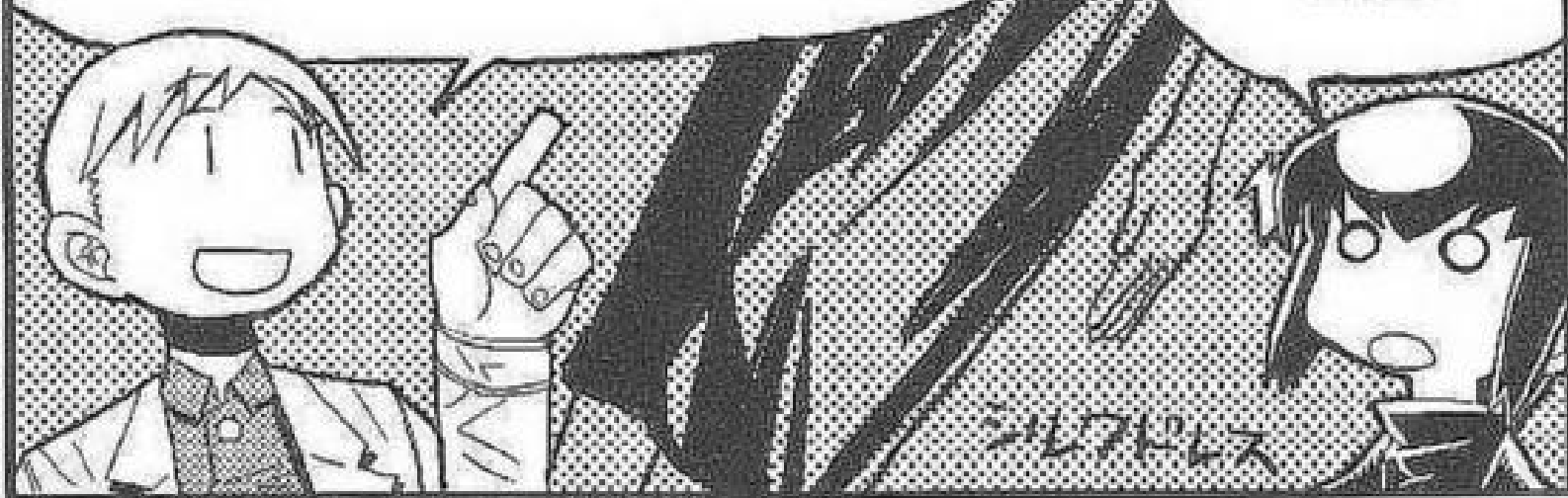




ALSO, SOME CLOTHES  
BECOME CHARGED  
EASILY, WHILE OTHERS  
DO NOT.



FOR EXAMPLE, SILK HAS GOOD  
WATER ABSORBENCY AND  
CONTAINS MUCH MORE MOISTURE  
THAN SYNTHETIC FIBERS DO.  
THEREFORE, IT CAN REDUCE  
THE OCCURRENCE OF STATIC  
ELECTRICITY.



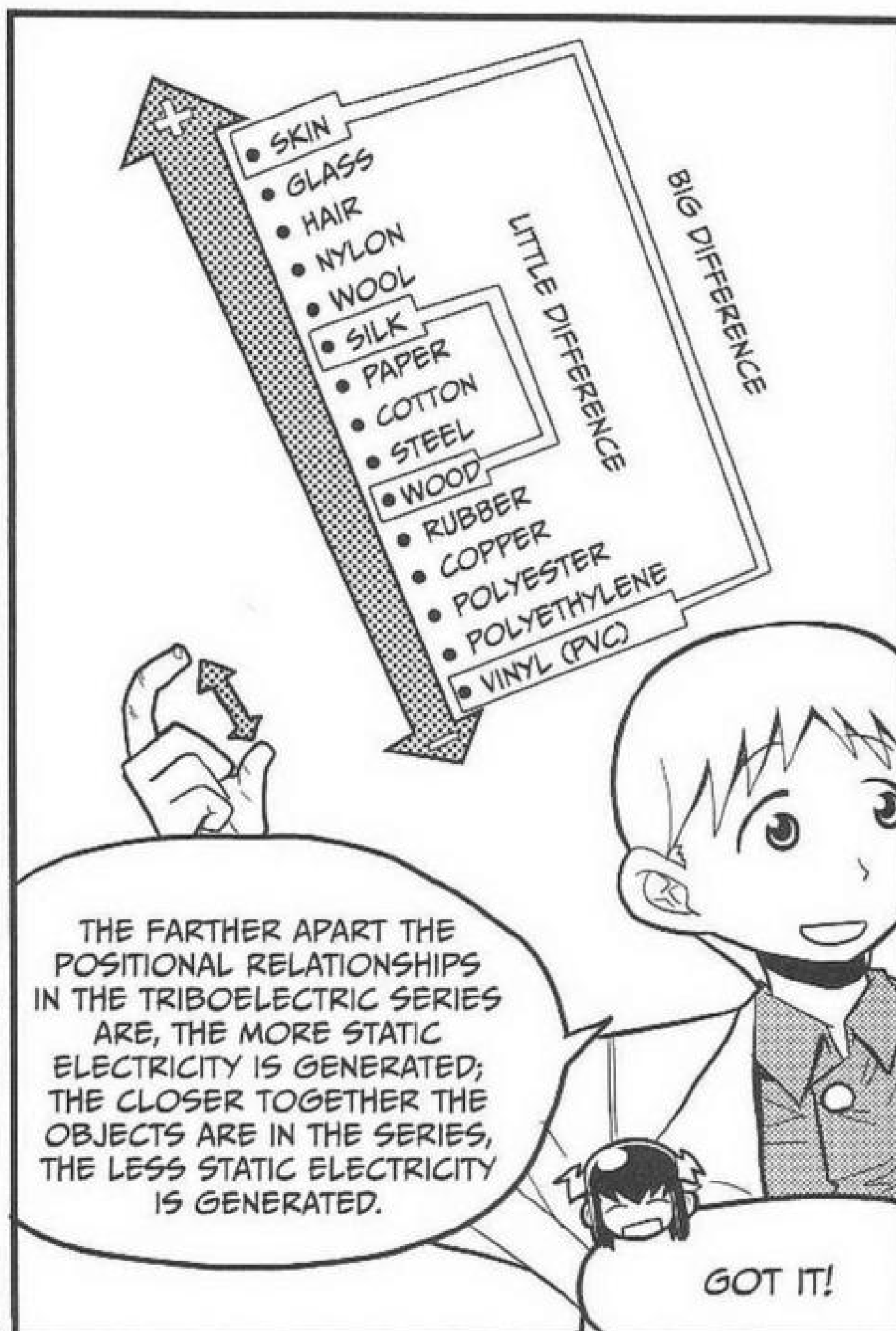
HOWEVER, THE POLARITY  
OF THE CHARGES THAT  
ARE GENERATED DIFFERS  
ACCORDING TO THE  
MATERIALS THAT ARE  
RUBBED TOGETHER.

THIS IS CALLED THE  
TRIBOELECTRIC  
SERIES.

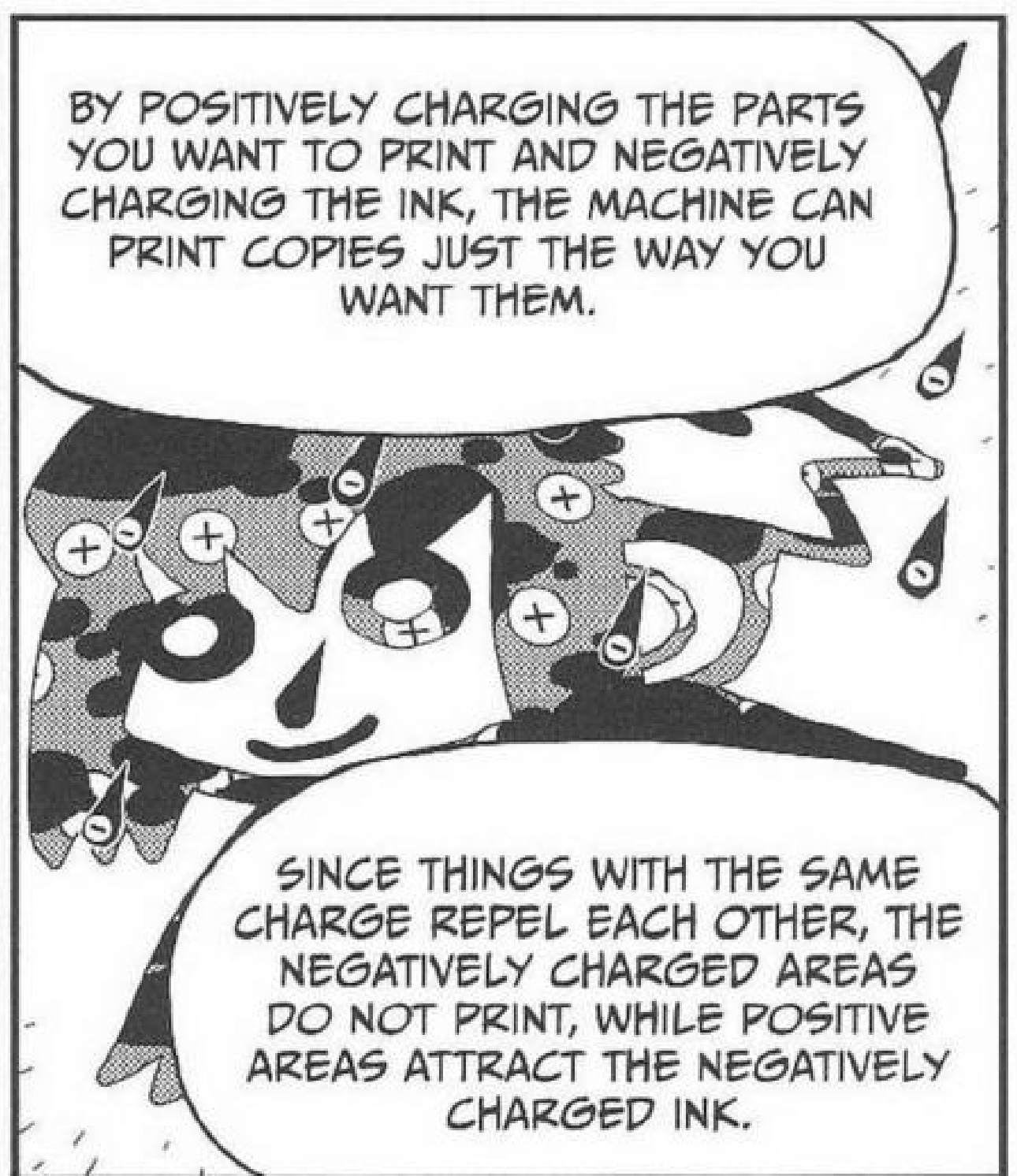
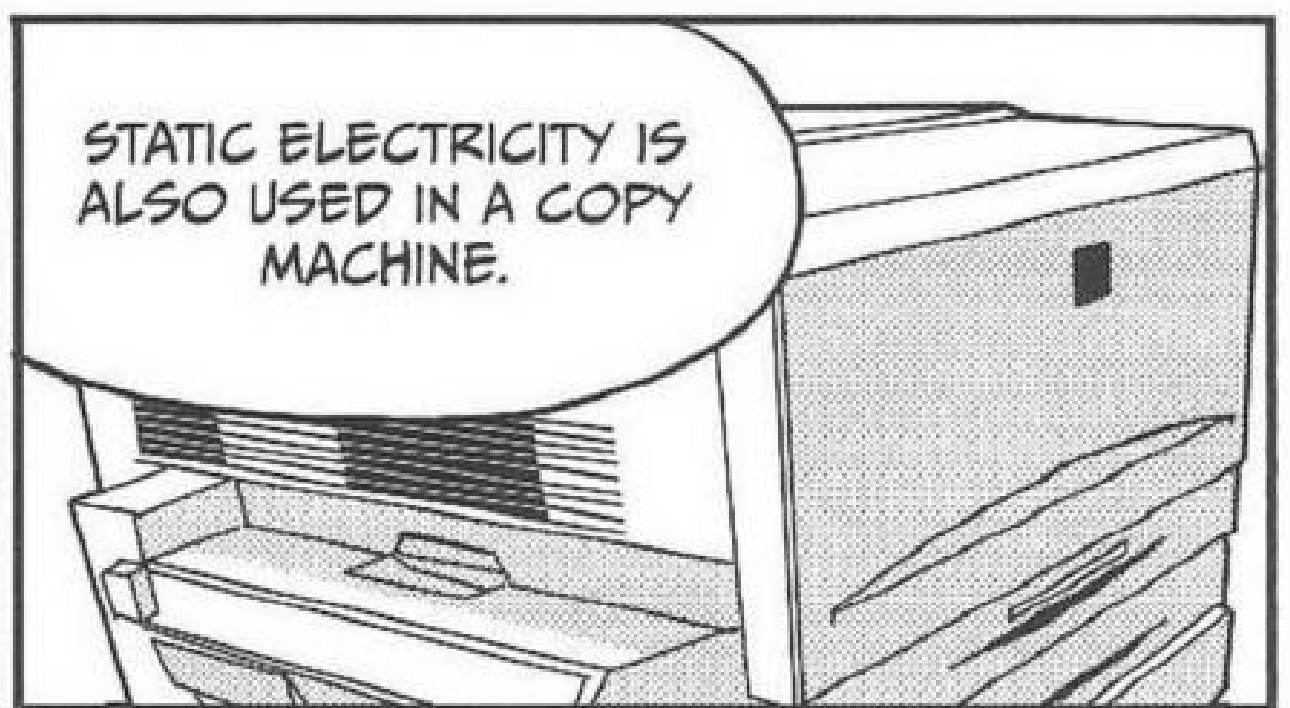
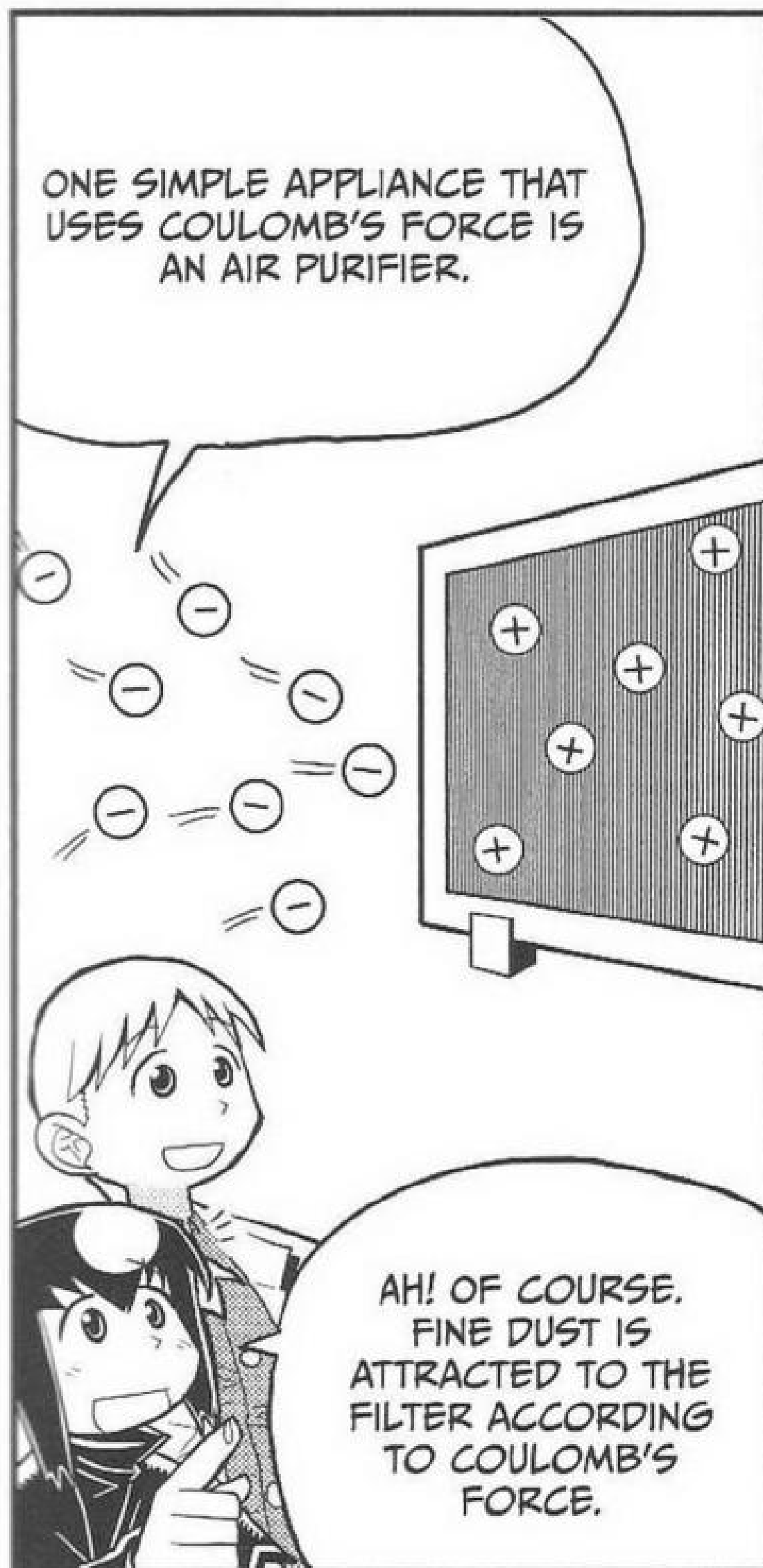
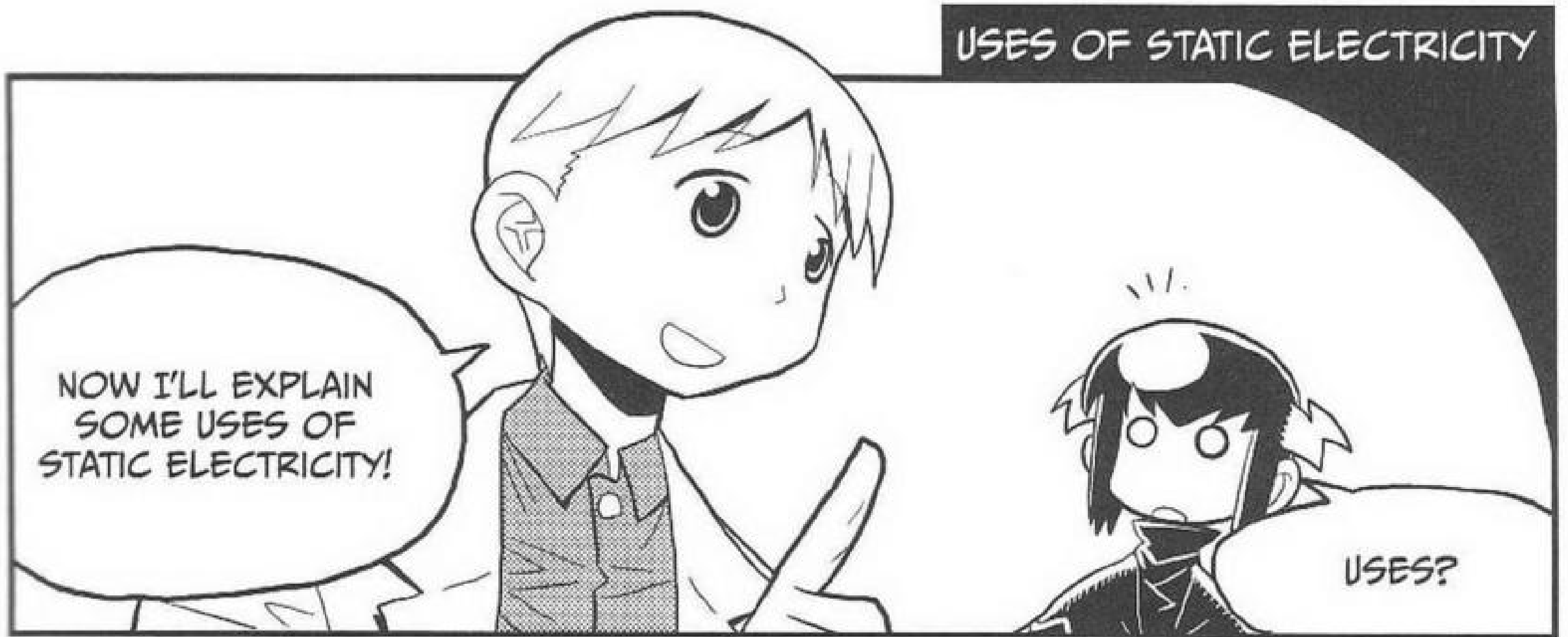
#### TRIBOELECTRIC SERIES

- 
- HUMAN SKIN
  - GLASS
  - HUMAN HAIR
  - NYLON
  - WOOL
  - SILK
  - PAPER
  - COTTON
  - STEEL
  - WOOD
  - RUBBER
  - COPPER
  - POLYESTER
  - POLYETHYLENE
  - VINYL (PVC)





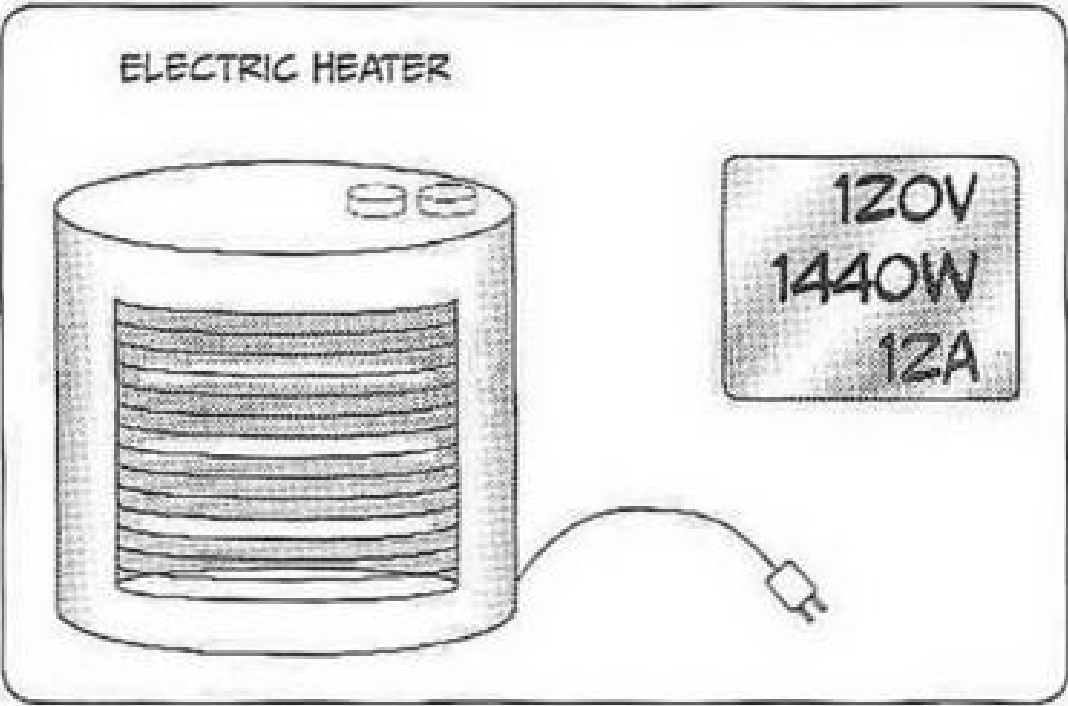






# TAGS ON CONSUMER ELECTRIC PRODUCTS

Consumer electric products have tags related to electricity with information such as voltage, current, and power—for example, 120V, 1440W, and 12A.



A tag on an electric heater

*Voltage*, the potential difference or “pressure” that makes electricity flow, is represented by the symbol  $V$ . The unit used to measure voltage is the *volt* ( $V$ ), which is named for the Italian physicist Alessandro Volta, who invented the battery. The voltage used in an ordinary household appliance is 120V in the United States, 240V in Europe, and 100V in Japan.

*Current* is the quantity of electricity flowing per second through an electric line, and it is represented using the symbol  $I$ , which comes from the initial letter of *Intensity of electricity*. Current is measured in *amperes* ( $A$ ), or *amps* for short, which are named for the French physicist André Marie Ampère. One amp is equal to one coulomb per second.

*Power*, which is the electric energy consumed in one second when current flows, is represented using the symbol  $P$ . Power is measured in *watts* ( $W$ ), which are named for the British mechanical engineer James Watt, who invented the steam engine. One watt is equal to one joule per second.

You can determine the power a device draws by multiplying its voltage and current. The power of a 120V device in which 12A of current flows is  $P = V \times I = 120V \times 12A = 1440W$ .

A typical American household contains many 120V devices. If you divide the power value that is displayed on each of these devices by 120V, you can find the value of the current that flows in each device. For devices with the same power, a 240V electronic device runs using half the current of an 120V electronic device.

Since  $P = V \times I$ , we can rearrange this equation to look like this using simple algebra.

$$I = \frac{P}{V}$$

For a 120V electric device...  $I = \frac{1440W}{120V} = 12A$  ...12A of current flows.

For a 240V electric device...  $I = \frac{1440W}{240V} = 6A$  ...6A of current flows.

## SI PREFIXES

1000W may also be represented by 1kW. This is because *k* stands for *kilo* and represents 1,000 or  $10^3$ . But we can use other prefixes, too: 3,600,000 joules (J) are equal to 3.6 megajoules (MJ). These prefixes for different powers of 10 are called *SI prefixes*, and they come from internationally determined rules for units called the *International System of Units (SI units)*. The most common ones are shown in the table below.

SI PREFIXES OFTEN USED IN ELECTRICAL RELATIONSHIPS

Prefix Symbol	Name	Quantity
T	tera	$10^{12}$ = 1,000,000,000,000
G	giga	$10^9$ = 1,000,000,000
M	mega	$10^6$ = 1,000,000
k	kilo	$10^3$ = 1,000
m	milli	$10^{-3}$ = 0.001
$\mu$	micro	$10^{-6}$ = 0.000 001
n	nano	$10^{-9}$ = 0.000 000 001
p	pico	$10^{-12}$ = 0.000 000 000 001

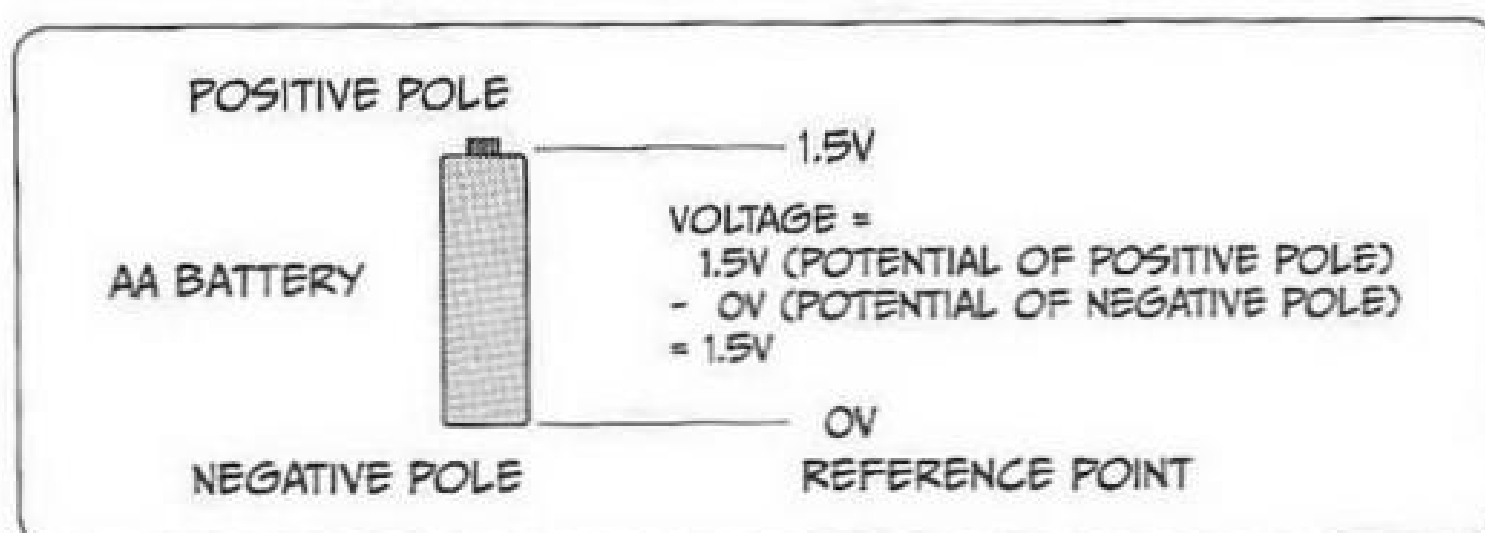
You can find the amount of *energy*, which is the total amount of *work* done by an electrical device, by multiplying the power it draws and the time the device operates. Power is often measured by power companies in kWh (kilowatt hours). For example, if an electric heater with 1kW is used for 1 hour, the amount of energy it uses is  $1\text{kW} \times 1 \text{ hour} = 1\text{kWh}$ .

However, when time is represented in seconds, Ws (watt second) can be used for the energy's unit. A watt-second is equivalent to a *joule (J)*. For example, when a 1kW electric heater is used for 1 hour, since  $1 \text{ hour} = 60 \text{ minutes} \times 60 \text{ seconds} = 3600 \text{ seconds}$ , the amount of energy used is  $1\text{kW} \times 3600 \text{ seconds} = 3600\text{kWs}$  or 3,600,000 joules.

You can calculate how much it will cost to use an ordinary household appliance by multiplying the amount of energy used (in kWh) by the utility company's price per kWh (you will also need to add in any flat-rate charges, if your utility company has them). Since the average electrical utility charge for 1kWh in the United States is approximately 12 cents for 1kWh, if a device with 1kW of power is used for 1 hour, the amount of energy used is 1kWh, and the electrical utility charge will be approximately 12 cents.

## VOLTAGE AND POTENTIAL

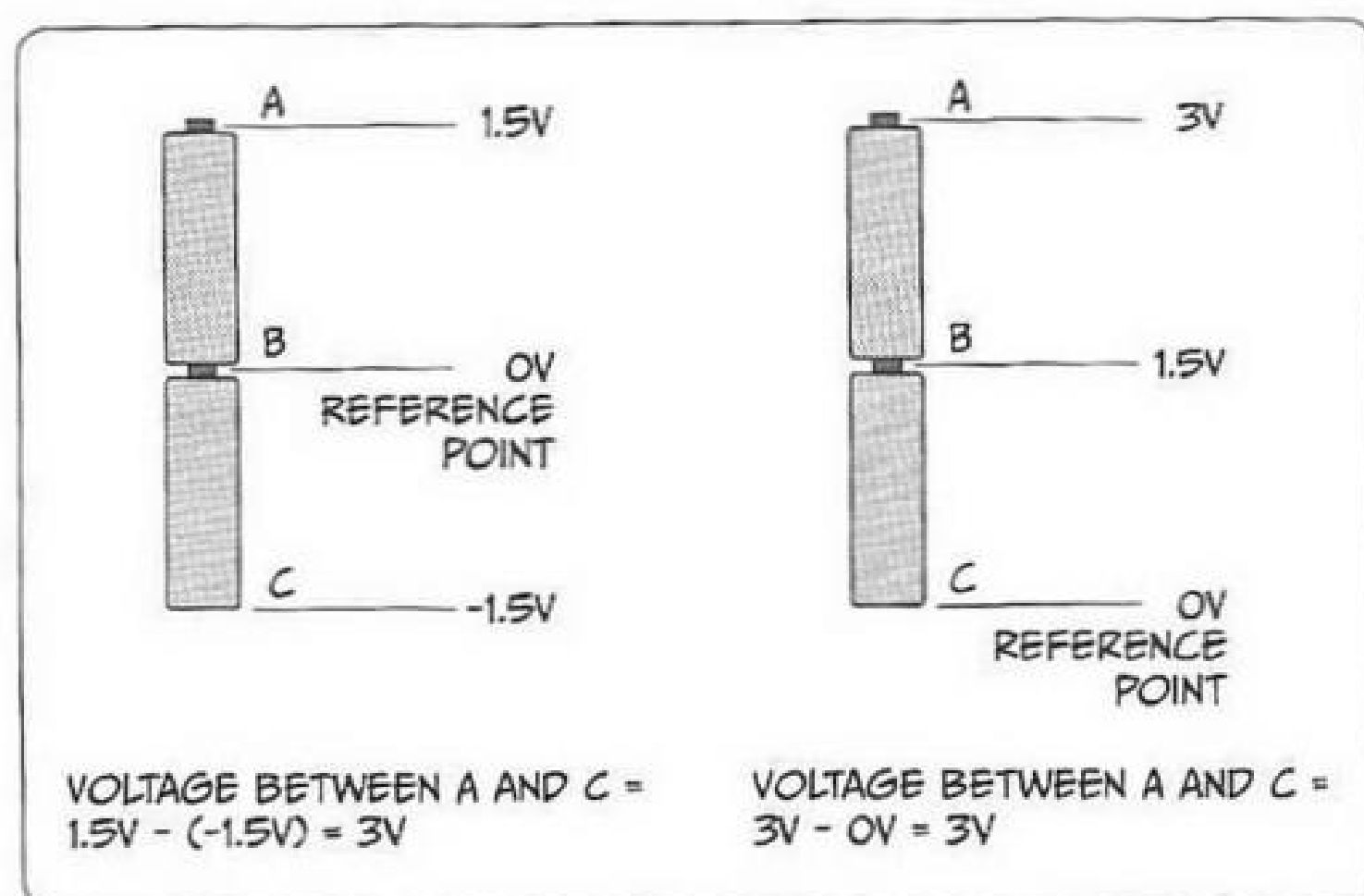
Electricity flows from a high potential to a low potential. The potential difference between two points is called *voltage*. For example, for a AA battery, if we let the negative pole be the reference point, then the potential of the negative pole is 0V and the potential of the positive pole is 1.5V. The potential difference between the positive and negative poles is the *supply voltage* of this battery.



Supply voltage of a AA battery

If we stack two batteries and let the reference point be point B, the potential of point A is 1.5V, the potential of point B is 0V, and the potential of point C is -1.5V. The voltage between points A and C can be obtained by subtracting the potential of point C from the potential of point A; the voltage, in this case, is 3V. If we let point C be the reference point, the potential of point C is 0V, the potential of point B is 1.5V, and the potential of point A is 3V. The voltage is still 3V.

The larger the difference in electrical potential, the larger the voltage.



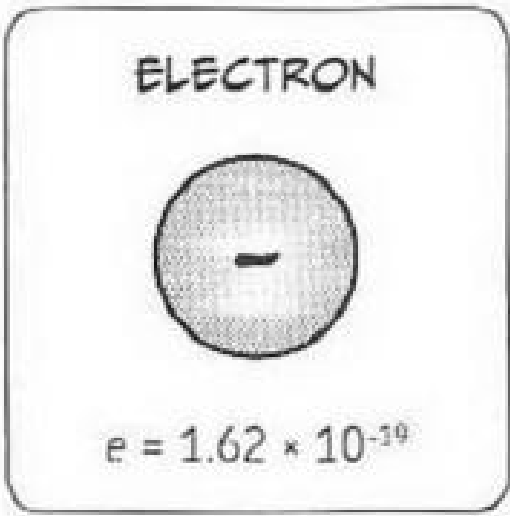
The voltage when two batteries are stacked

## ATOMS AND ELECTRONS

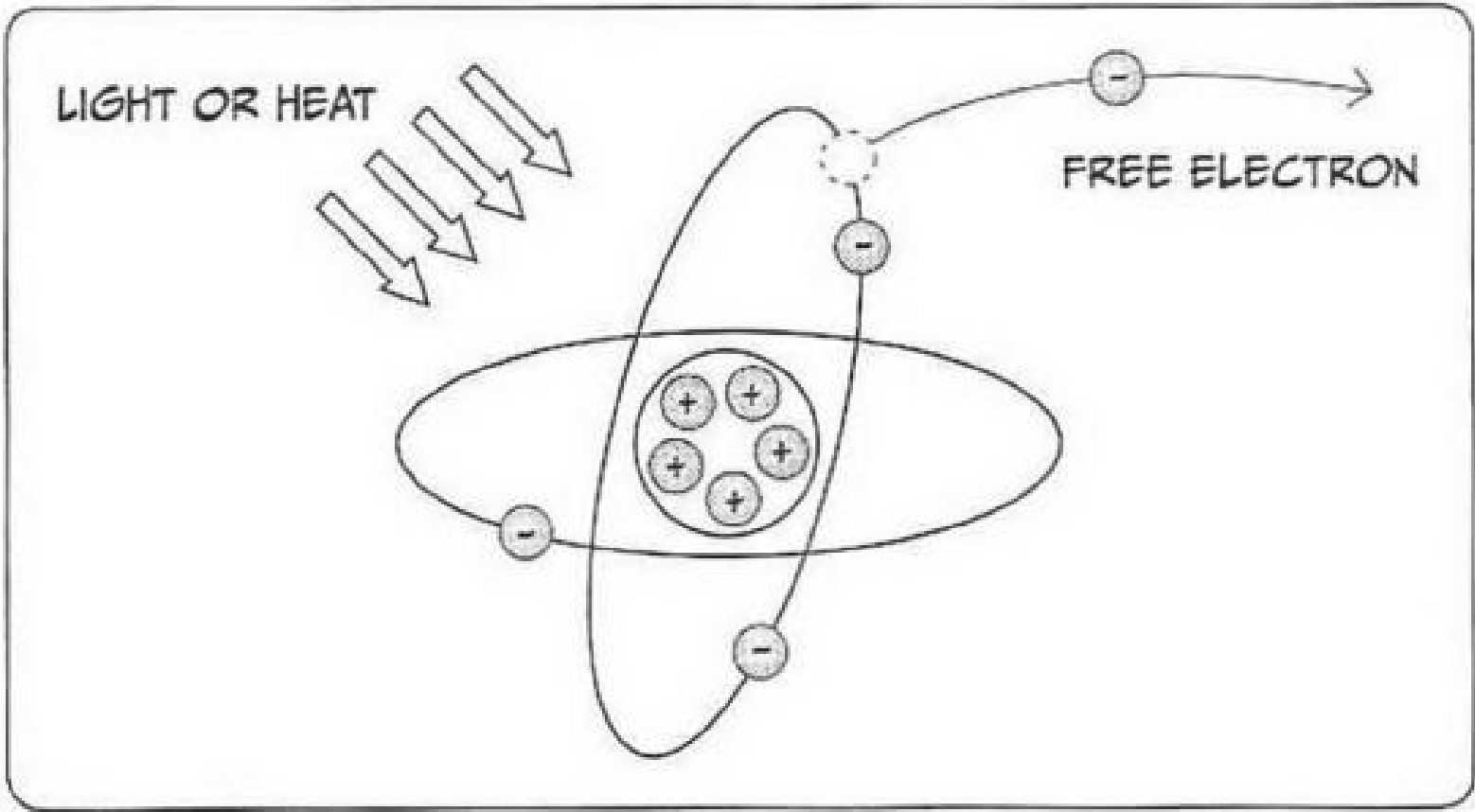
All substances are made of atoms. An *atom* consists of a nucleus, which is made of protons and neutrons, and electrons. Since protons have a positive charge and neutrons are electrically neutral, the nucleus itself is electrically positive. Electrons, on the other hand, have a negative charge. But since protons and electrons are equally and oppositely charged, an atom is typically electrically neutral.

Electrons move around the nucleus in a series of orbits called *electron shells*. Since the attraction from the nucleus is weaker for electrons in the outermost shells than ones in the innermost shells, electrons in those outermost shells may escape from orbit if external energy such as heat or light is applied. An electron that has escaped from orbit can move around freely and is called a *free electron*. In substances like copper and other metals,





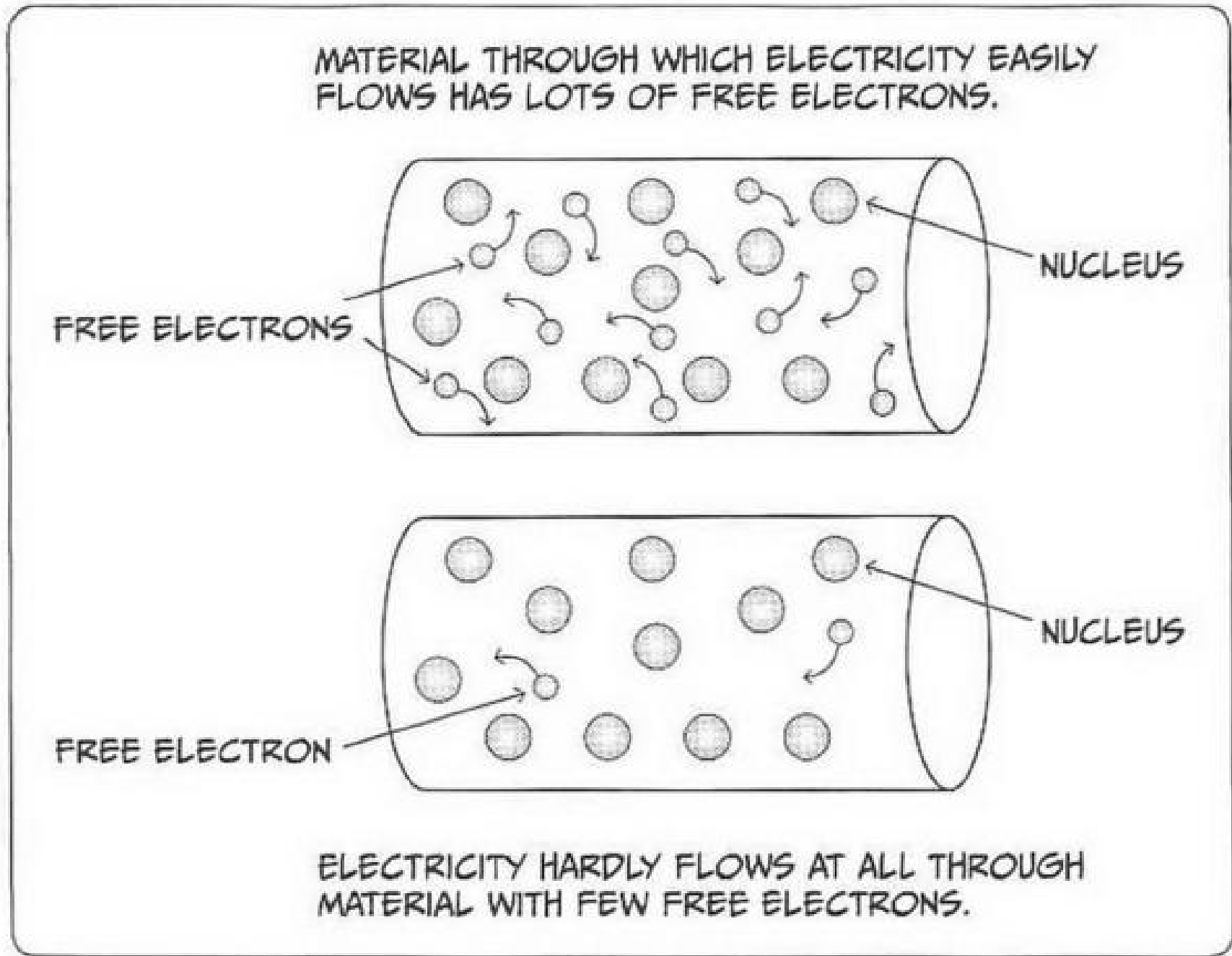
The smallest quantity of electricity that exists in the natural world is a single electron.



The escape of an electron

through which electricity easily flows, there are many free electrons, and if a voltage is applied to this substance, the free electrons all flow in one direction. This is how electricity flows through an electric line. The outermost electron shell of an atom is called the *valence shell*, and the electrons that are in it are called *valence electrons*.

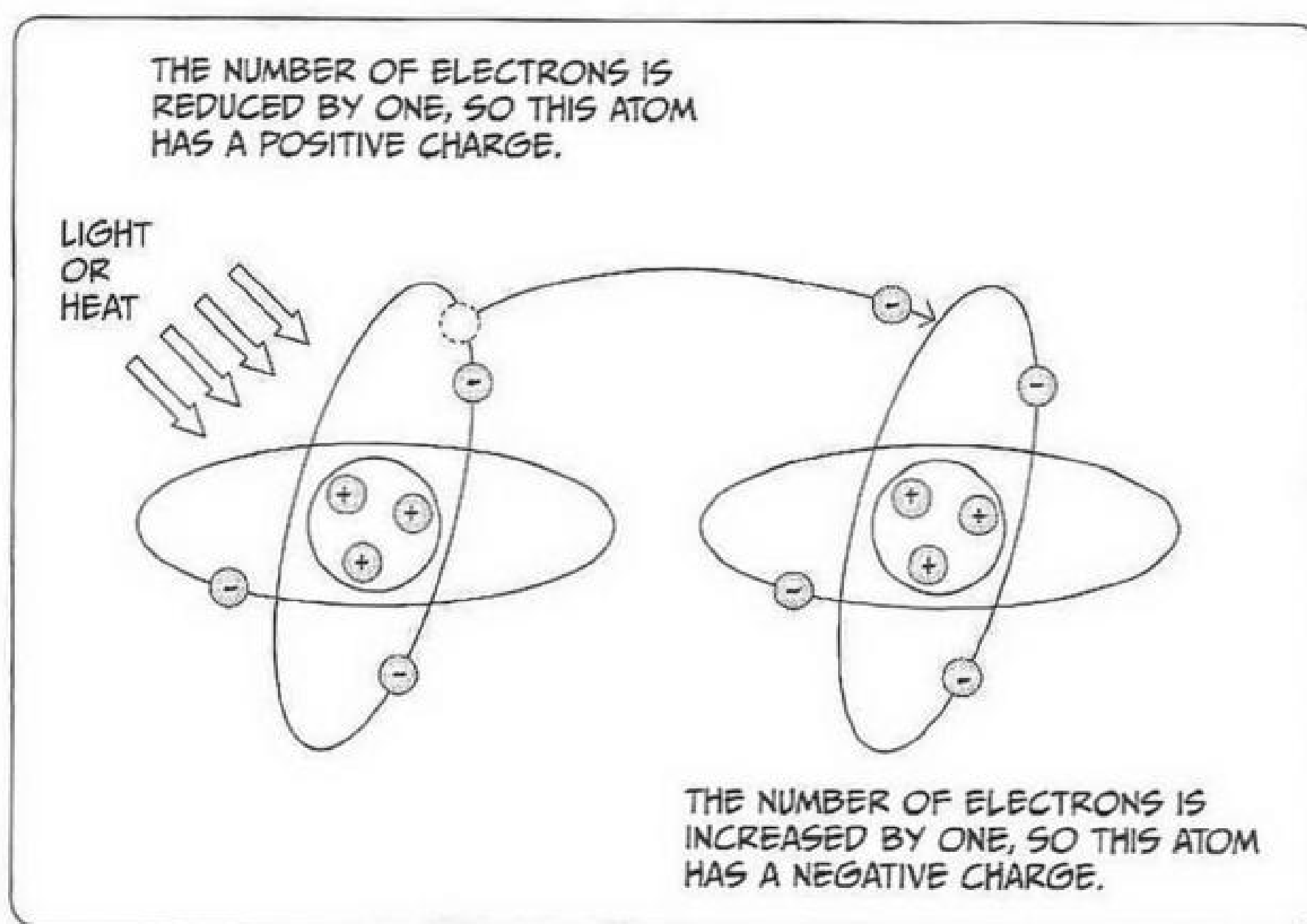
The total number of electrons in an atom is the same as that atom's atomic number. Although there are many atoms with high atomic numbers and a lot of electrons, those substances are not necessarily ones through which electricity easily flows—the flow of electricity depends on the number of valence electrons.



Different materials have different amounts of free electrons.

# STATIC ELECTRICITY

When two different substances are rubbed together, atoms collide, and electrons that are easily separated from the atoms of one substance may escape and move to the atoms of the other substance. At this time, the substance that lost electrons becomes positively charged, and the substance that gained electrons becomes negatively charged. A substance that carries electricity in this way is said to be *charged*, and since this electricity is stationary (that is, it's not flowing), it is called *static electricity*. The quantity of the positive charge that is generated by this process is always the same as the quantity of the negative charge. Since static electricity is generated by friction, it is also called *frictional electricity*.

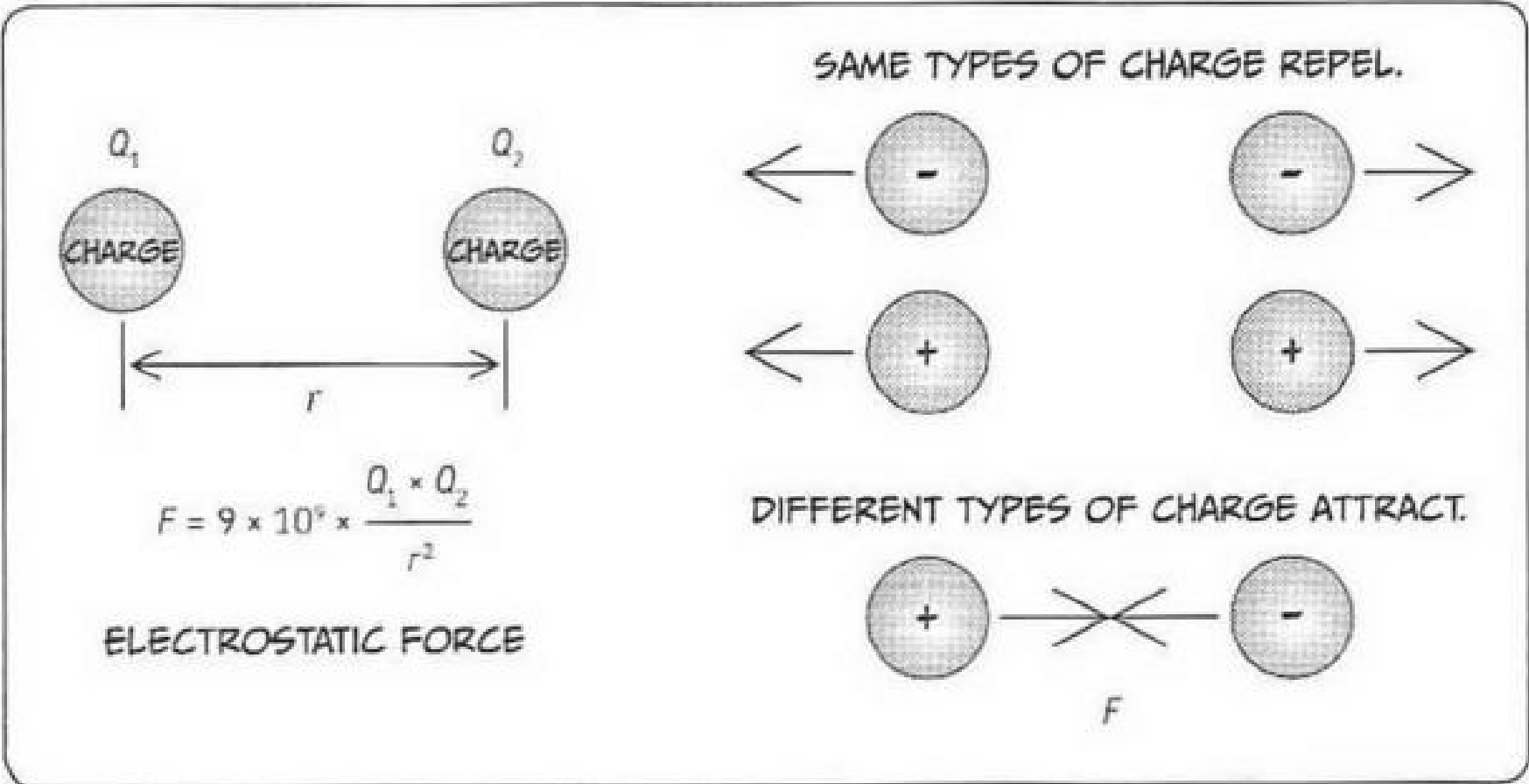


Electron movement and electric charge

## ELECTROSTATIC FORCE

Charge is measured in *coulombs* and is represented by  $Q$ , the quantity of charge. The name of the unit comes from Charles Augustine Coulomb, a French physicist who studied electricity.

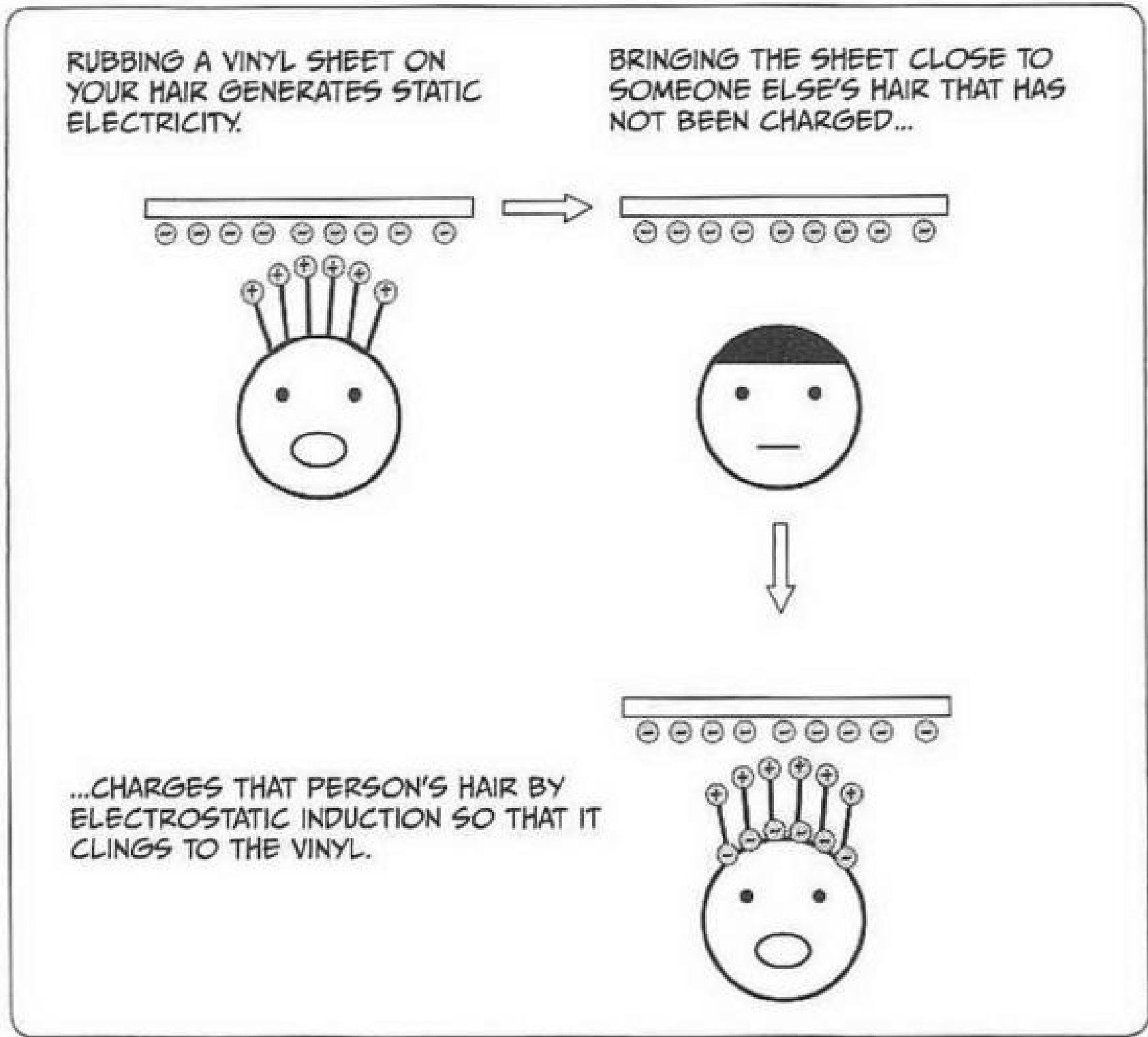
A force called *electrostatic force* (also known as *Coulomb's force*) operates between two charges. This force causes the same types of charge to repel each other and different types of charge to attract each other. The size of the electrostatic force  $F$  of attraction or repulsion (measured in a unit called a newton) operating between charge  $Q_1$  and  $Q_2$  is directly proportional to the product of  $Q_1$  and  $Q_2$  and inversely proportional to the square of the distance ( $r$  meters) between the charges. The stronger the charges, and the smaller the distance, the larger the resulting electrostatic force. This is called *Coulomb's law* with respect to static electricity.



Electrostatic force operating between charges and Coulomb's law

If static electricity is generated by rubbing a vinyl sheet on a person's hair, the hair has a positive charge, the vinyl has a negative charge, and the hair clings to the vinyl due to the electrostatic force.

Also, if the negatively charged vinyl sheet is brought close to hair that has not been charged, the hair will become positively charged and will cling to the vinyl. This phenomenon, in which something that is not charged becomes charged when it is in close proximity to something else that is charged, is called *electrostatic induction*.

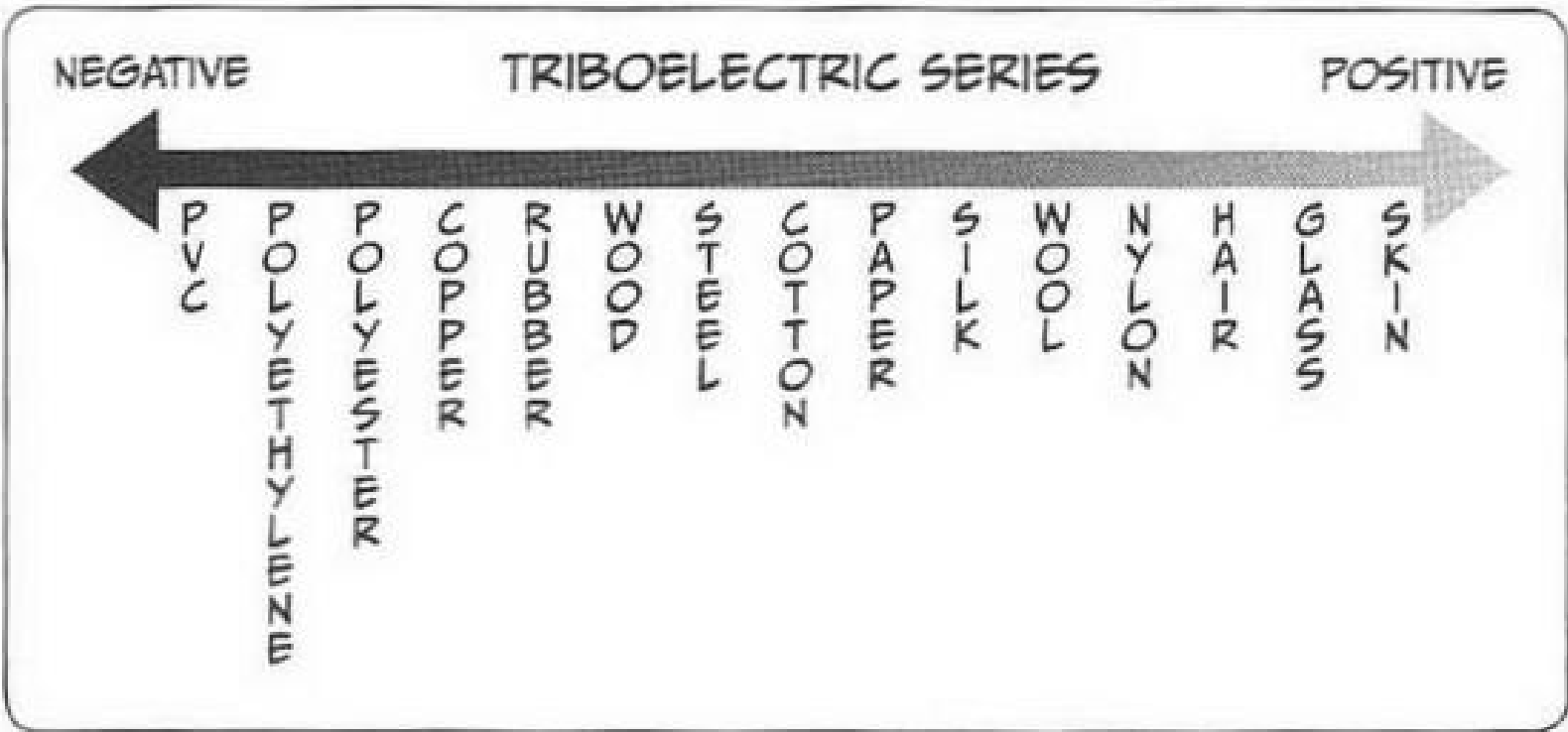


Electrostatic induction

# THE TRIBOELECTRIC SERIES

Static electricity is more easily generated as the air gets drier—humidity prevents static electricity from gathering on a surface. Also, some clothes easily become charged, while others do not, depending on the material they are made from. Since silk has good water absorbency and contains much more moisture than synthetic fibers, it can reduce the occurrence of static electricity.

The polarities of the charges that are generated by friction differ according to the materials that are rubbed together. These differences are represented by the *triboelectric series*. For example, if hair and cotton are rubbed together, the hair will become positively charged and the cotton will become negatively charged, but for cotton and vinyl, the cotton will become positively charged and the vinyl will become negatively charged.



The triboelectric series

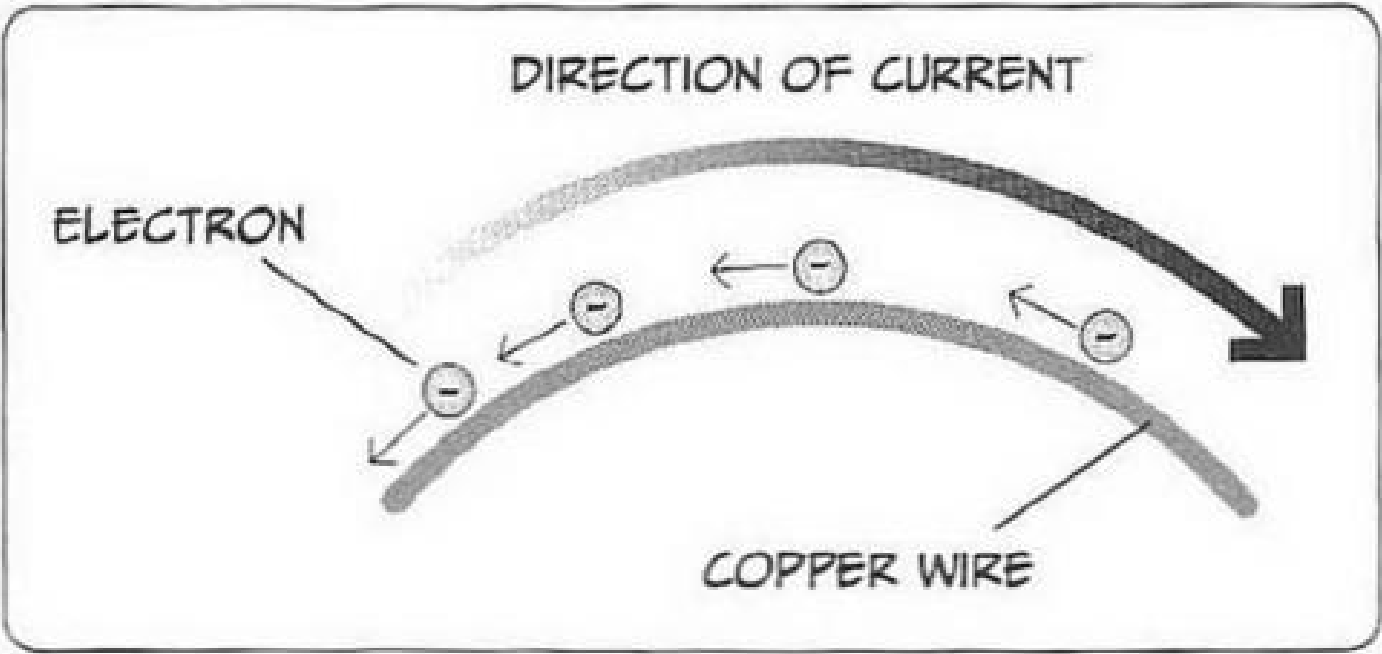
The farther apart the materials are in the triboelectric series, the more static electricity is generated between them, and the closer together the objects are in the triboelectric series, the less static electricity is generated. In other words, you can reduce the occurrence of static electricity by wearing clothes that are made of materials that are close together in the triboelectric series.

## MOVEMENT OF CHARGE AND DIRECTION OF CURRENT

Lightning is also a result of static electricity. Lightning occurs when the static electricity that is produced by the friction between hail and ice particles in a cloud discharges between the cloud and ground. In the case of lightning, air (which is an insulator through which electricity has difficulty flowing) exists between the positive and negative charges, so a discharge does not easily occur.

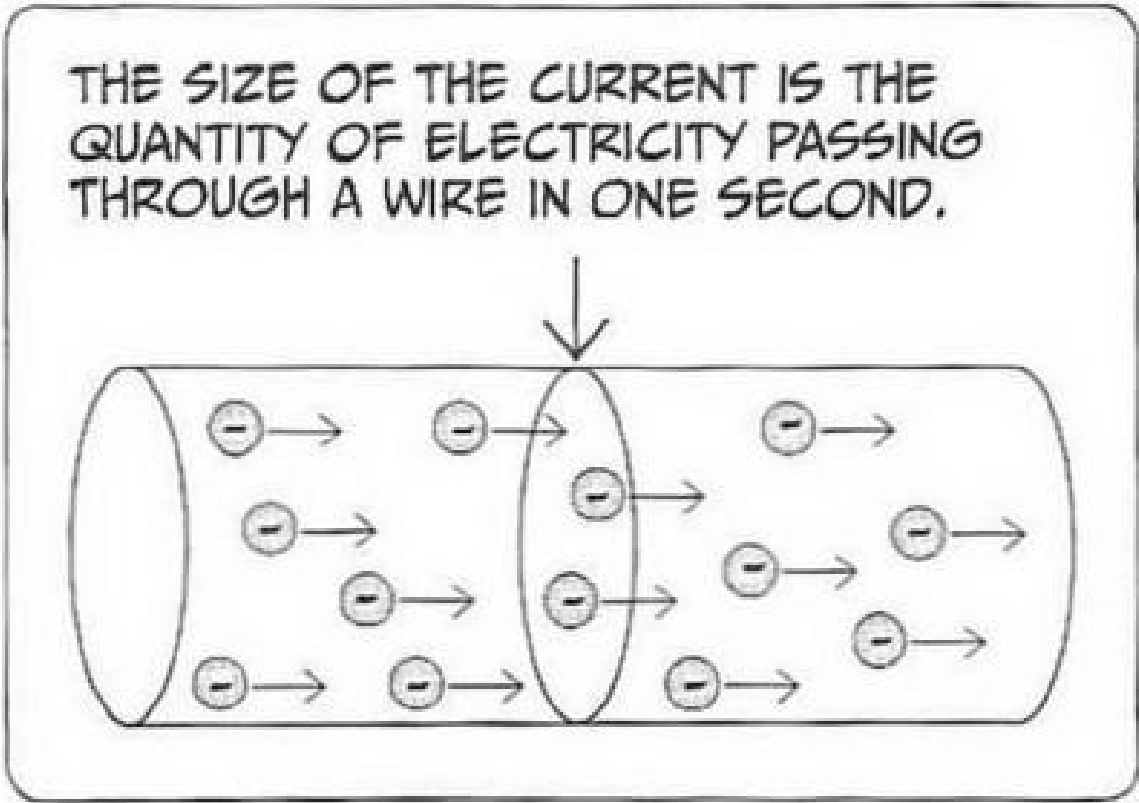
When a large amount of charge builds up and the potential difference between the positive and negative charges is extremely large, the insulation of the air suddenly breaks down and an electrical discharge occurs. *Electrical discharge* is the phenomenon in which charge flows continuously. This continuous flow of electricity is called *current*.

Electric current flows from positive to negative. Scientists have discovered that the movement of electrons, however, is from negative to positive. Therefore, the direction in which the electrons move is actually opposite to the direction in which current flows.



Direction of current and direction of electron movement

The amount of current is represented by the quantity of electricity passing through a wire in a second.



Size of the current

For example, when a charge of 1C passes through a given point, the current  $I$  can be obtained by dividing the charge ( $Q$ ) in coulombs by the time ( $t$ ) in seconds as follows.

$$I = \frac{Q}{t} = \frac{1\text{C}}{1\text{s}} = 1\text{A}$$

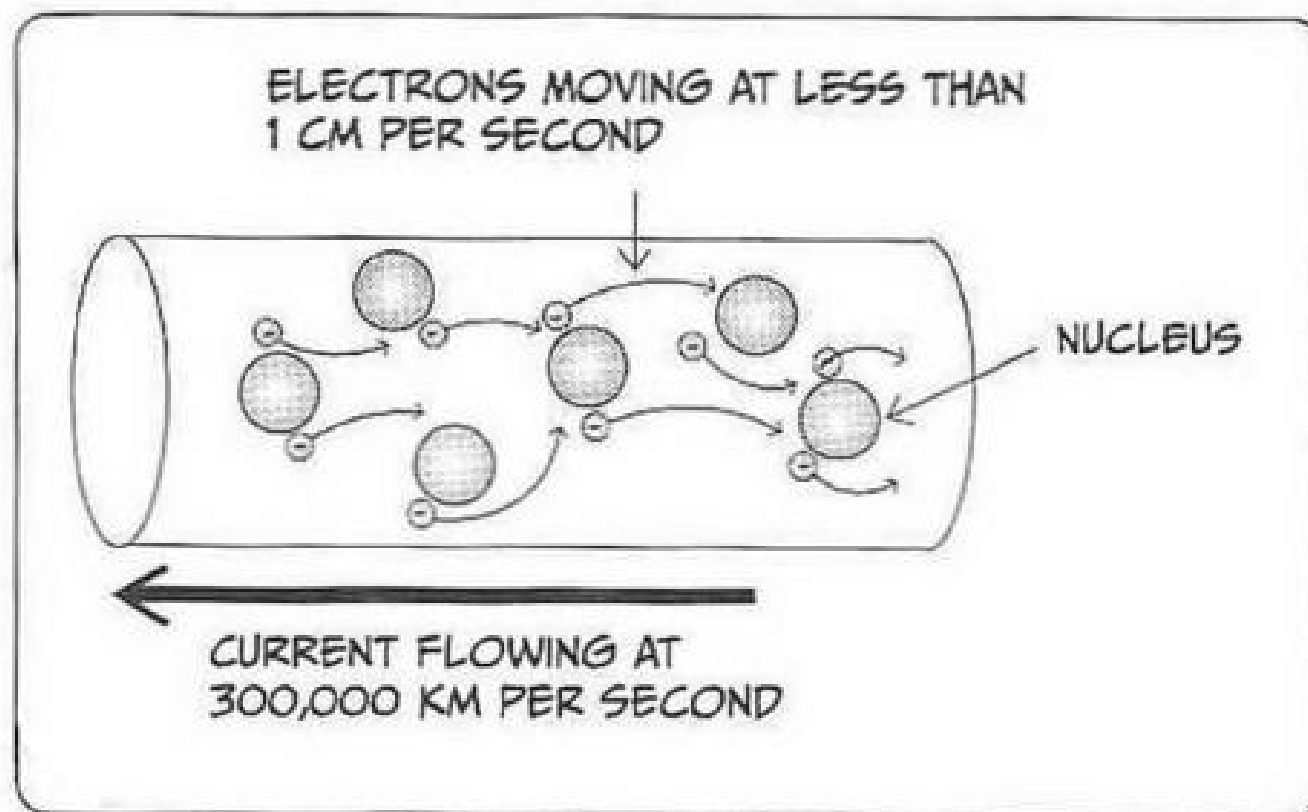
Also, the number of electrons flowing at 1A can be obtained by dividing 1C by the quantity of charge in 1 electron, as follows:

$$\frac{1\text{C}}{1.602 \times 10^{-19}\text{C/electron}} = 6.24 \times 10^{18} \text{ electrons}$$

In other words, when a current of 1A is flowing, there are  $6.24 \times 10^{18}$  electrons flowing per second.



The speed at which the electrons move is very slow—less than 1 cm per second. However, the speed at which electrical motion is transmitted to neighboring electrons is the same as the speed of light: 300,000 km per second. Therefore, the current also flows at 300,000 km per second (the speed of light).



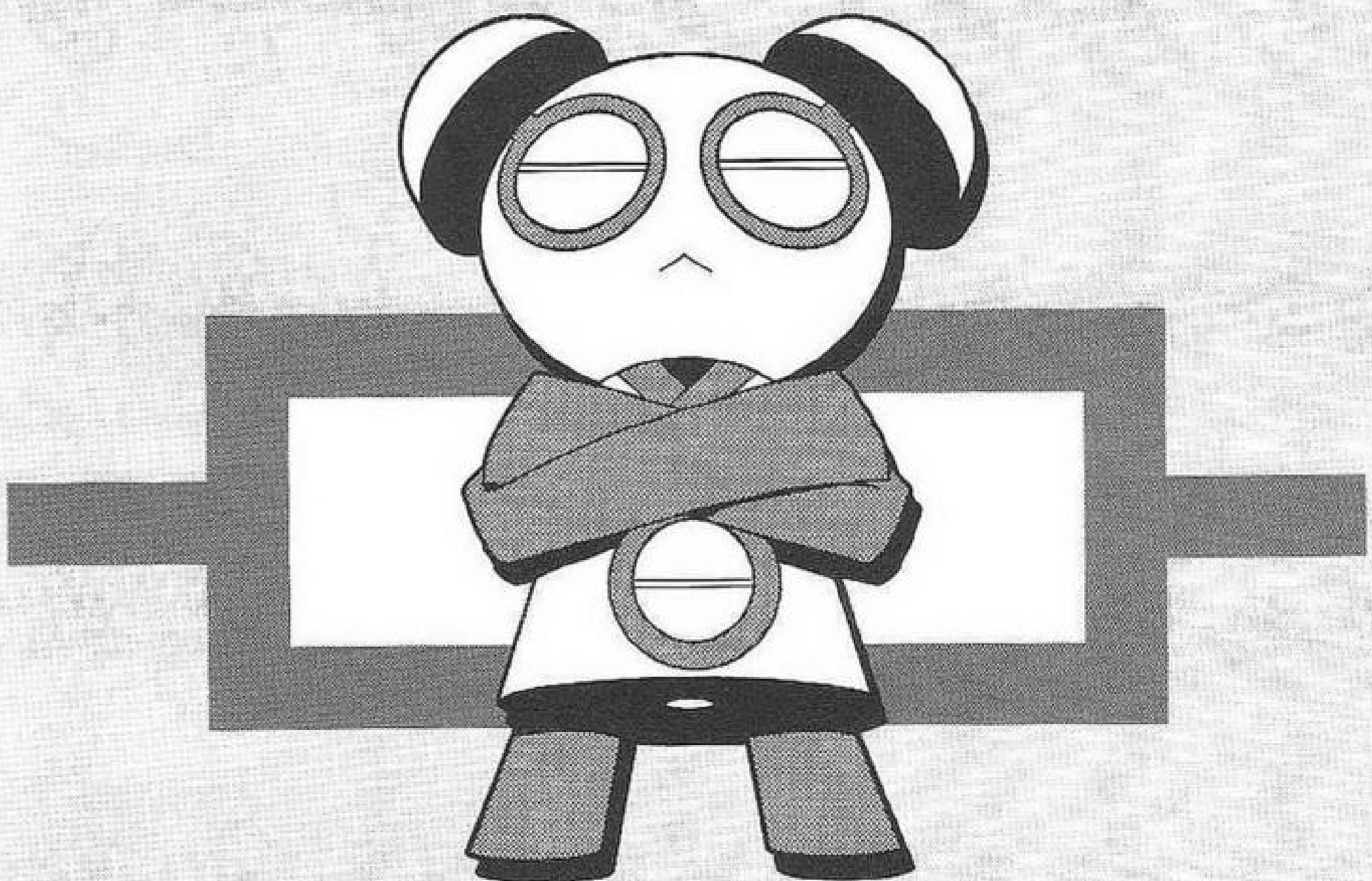
*Speed of electrons and speed of current*

Although electricity itself cannot be seen with the naked eye, heat or light is often produced when current flows. Therefore, we know that electricity exists by observing the phenomena caused by current.



2


WHAT ARE ELECTRIC CIRCUITS?




ELECTRIC CIRCUITS IN  
EVERYDAY DEVICES



THANK YOU FOR  
LOANING ME THESE  
CLOTHES!



SURE! YOU STUCK OUT  
LIKE A SORE THUMB  
WALKING AROUND IN  
THAT CRAZY OUTFIT.




MANY ELECTOPIANS  
WHO HAVE COME  
TO EARTH LIVE  
PERFECTLY FINE  
WEARING THEIR  
REGULAR CLOTHES!

REALLY!?



DO YOU REALLY  
THINK SO?



OF COURSE!  
THEY HANG OUT AT  
PLACES LIKE HARAJUKU...



WELL...



WE'RE HOME!



HUH? THE LIGHTS  
WON'T TURN ON.

HMM...JUST A SECOND.



UH OH!

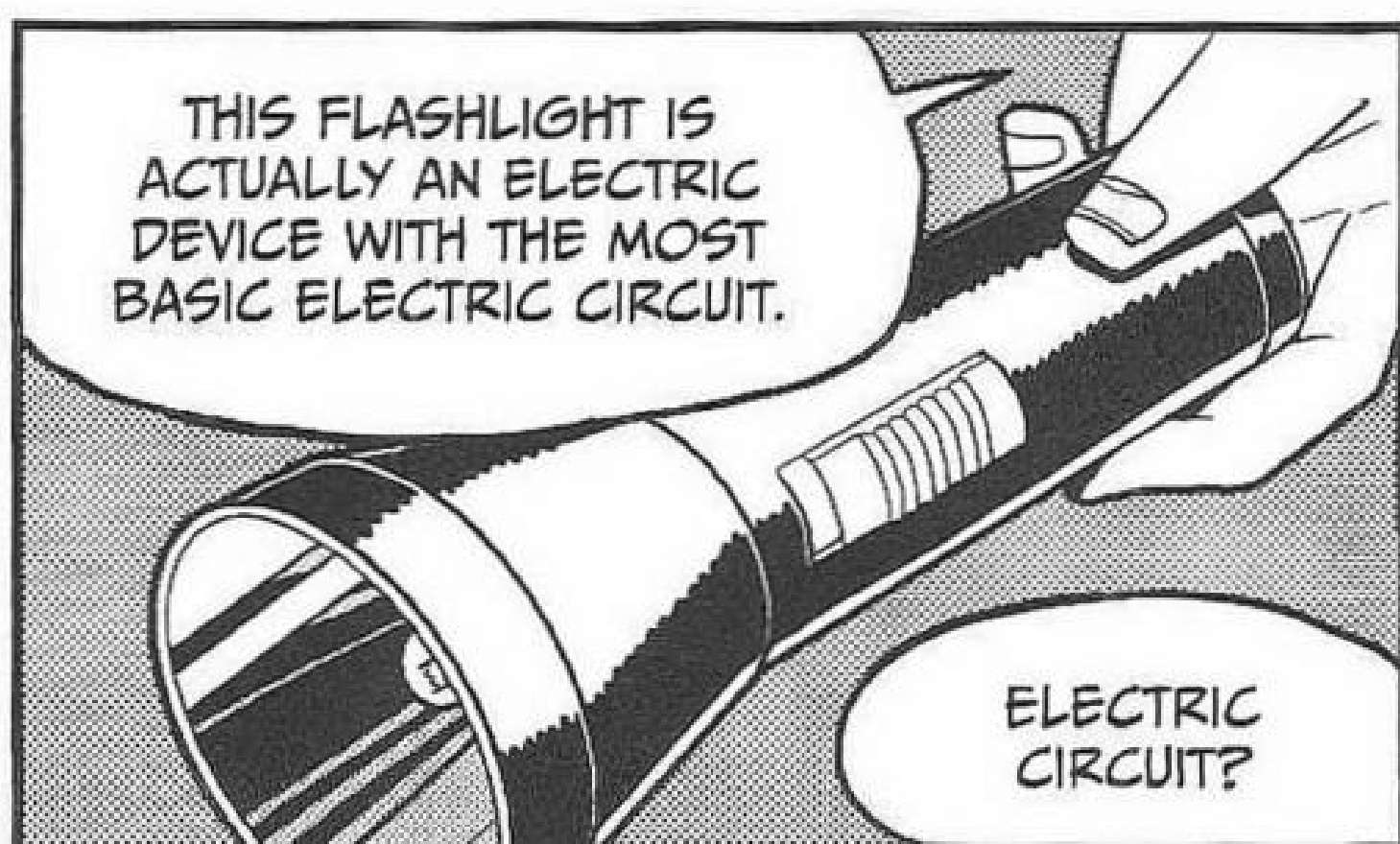
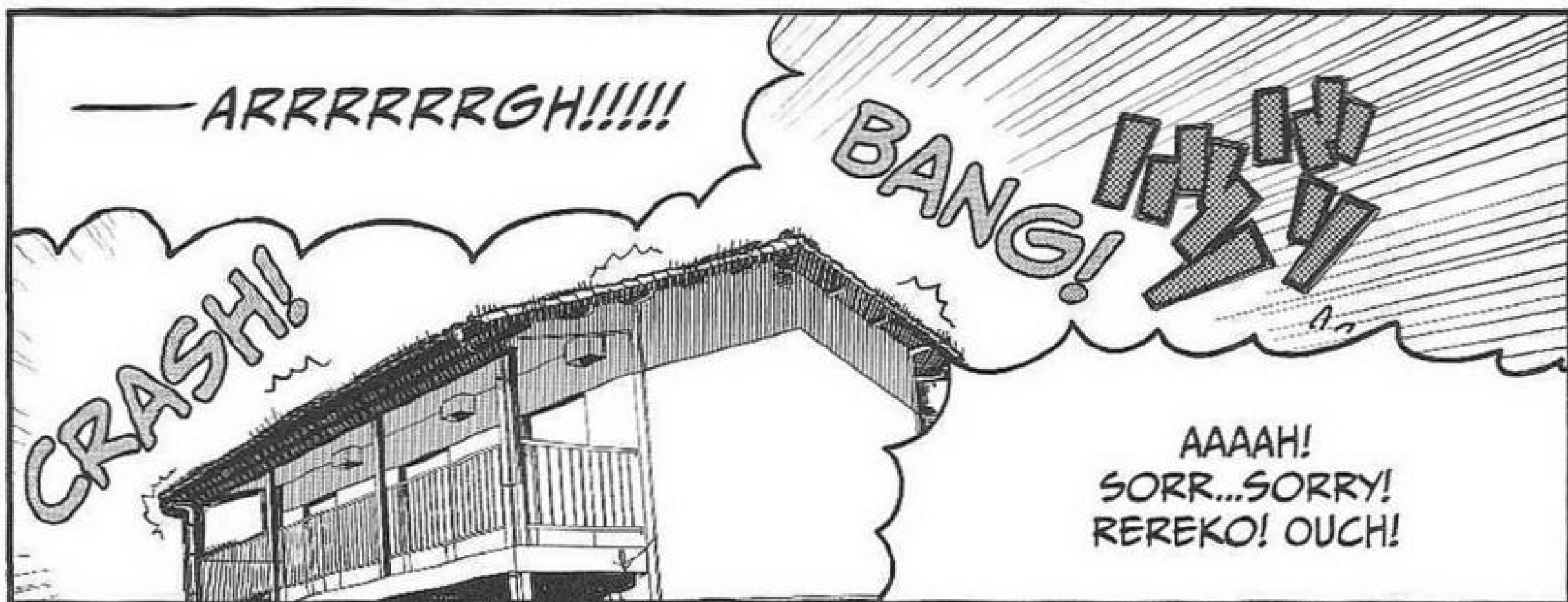
EVEN HIKARU SENSEI, WHO  
NORMALLY WOULDN'T HURT  
A FLY, COULD BEHAVE VERY  
DIFFERENTLY WHEN LEFT IN THE  
DARK WITH A BEAUTIFUL GIRL....



HEY,  
REREKOOOOO...

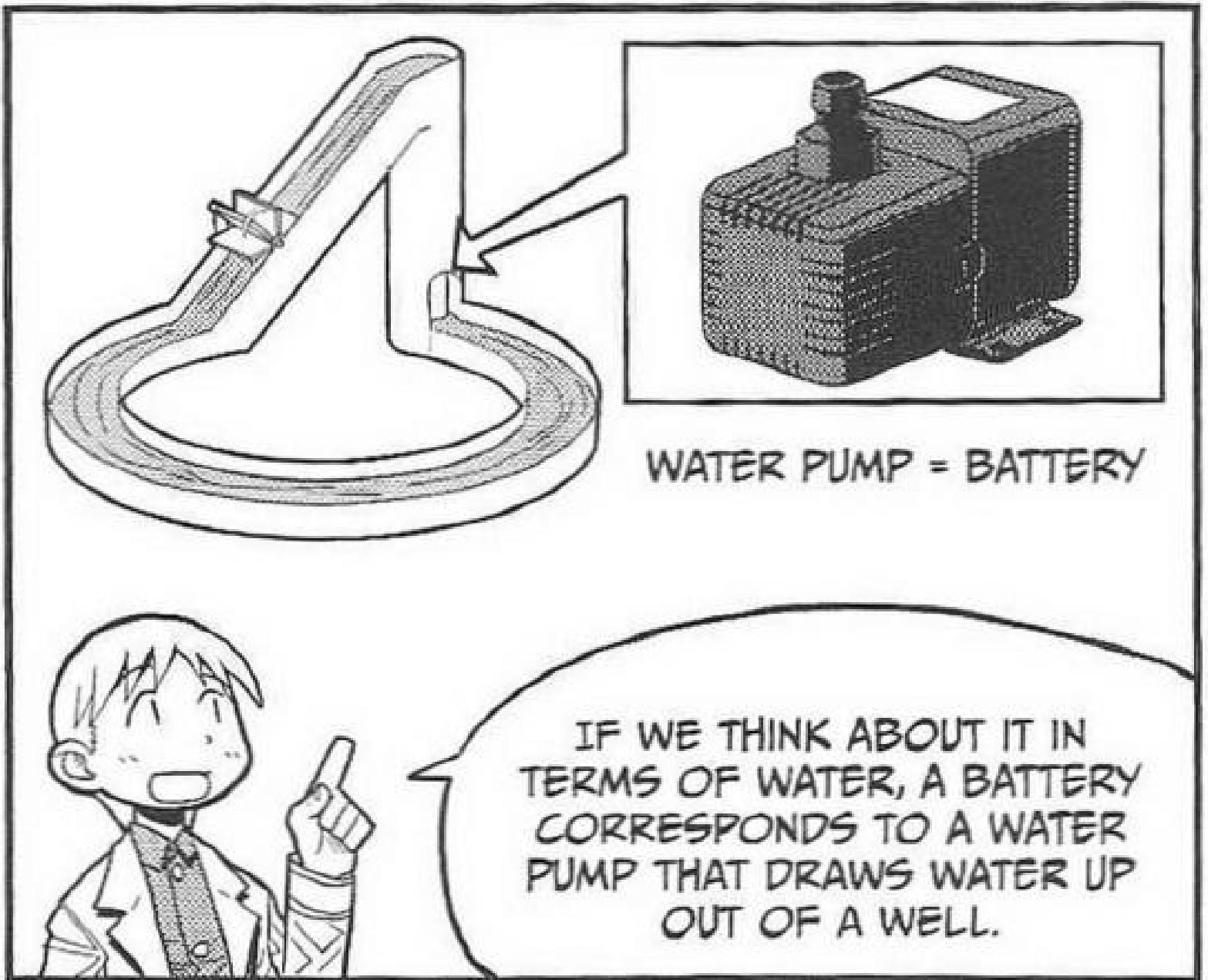
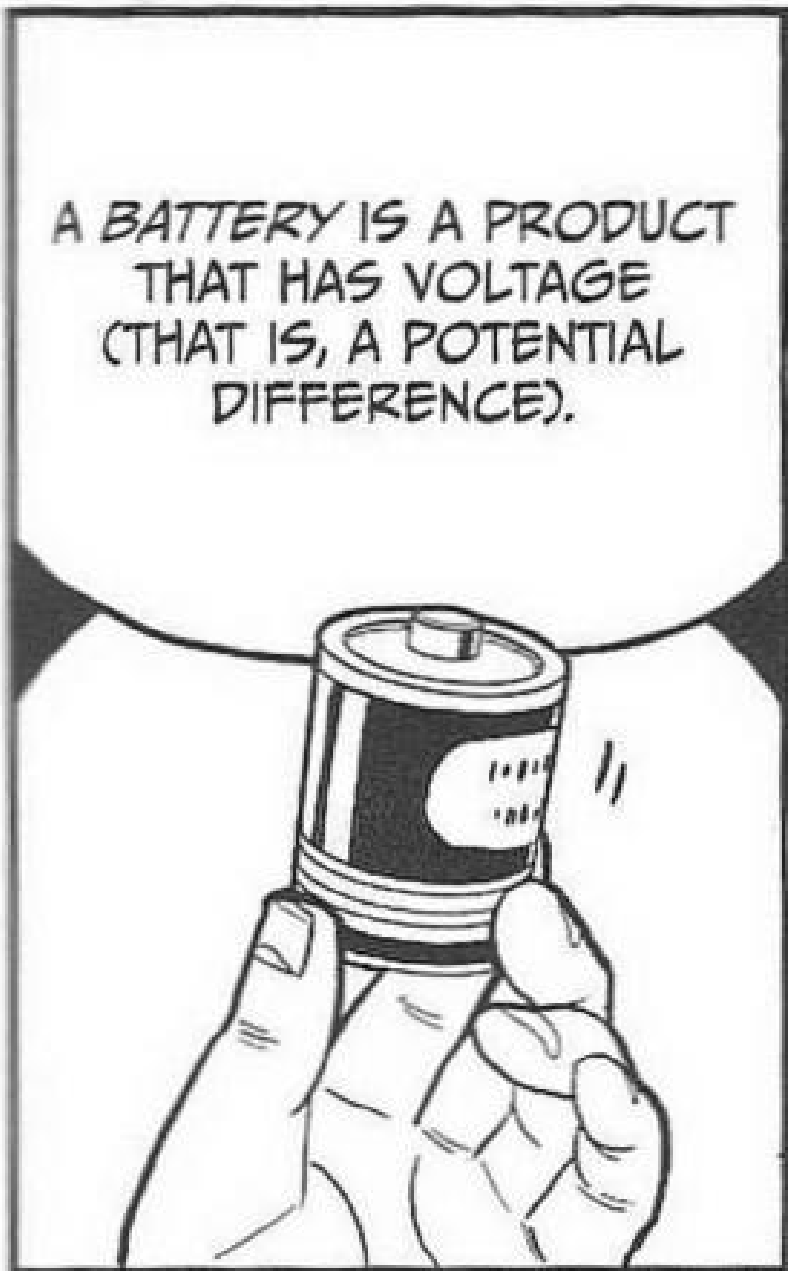
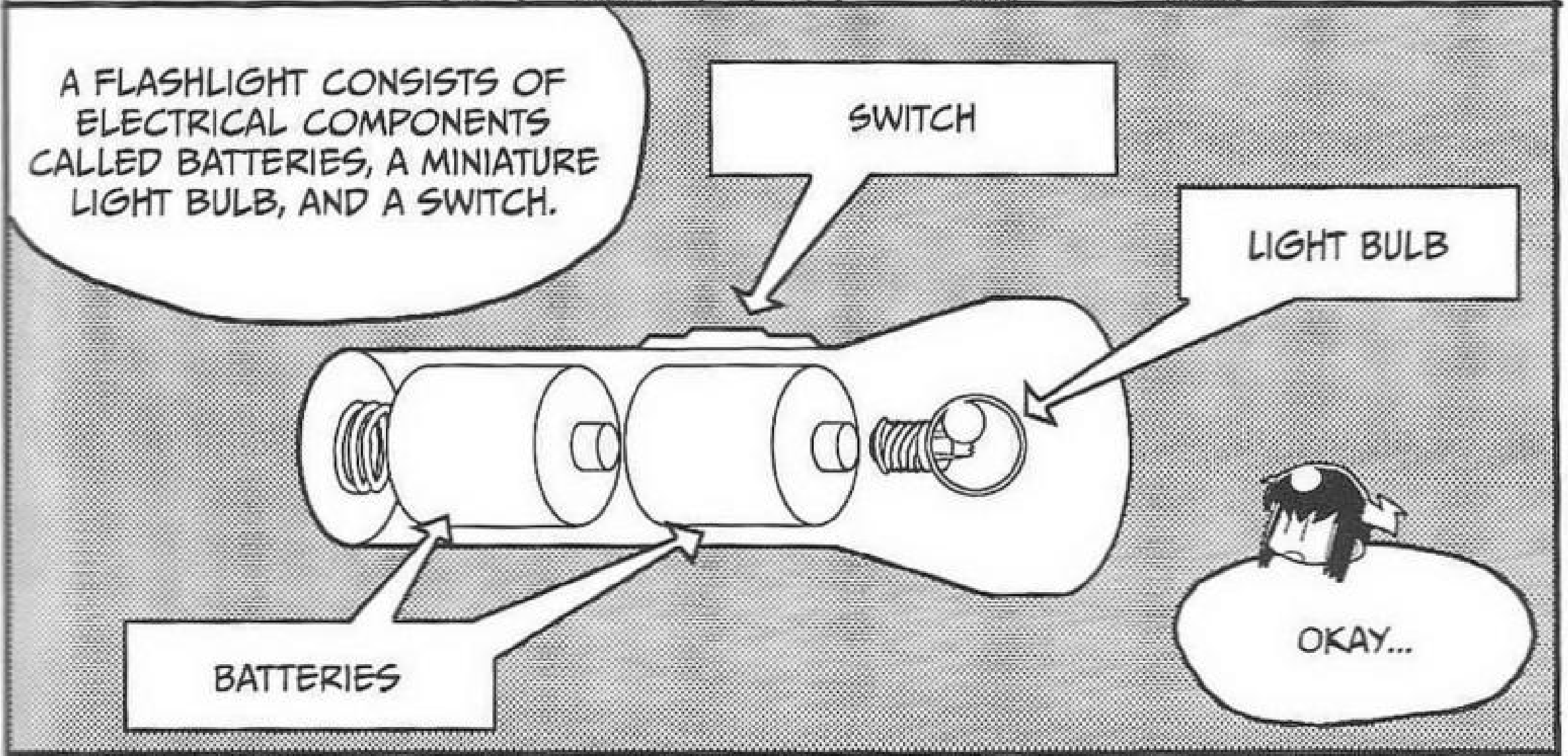
AIEEEEE!



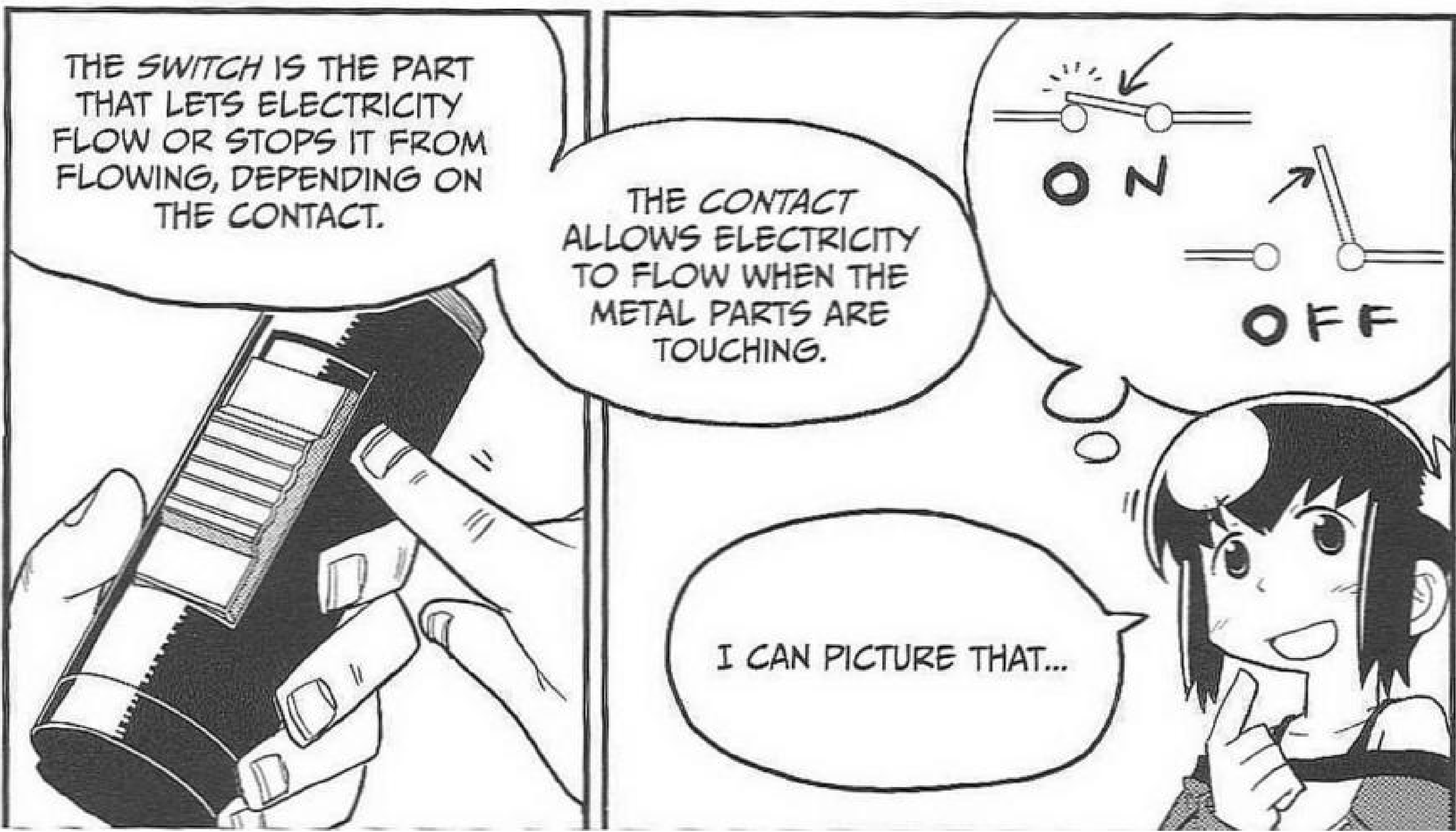
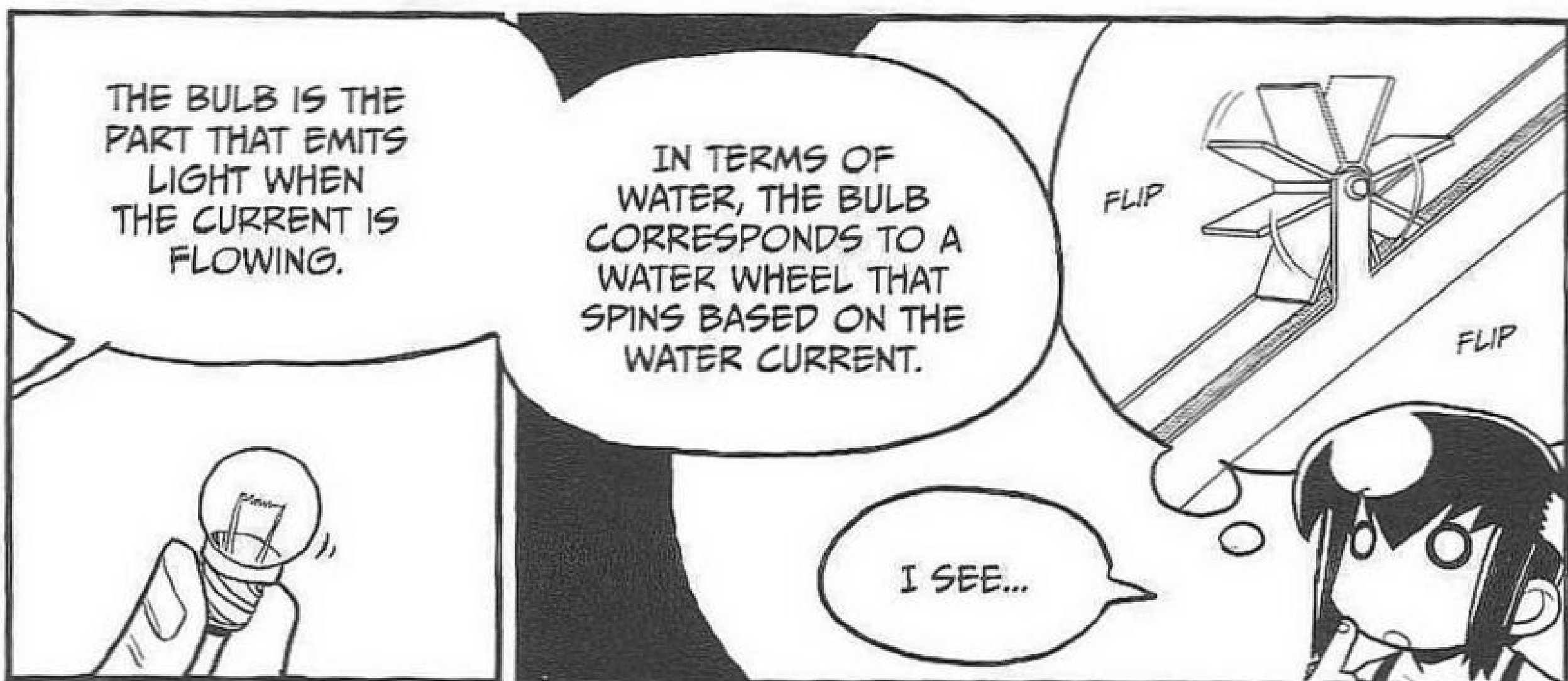




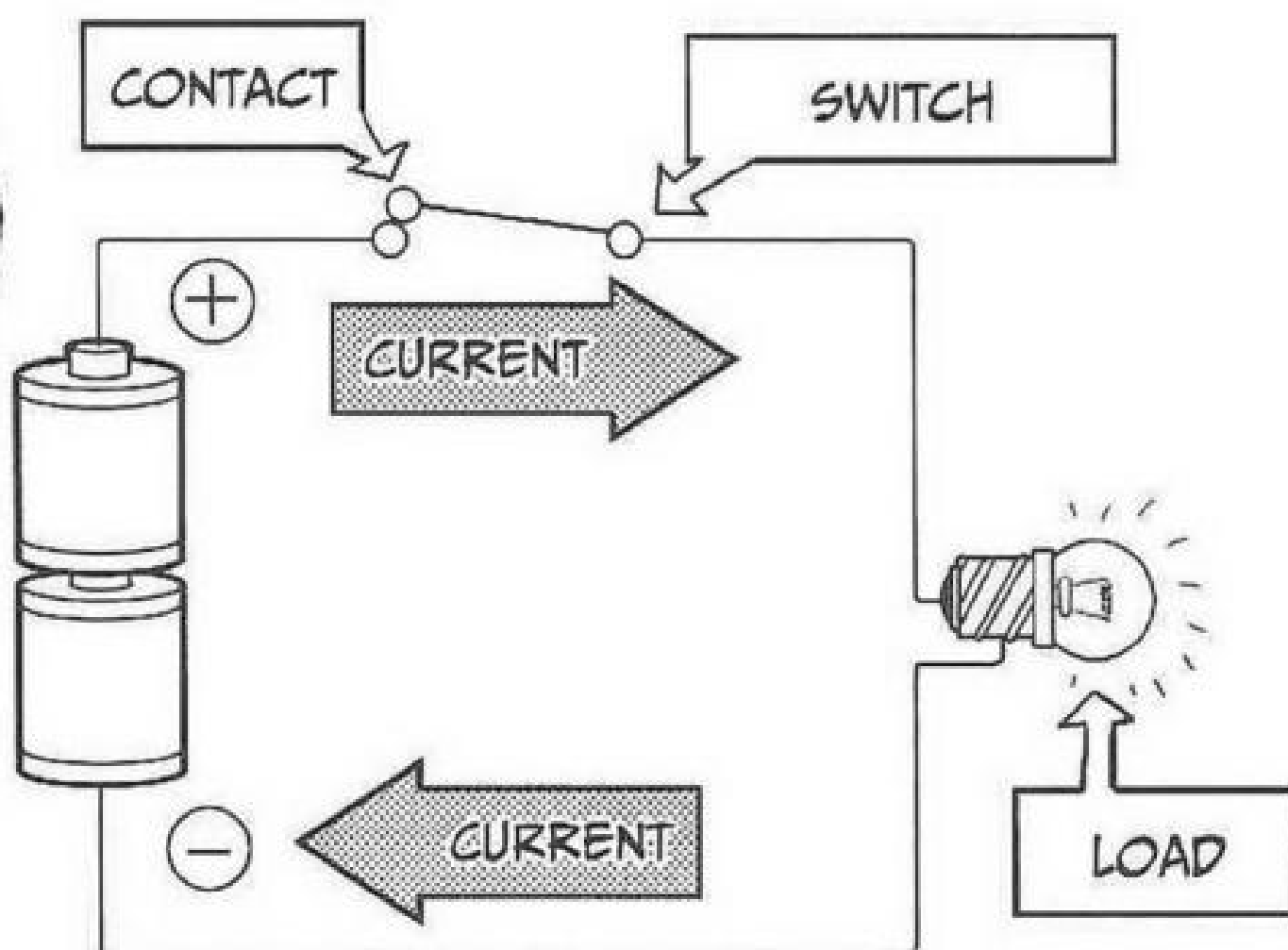
A FLASHLIGHT'S CIRCUIT







WHEN THE SWITCH IS CLOSED, CURRENT LEAVES THE POSITIVE POLE OF THE BATTERY, PASSES THROUGH THE MINIATURE BULB AND SWITCH, AND RETURNS TO THE NEGATIVE POLE.



POWER  
SUPPLY

THE PATH THROUGH WHICH THIS CURRENT FLOWS IS CALLED AN *ELECTRIC CIRCUIT*, WHICH ALWAYS HAS A CLOSED FORM (CLOSED CIRCUIT).

## PARTS OF AN ELECTRIC CIRCUIT

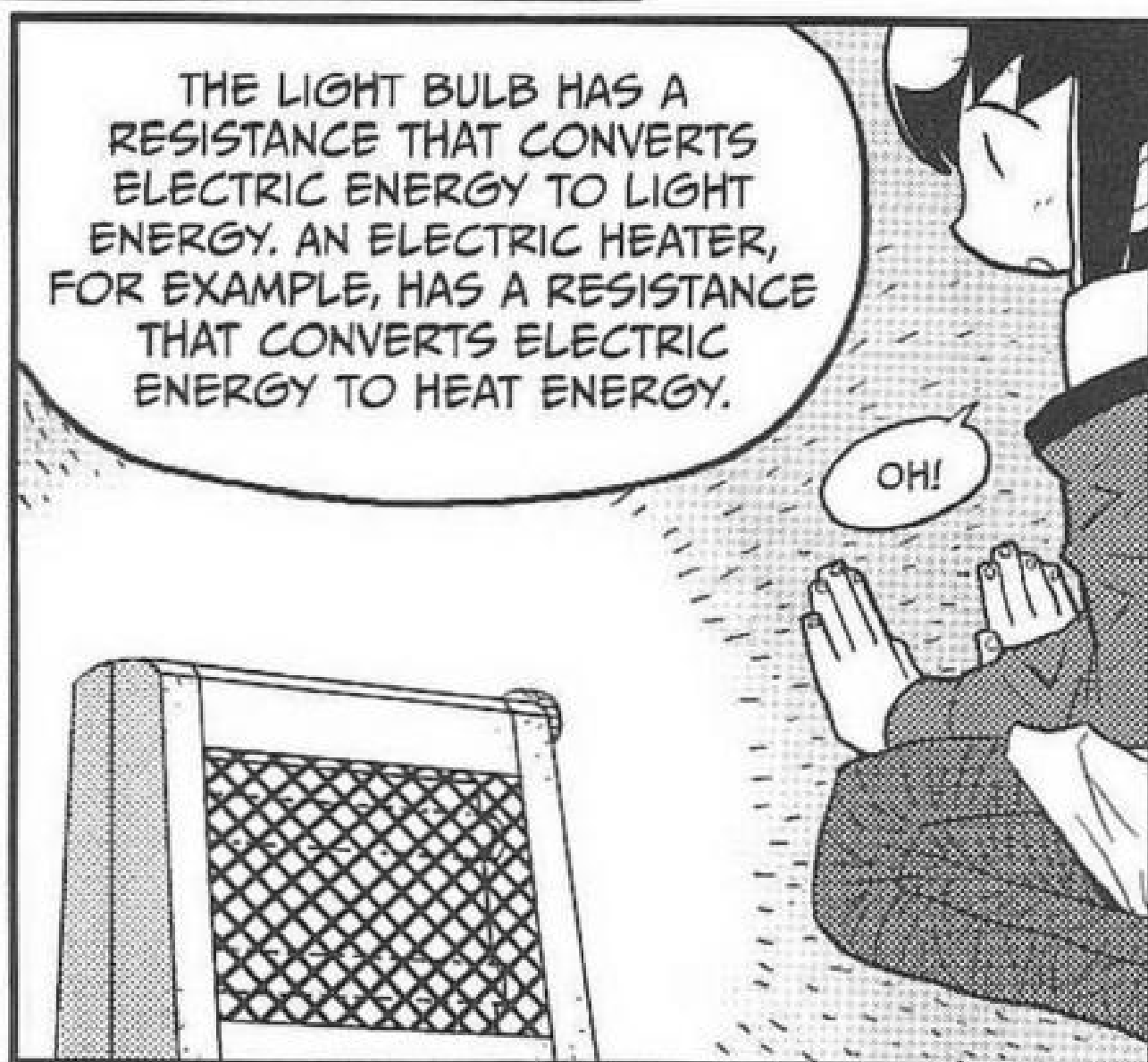
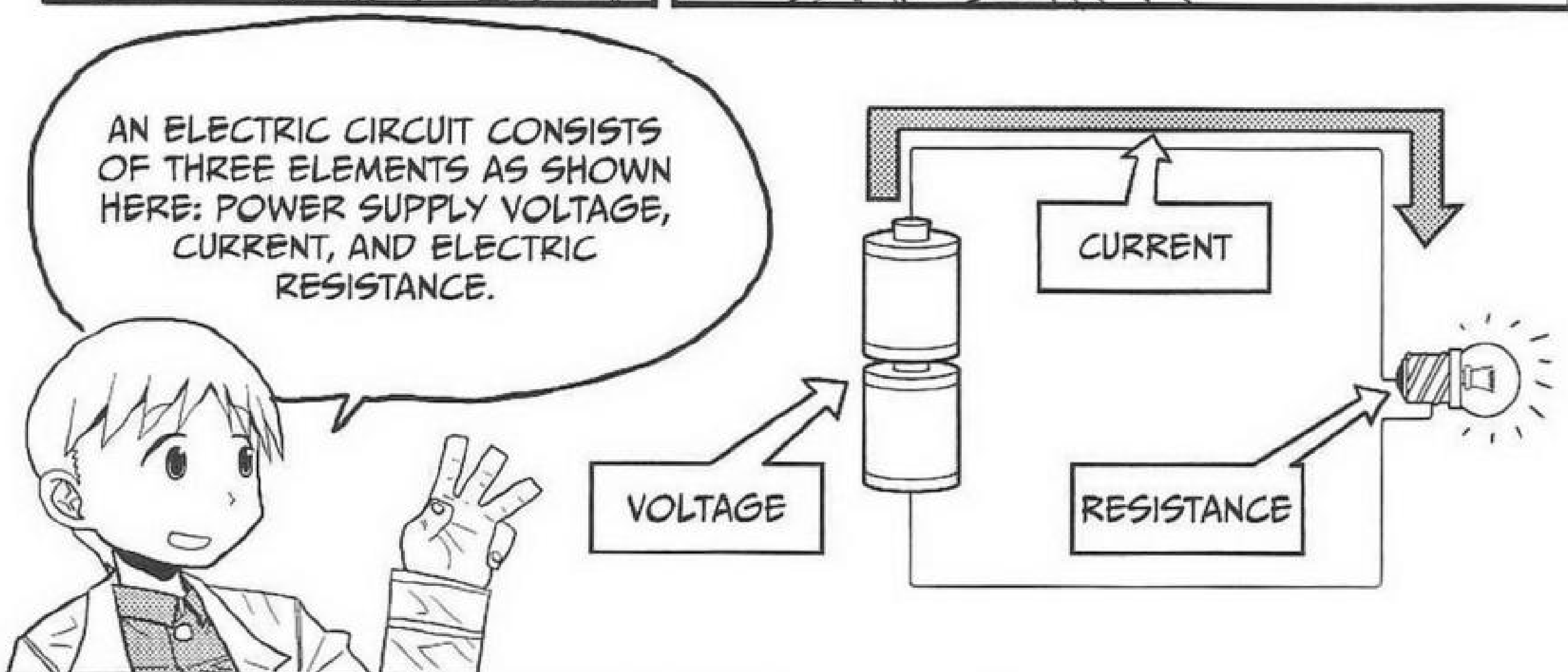
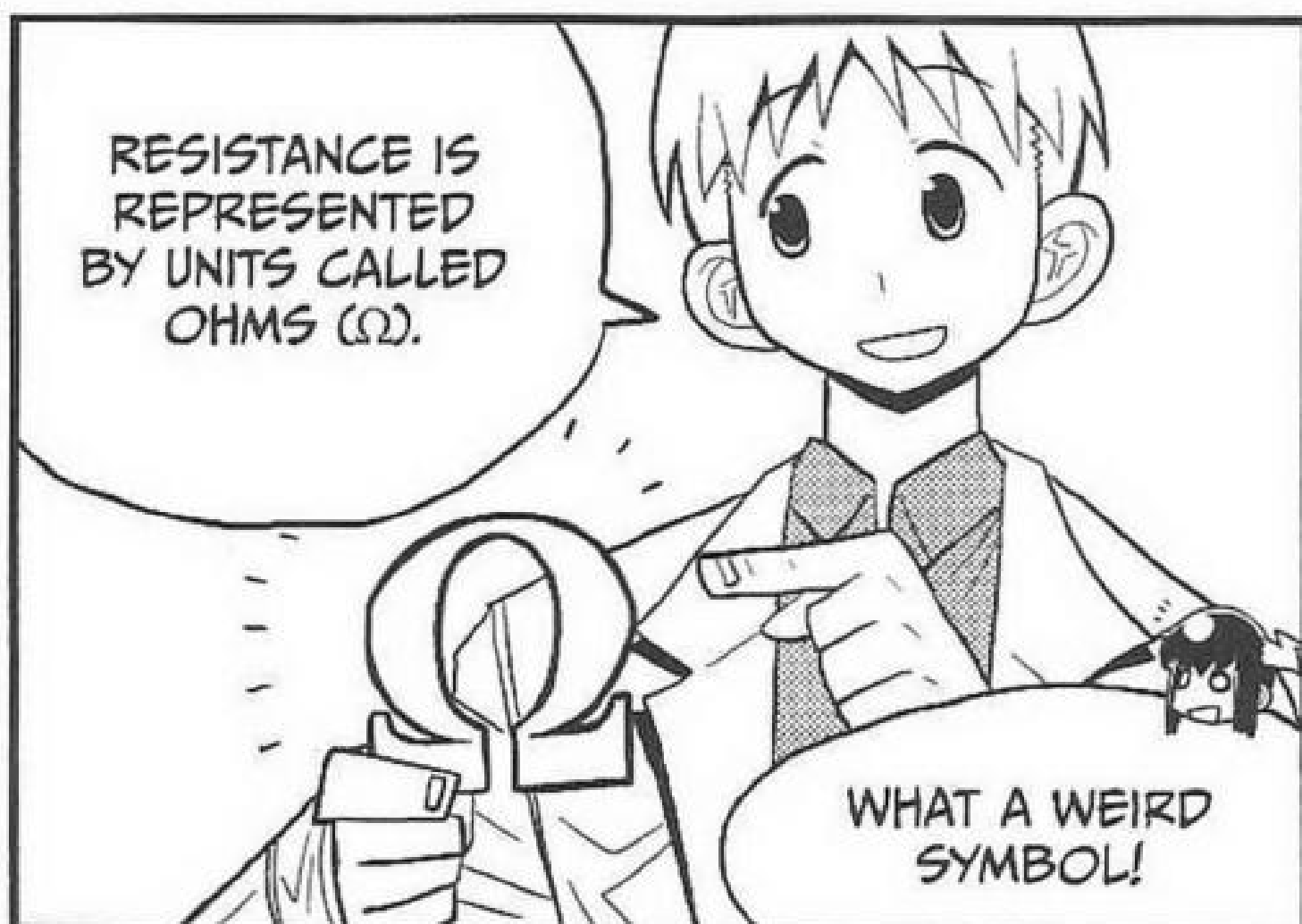
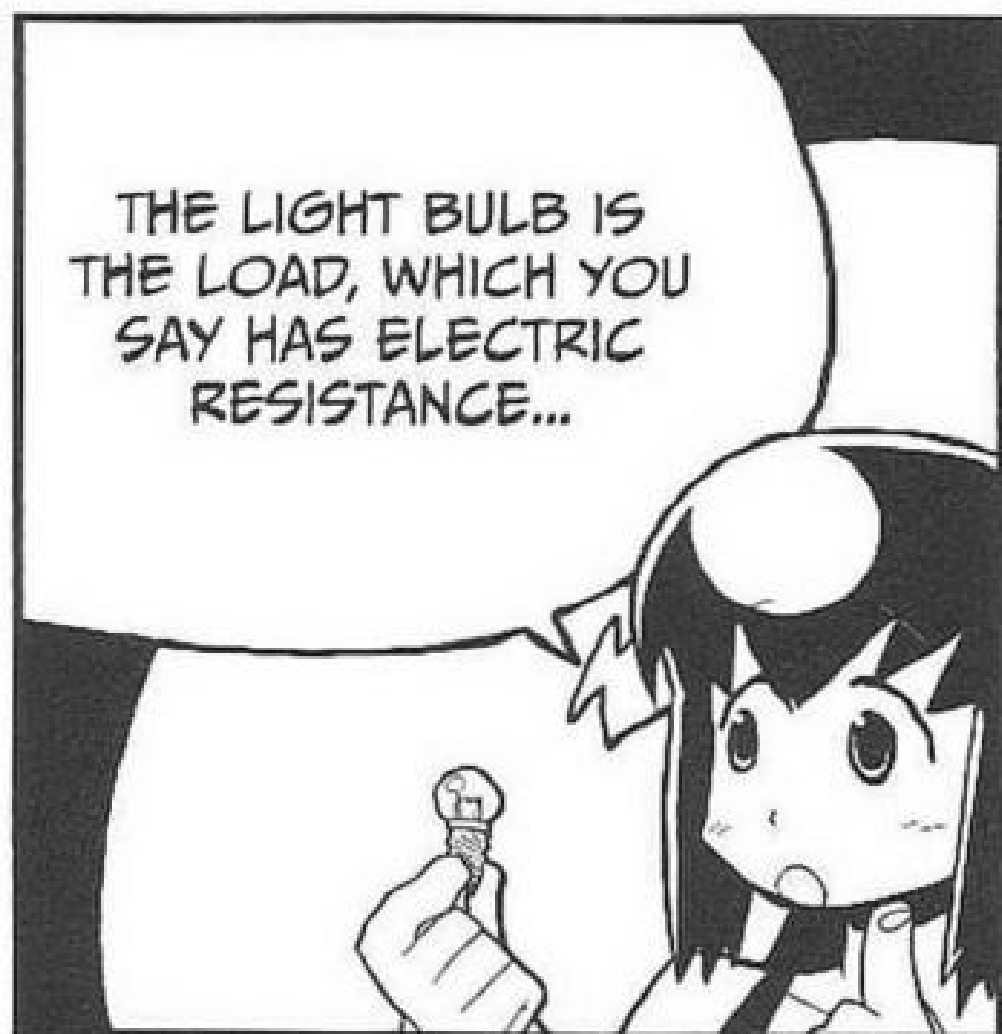
THE VOLTAGE OF THE POWER SUPPLY IS CALLED THE *POWER SUPPLY VOLTAGE* OR *ELECTROMOTIVE FORCE*.

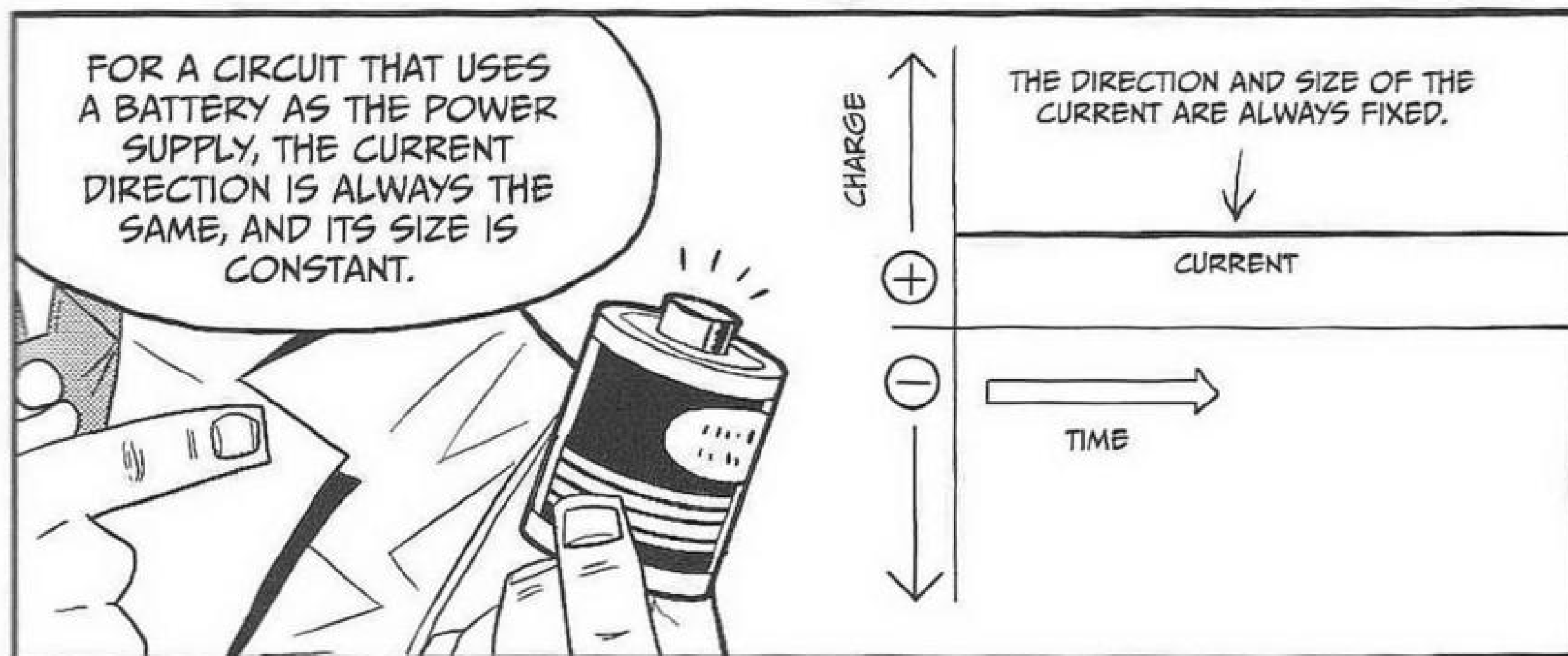
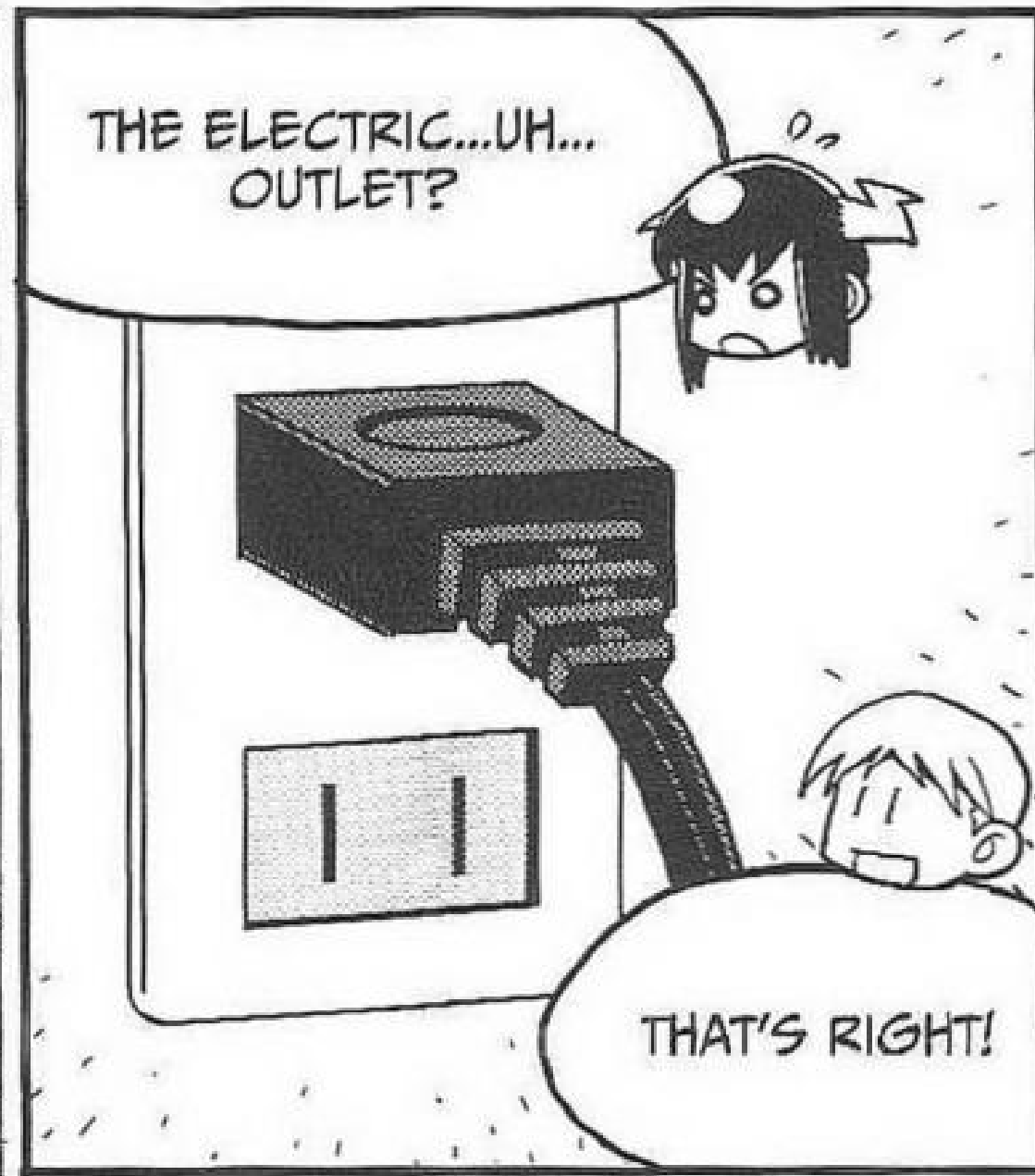
WHEN CURRENT FLOWS, THE *LOAD* CONVERTS ELECTRICAL ENERGY TO LIGHT OR HEAT ENERGY – THAT IS THE WORK THE BATTERY DID ON THE BULB.

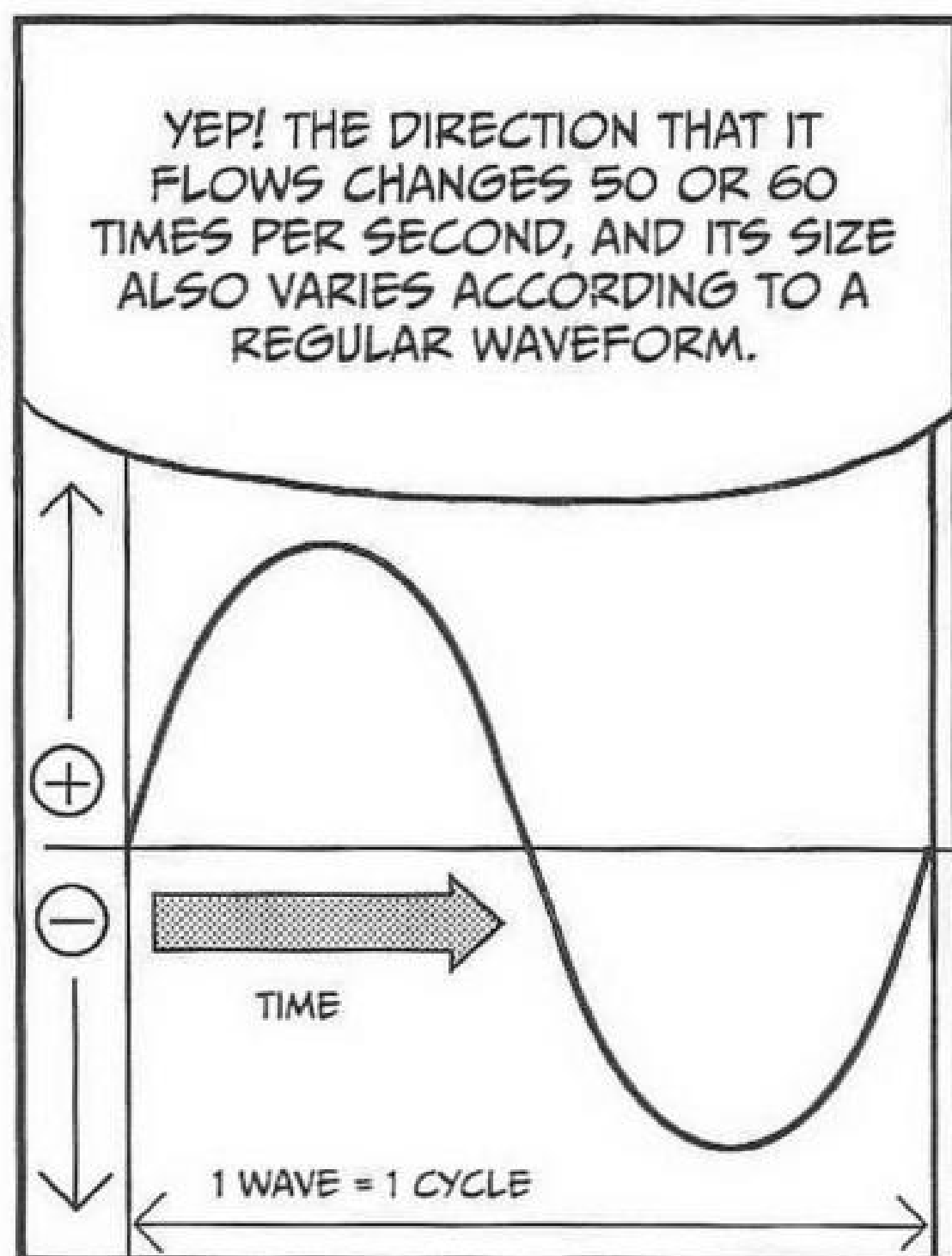
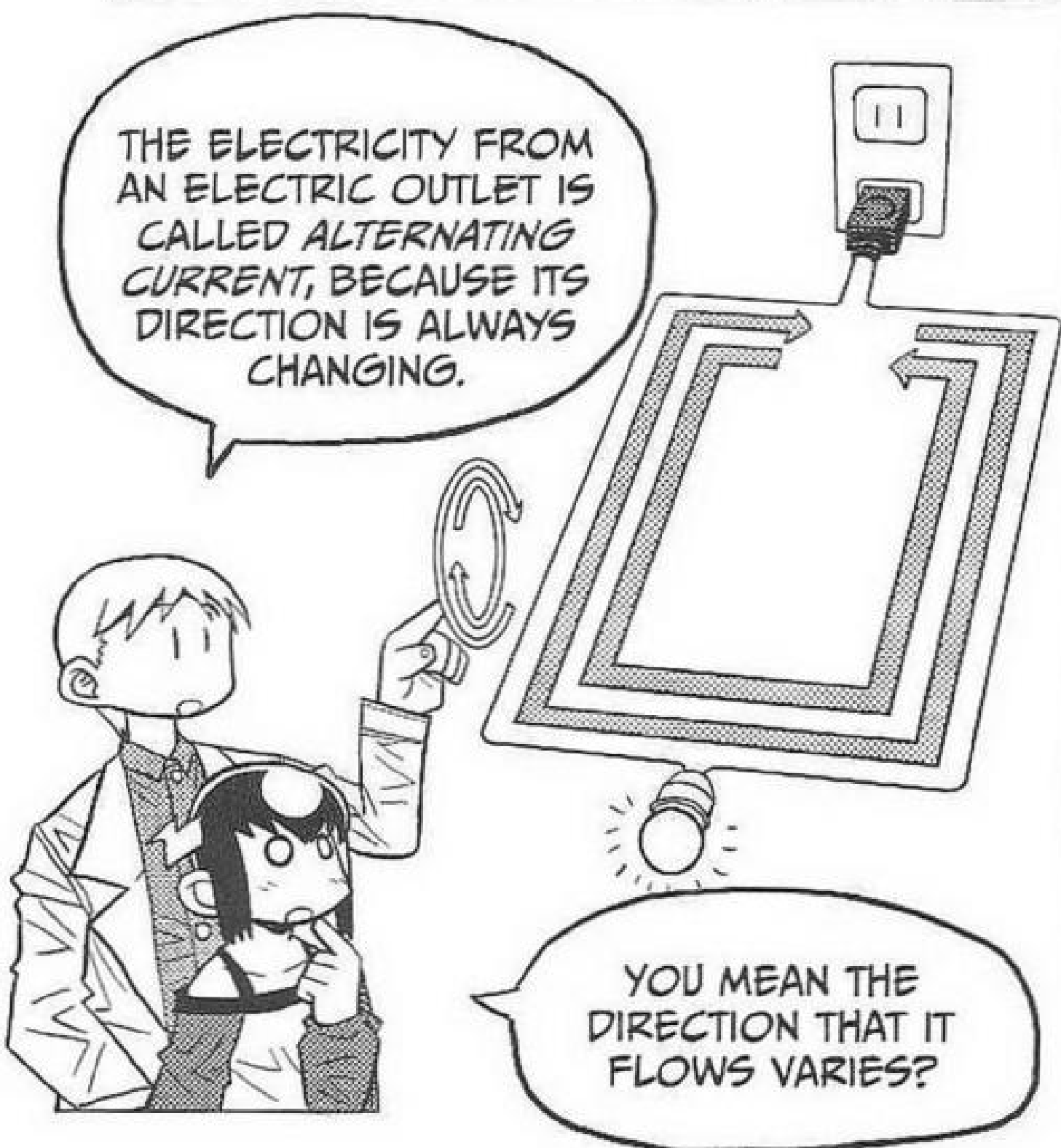
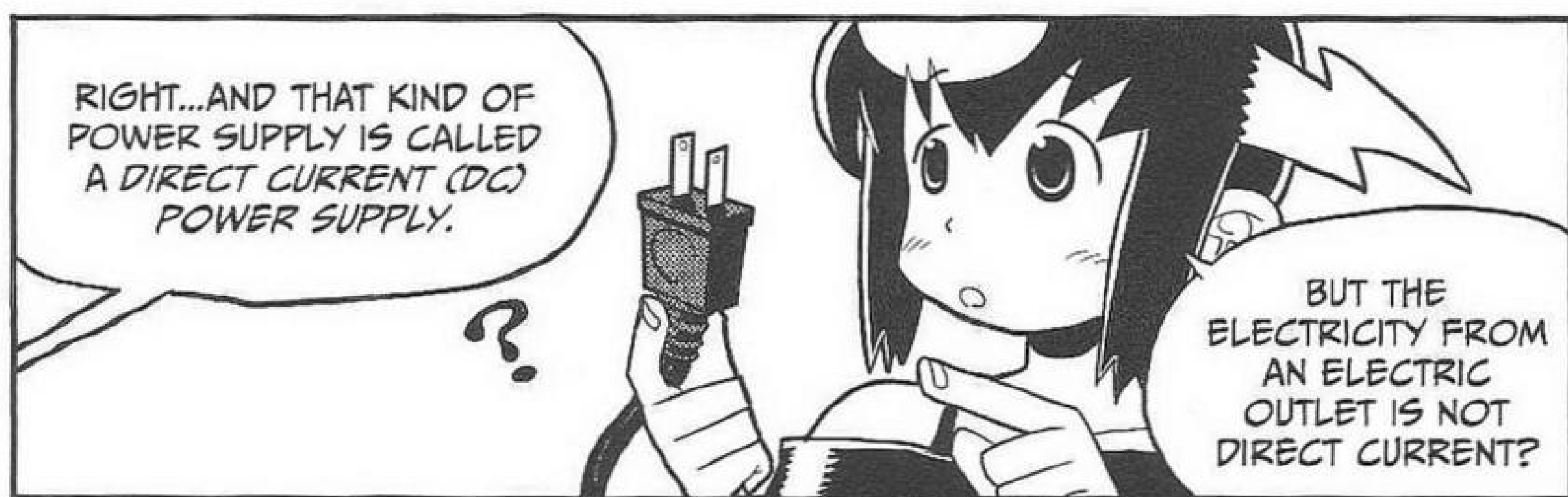
I SEE!  
IN THE FLASHLIGHT,  
THE LIGHT BULB IS THE  
LOAD, RIGHT?

THAT'S RIGHT!

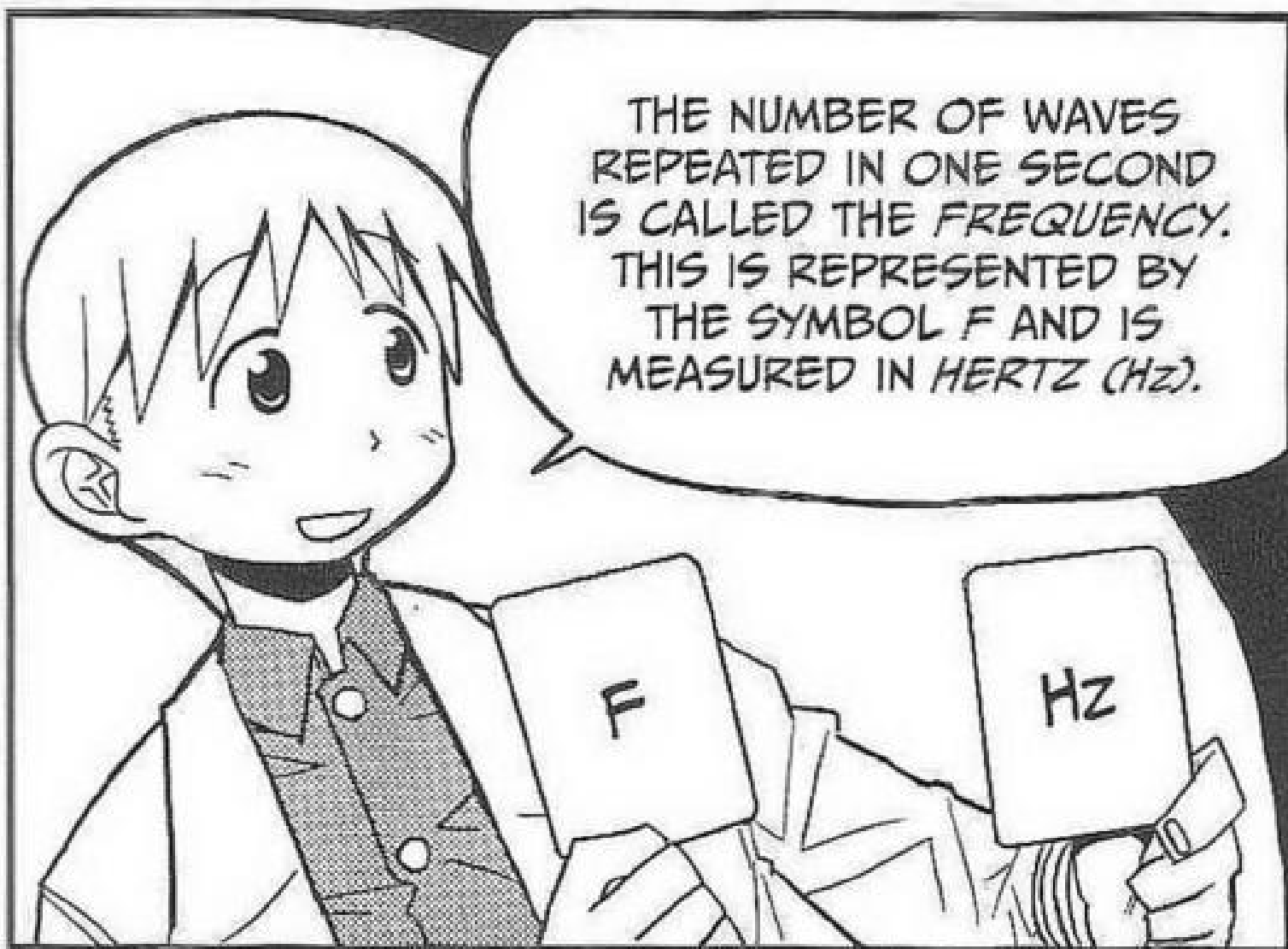
THE LOAD ALSO HAS A PROPERTY THAT HINDERS THE FLOW OF CURRENT. THIS IS CALLED *ELECTRIC RESISTANCE*.







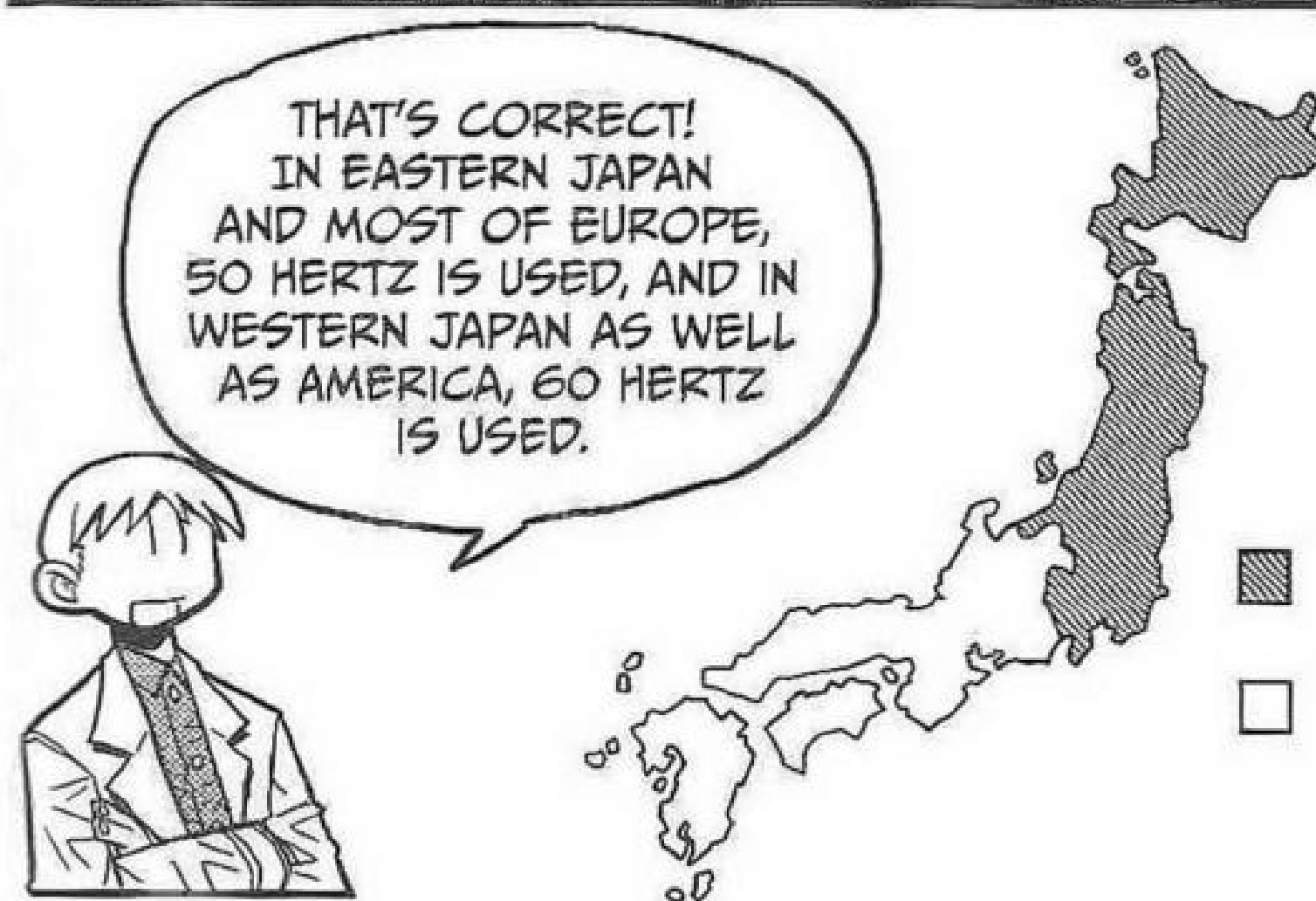




THE NUMBER OF WAVES REPEATED IN ONE SECOND IS CALLED THE *FREQUENCY*. THIS IS REPRESENTED BY THE SYMBOL *F* AND IS MEASURED IN HERTZ (Hz).



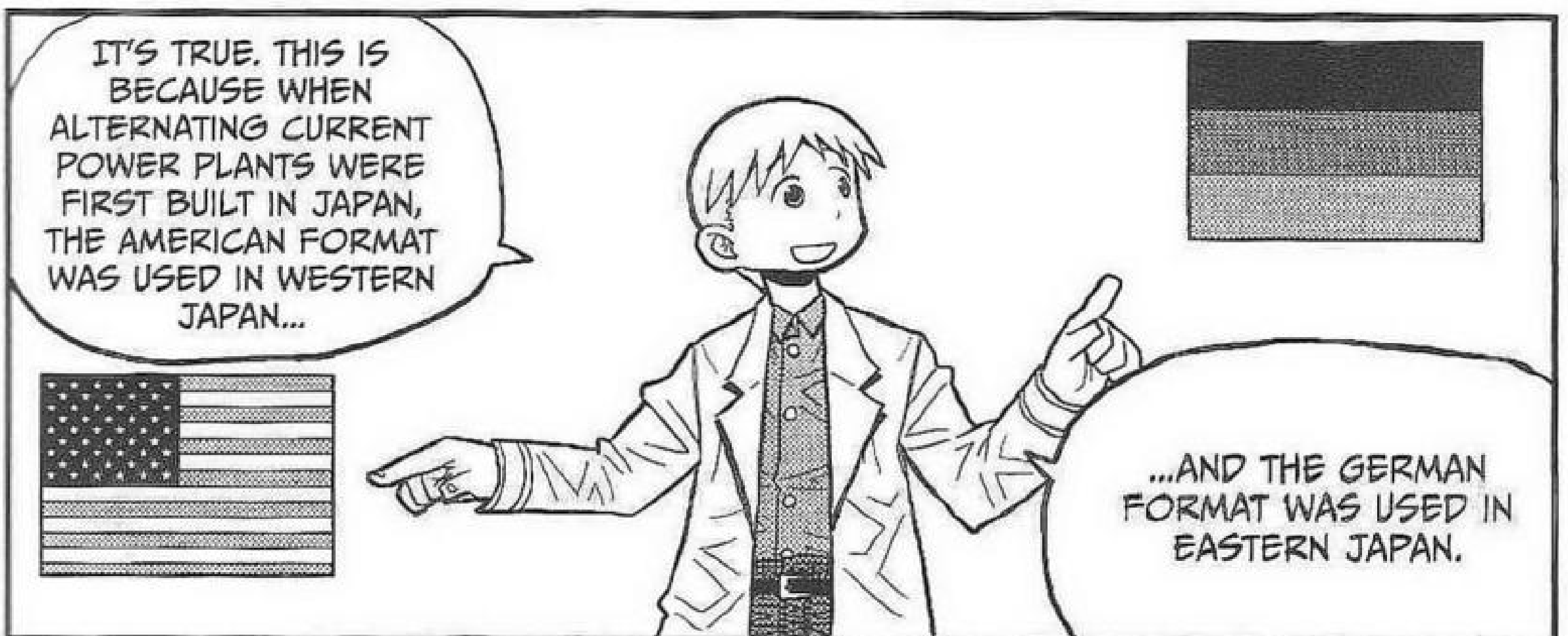
SO, IF THE DIRECTION THAT THE CURRENT FLOWS CHANGES 50 TIMES PER SECOND, IT'S 50 HERTZ, AND IF IT CHANGES 60 TIMES PER SECOND, IT'S 60 HERTZ?



THAT'S CORRECT! IN EASTERN JAPAN AND MOST OF EUROPE, 50 HERTZ IS USED, AND IN WESTERN JAPAN AS WELL AS AMERICA, 60 HERTZ IS USED.



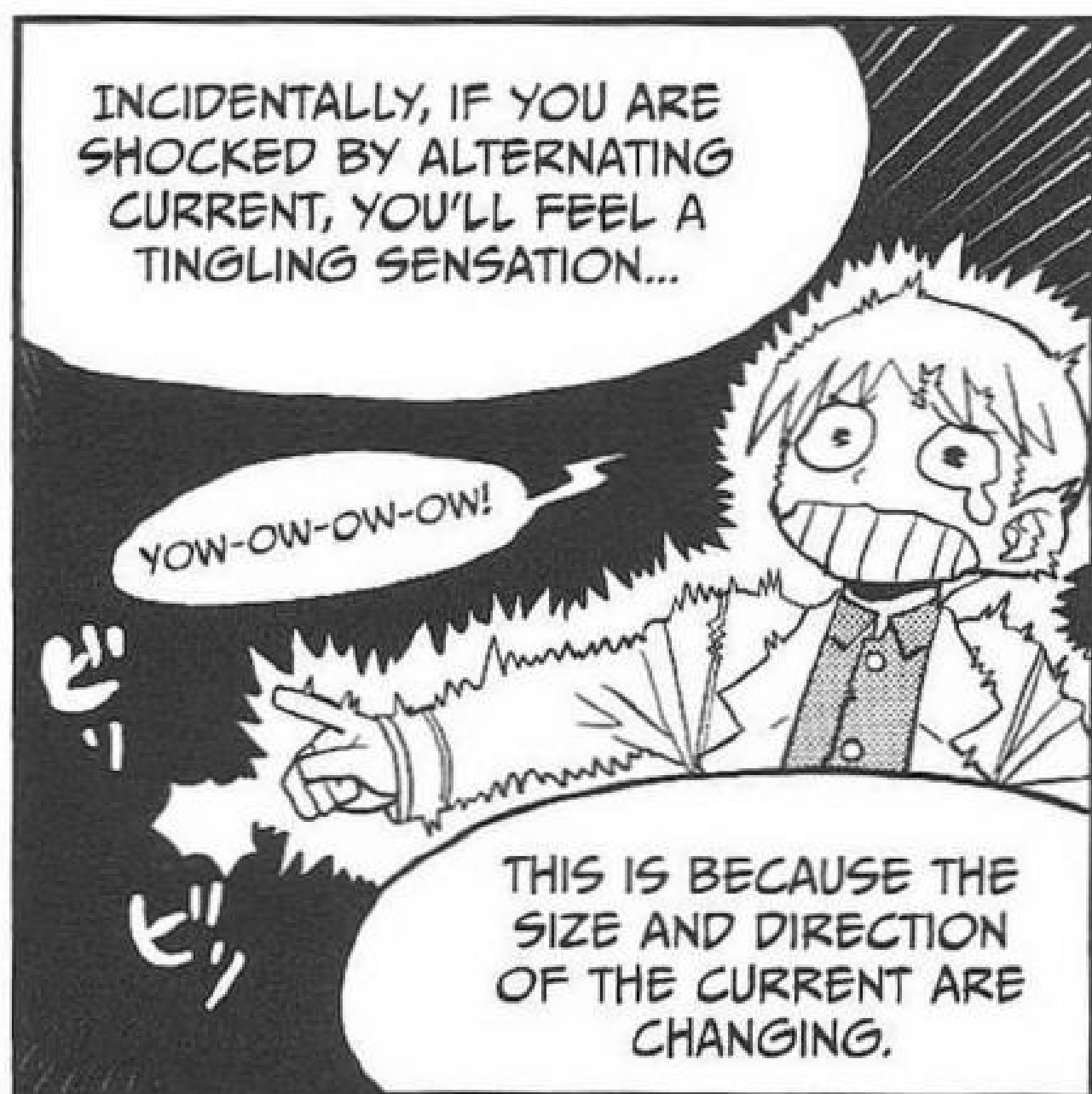
HUH? DIFFERENT FREQUENCIES ARE USED IN THE SAME COUNTRY?



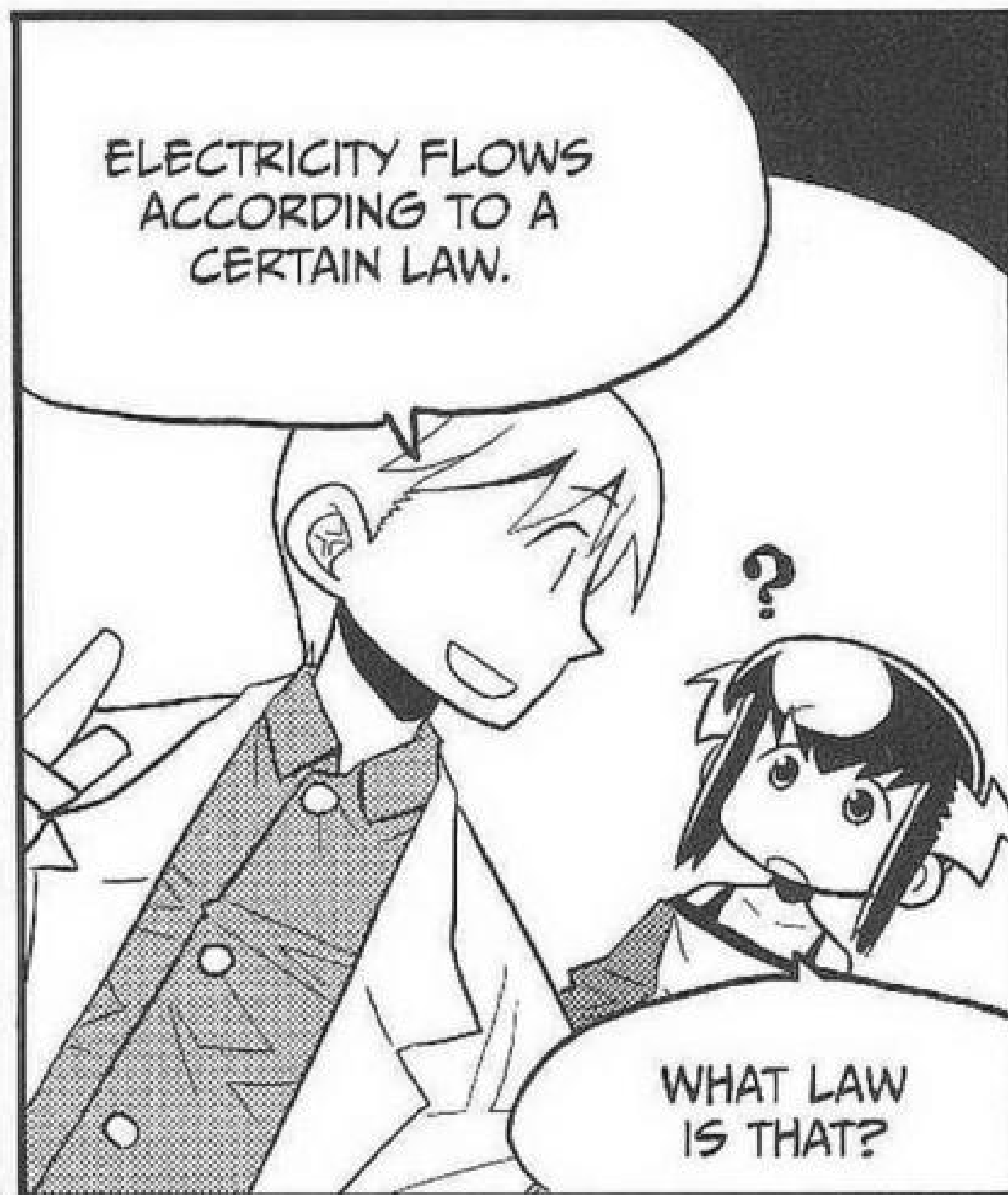
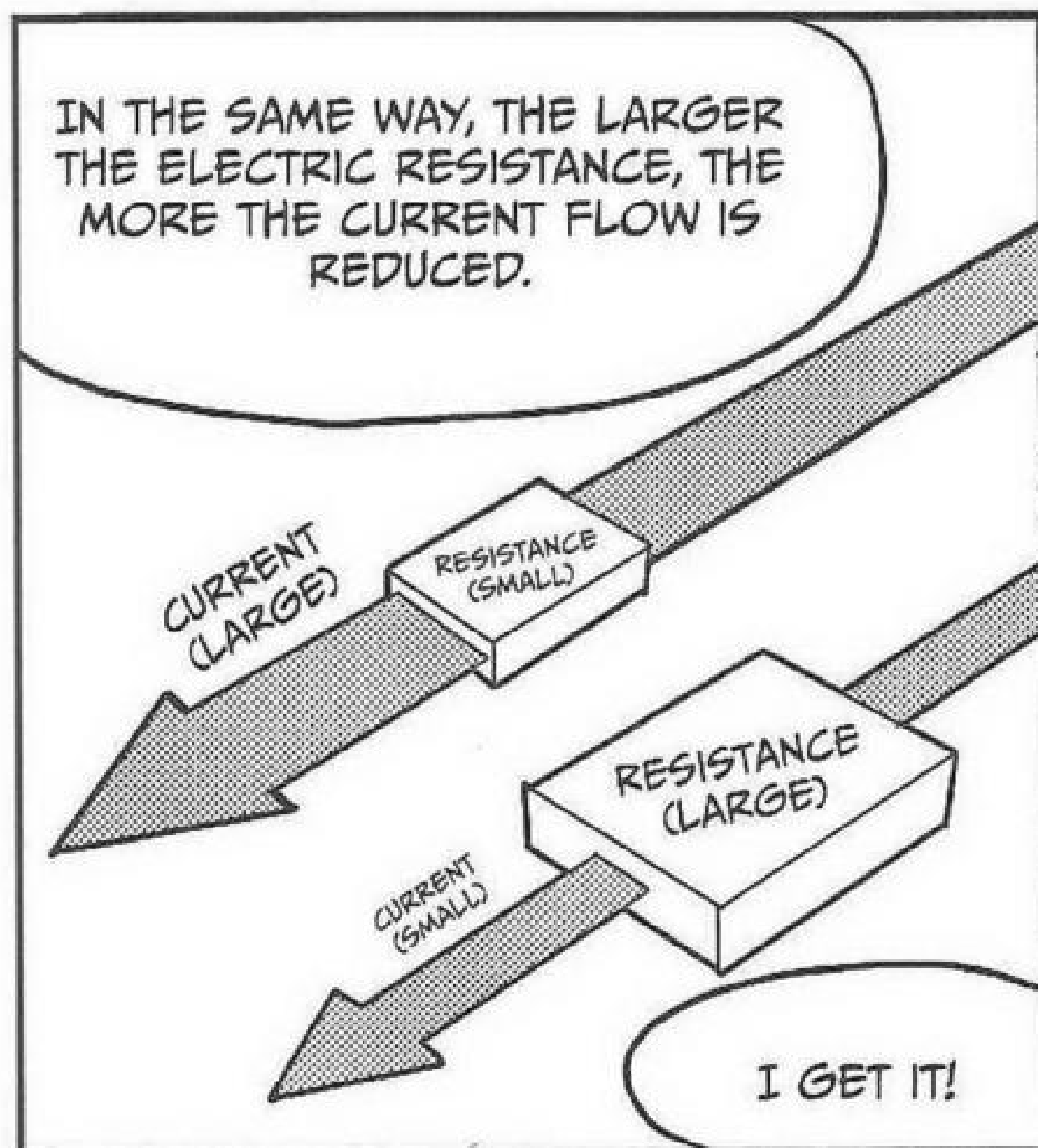
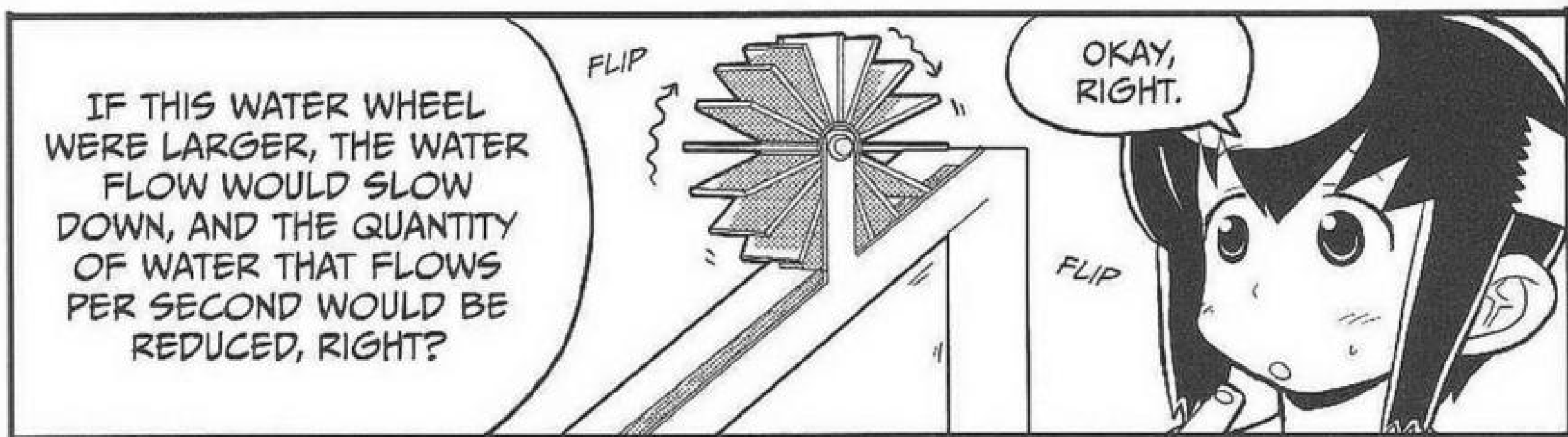
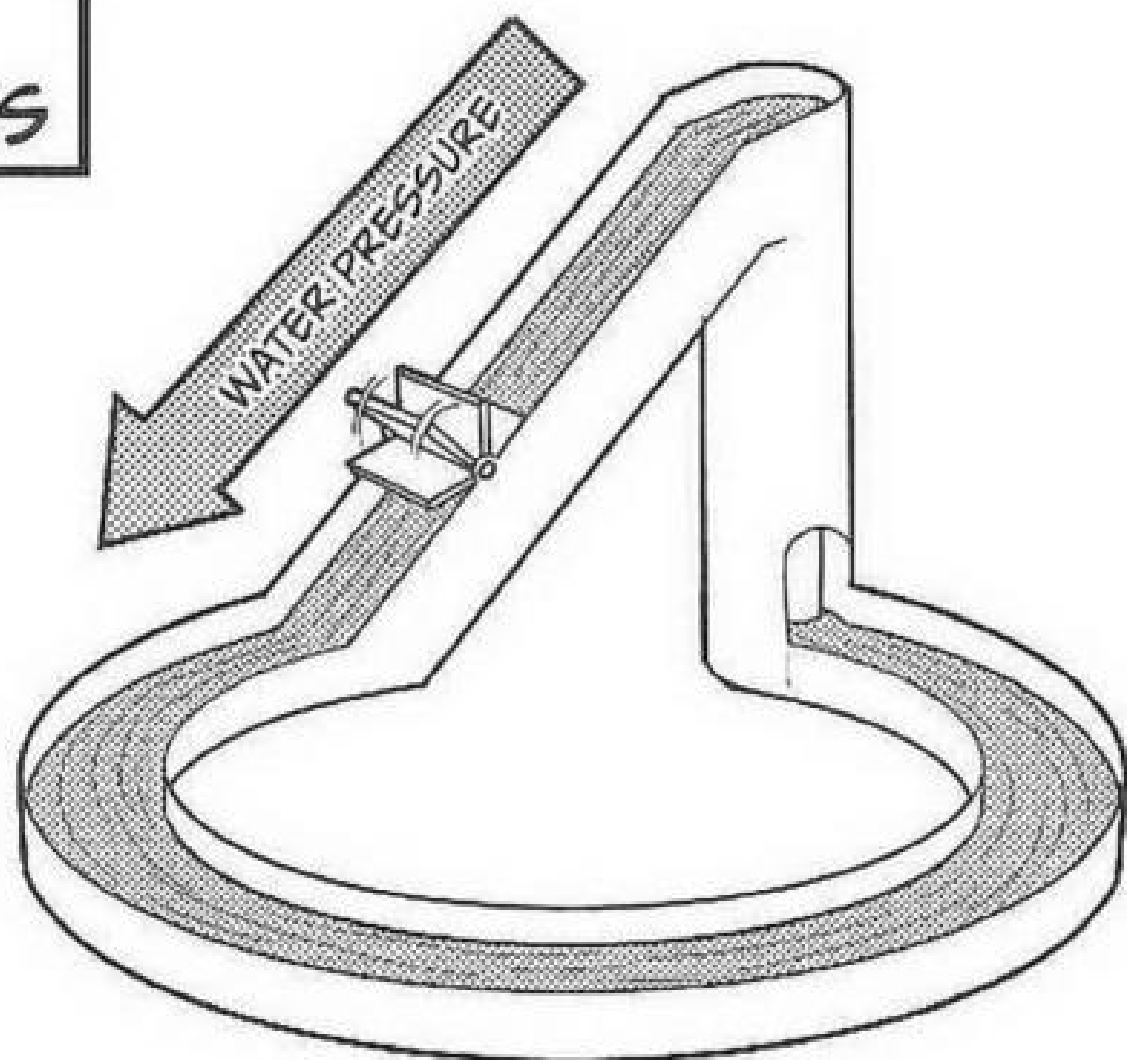
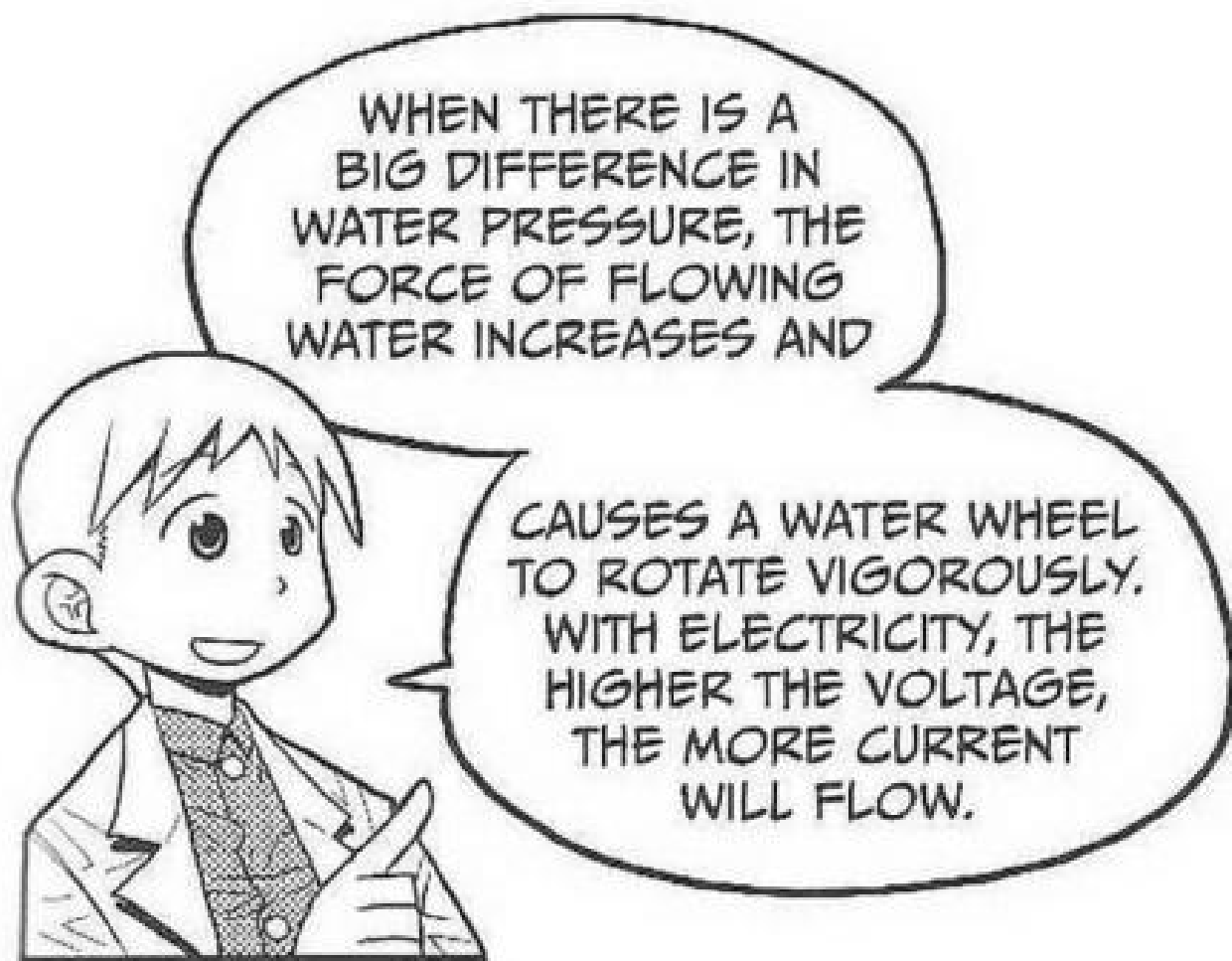
IT'S TRUE. THIS IS BECAUSE WHEN ALTERNATING CURRENT POWER PLANTS WERE FIRST BUILT IN JAPAN, THE AMERICAN FORMAT WAS USED IN WESTERN JAPAN...

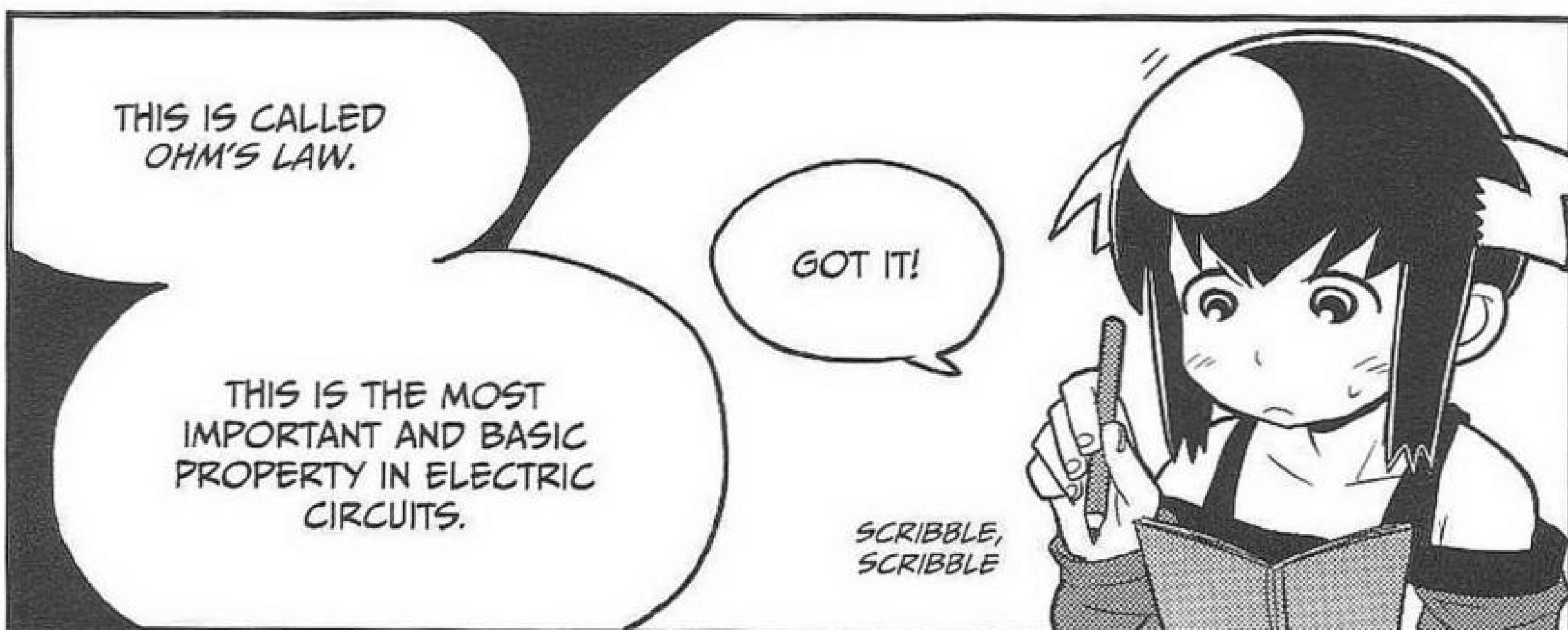
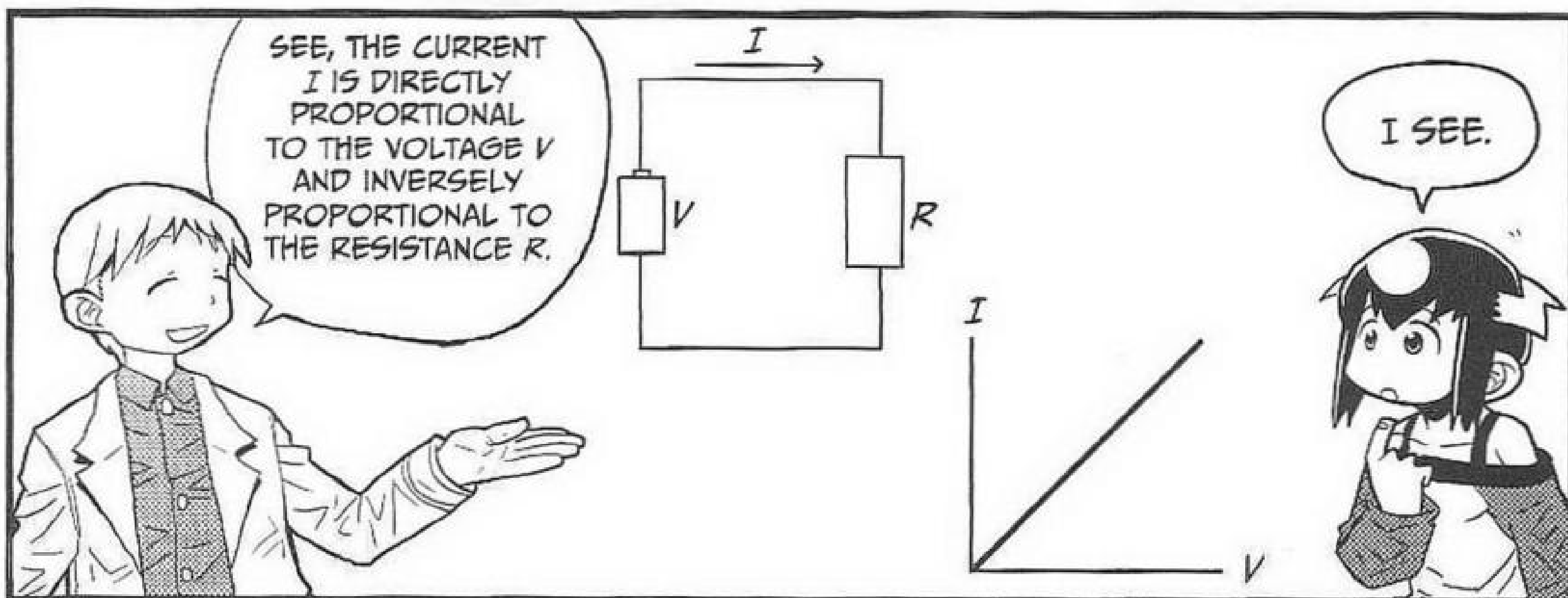
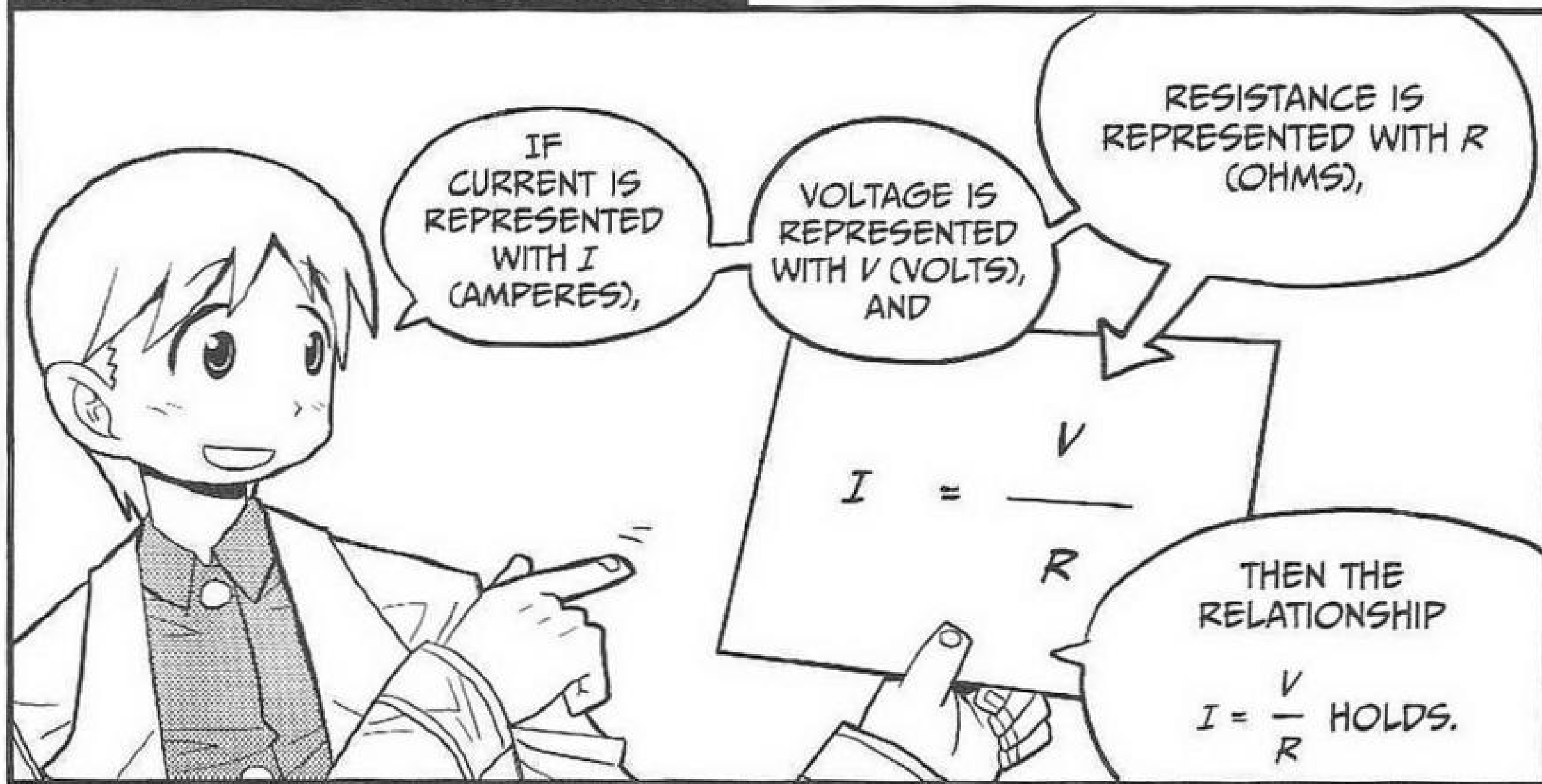
...AND THE GERMAN FORMAT WAS USED IN EASTERN JAPAN.





# OHM'S LAW AND METHODS OF CONNECTING ELECTRICAL COMPONENTS

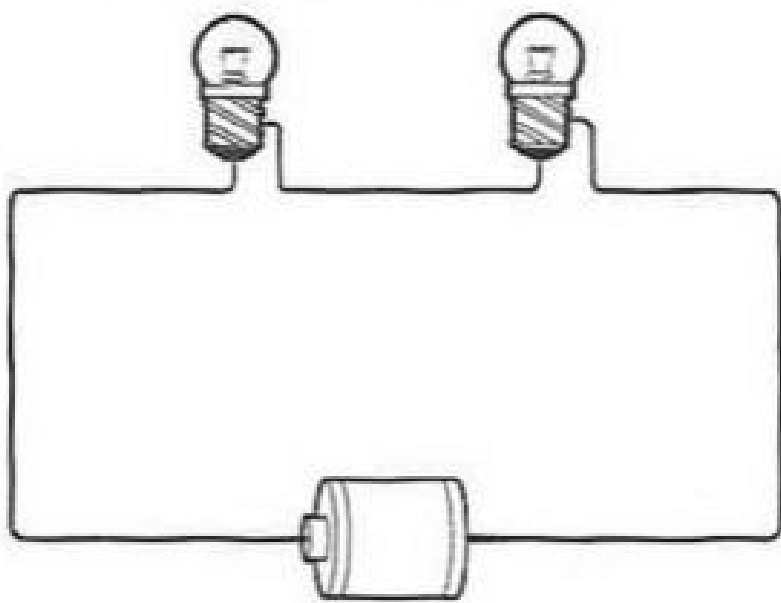




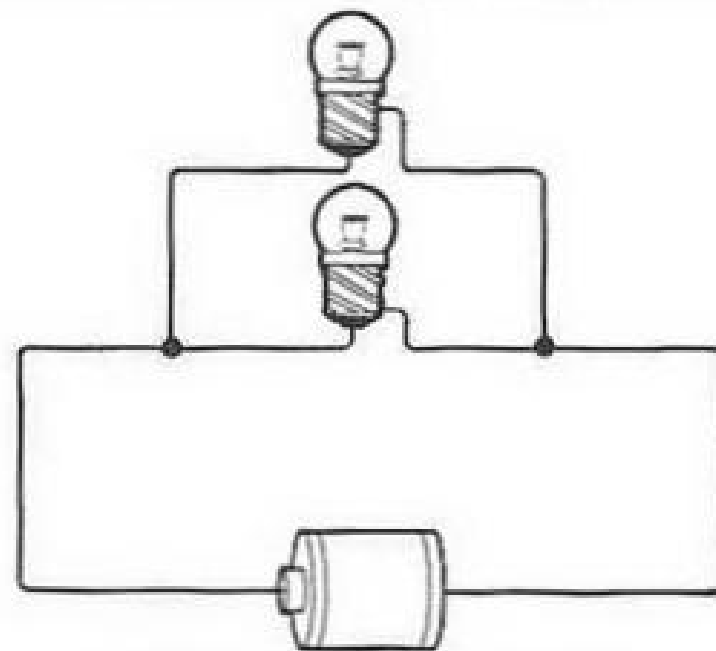
## SERIES AND PARALLEL CONNECTIONS

THERE ARE TWO MAIN CONNECTION METHODS USED IN ELECTRIC CIRCUITS.

WHAT ARE THEY?



SERIES CONNECTIONS FOR CONNECTING TWO RESISTANCES IN A LINE...



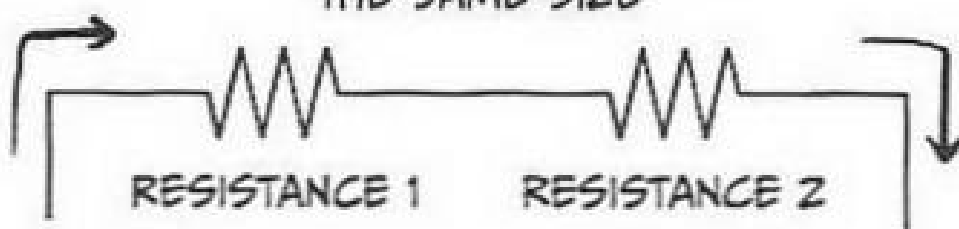
AND PARALLEL CONNECTIONS FOR CONNECTING TWO RESISTANCES SIDE BY SIDE.

HOW DO THEY DIFFER?

THE WAY IN WHICH CURRENT FLOWS AND THE WAY IN WHICH VOLTAGE IS APPLIED BOTH DIFFER.

### SERIES CONNECTION

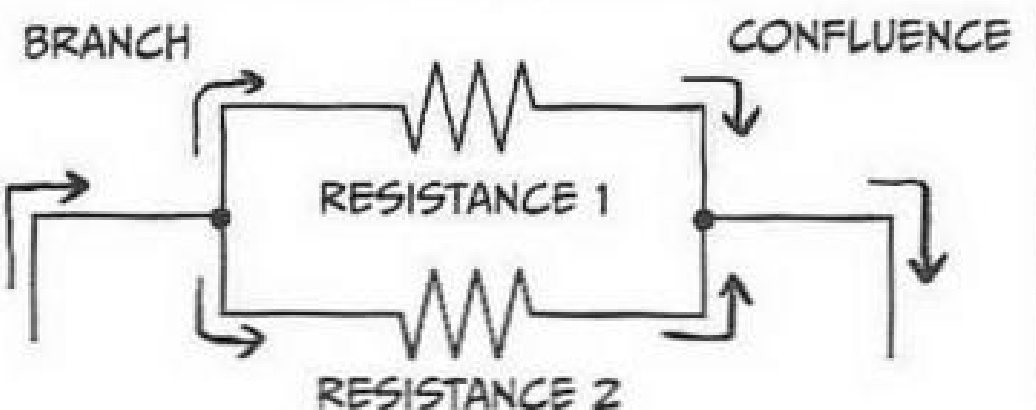
CURRENT FLOWS WITH THE SAME SIZE



CURRENT OF POWER SUPPLY = CURRENT OF RESISTANCE 1 = CURRENT OF RESISTANCE 2

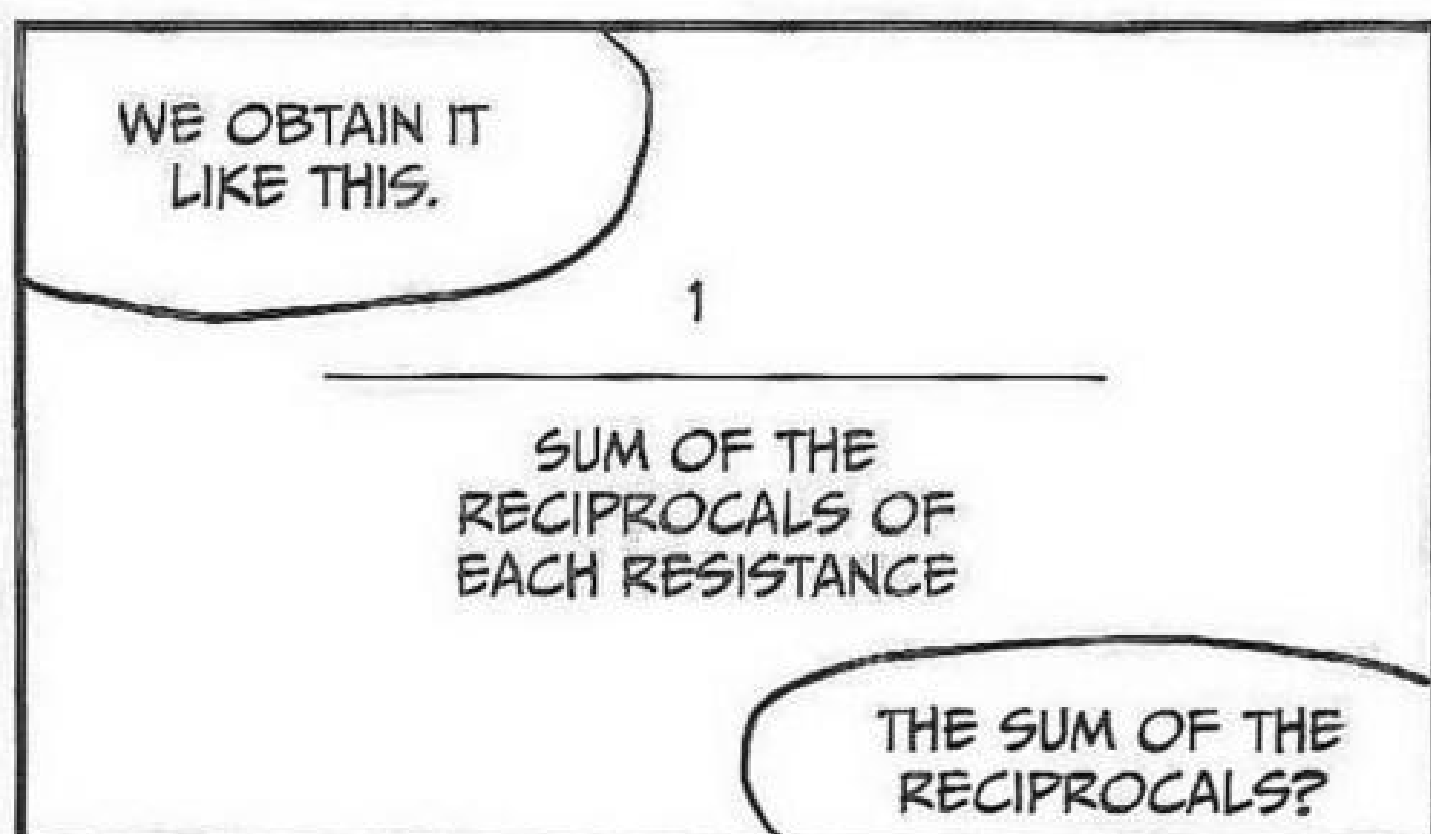
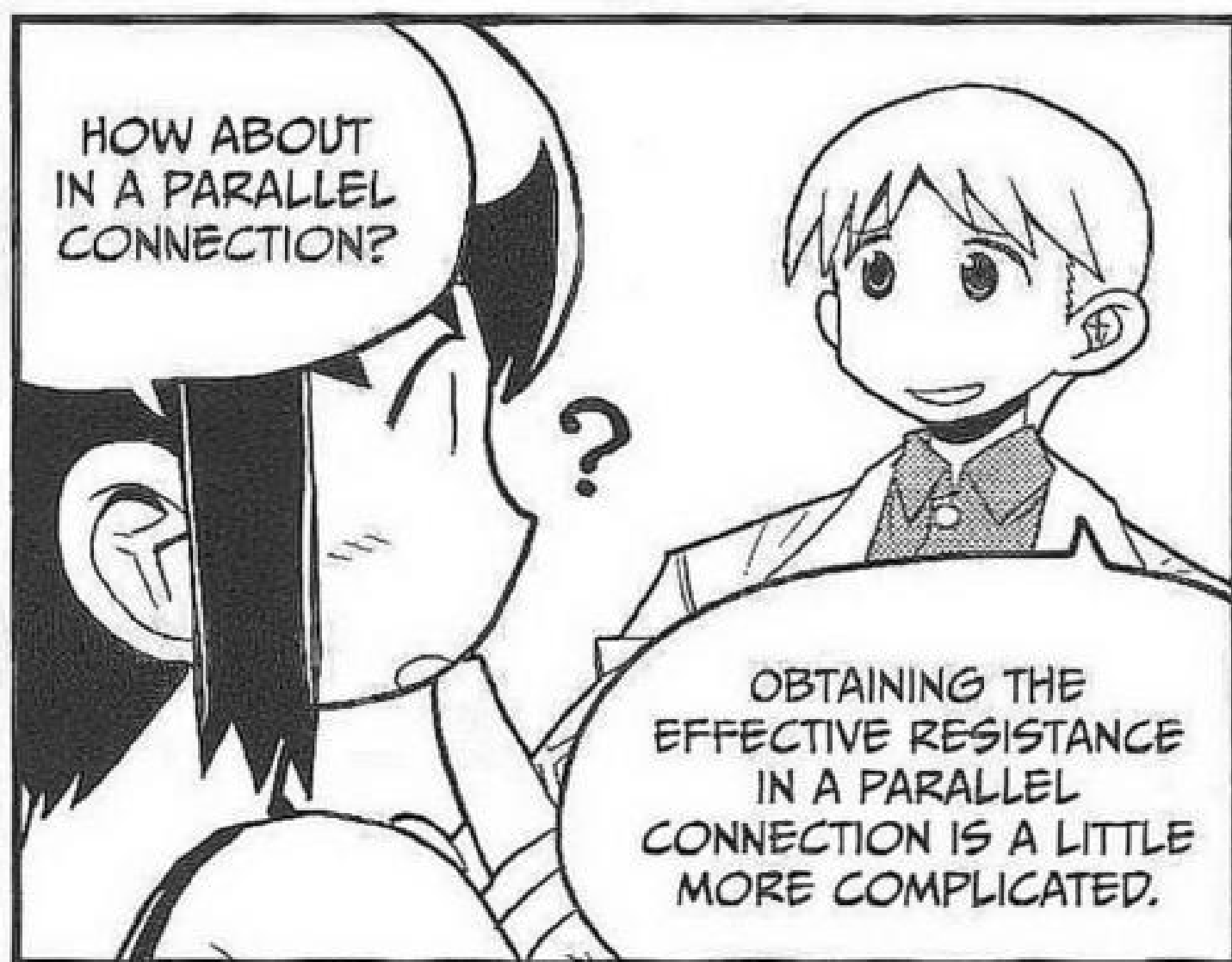
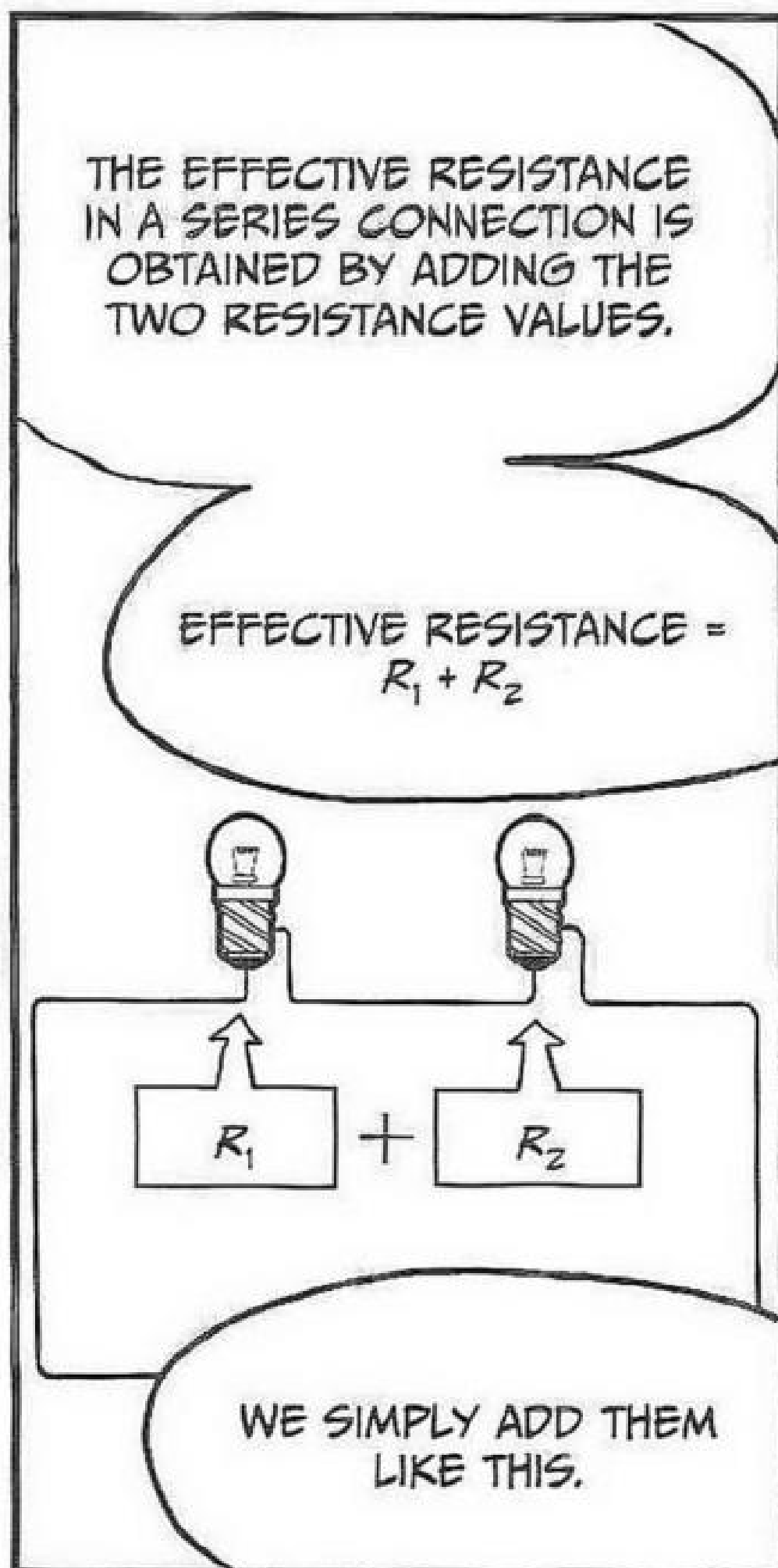
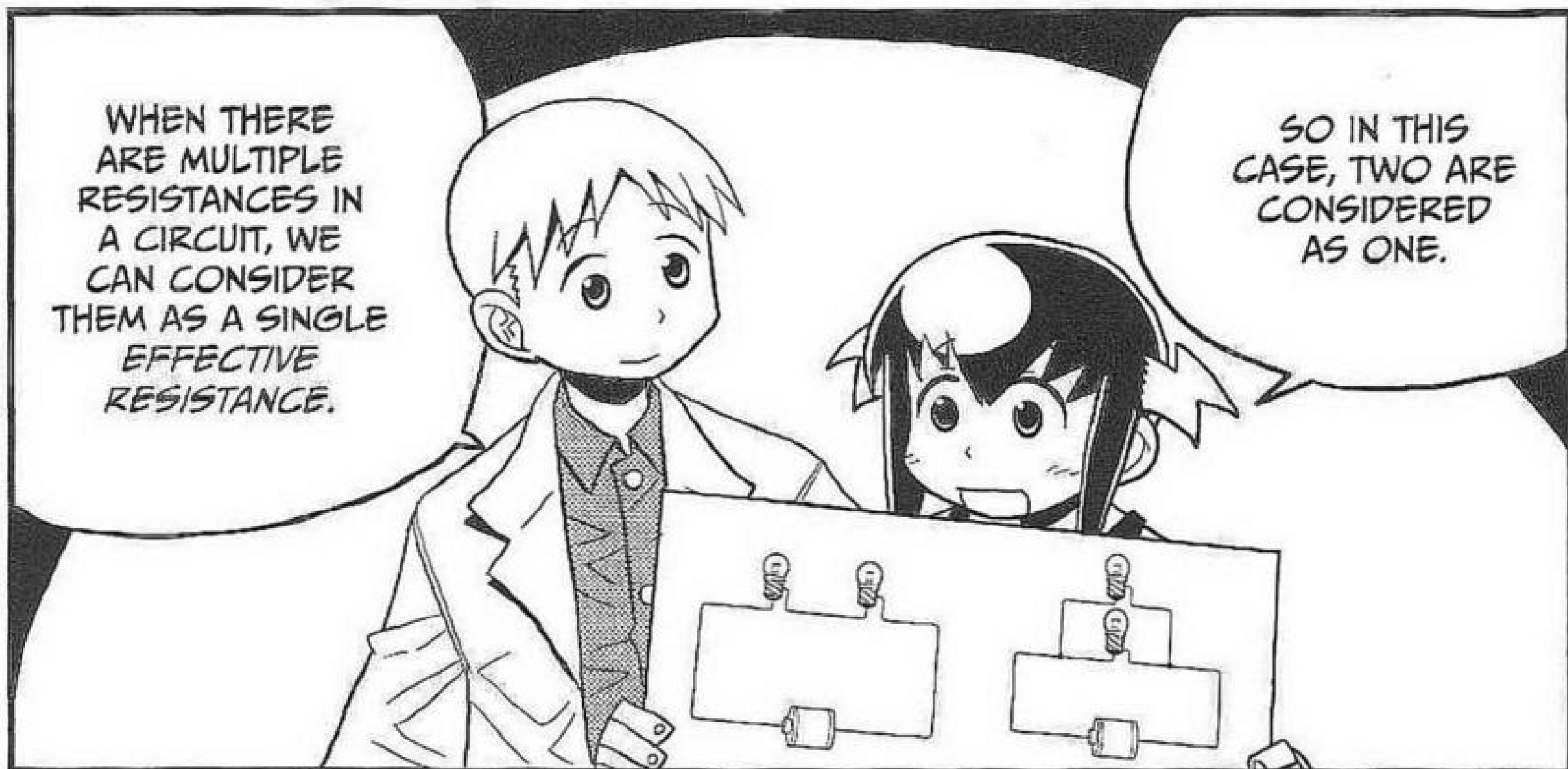
VOLTAGE OF POWER SUPPLY = VOLTAGE OF RESISTANCE 1 + VOLTAGE OF RESISTANCE 2

### PARALLEL CONNECTION



CURRENT OF POWER SUPPLY = CURRENT OF RESISTANCE 1 + CURRENT OF RESISTANCE 2

VOLTAGE OF POWER SUPPLY = VOLTAGE OF RESISTANCE 1 = VOLTAGE OF RESISTANCE 2





IF WE REPRESENT IT IN A FORMULA,  
IT LOOKS LIKE THIS:

$$\text{EFFECTIVE RESISTANCE} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{R_1 \times R_2}{R_1 + R_2}$$

(PRODUCT OVER SUM)

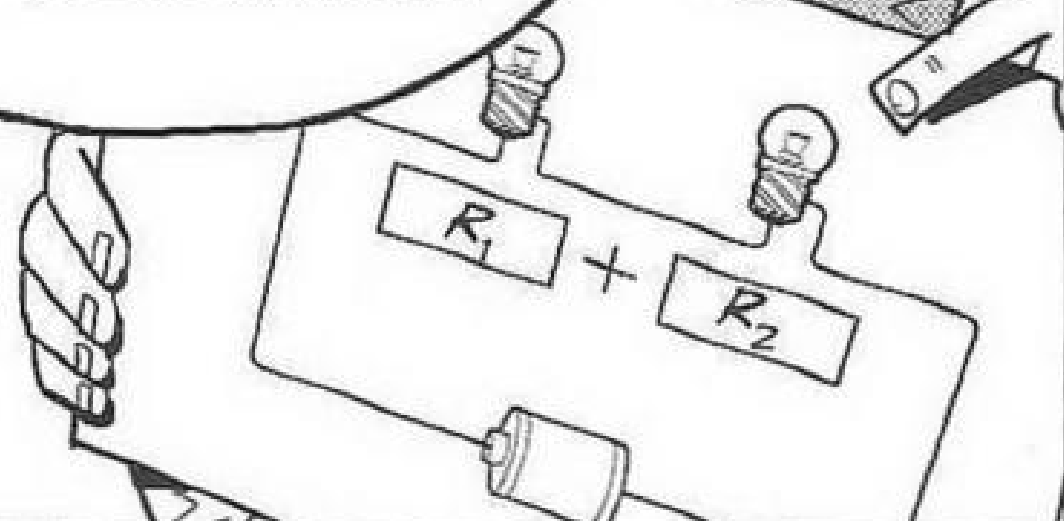


WELL, LET'S GET A  
FEEL FOR IT FIRST,  
OKAY?

HUFF

OKAY...

IF TWO IDENTICAL  
LIGHT BULBS ARE  
CONNECTED IN SERIES,  
THE RESISTANCE VALUE  
IS DOUBLED, RIGHT?

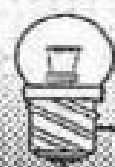


1 BULB



BRIGHT —

2 BULBS



DIM —

IN THIS CASE, SINCE THE  
CURRENT IS HALVED, THE  
BRIGHTNESS OF EACH BULB IS  
DIMMER THAN WHEN JUST ONE  
BULB IS CONNECTED.

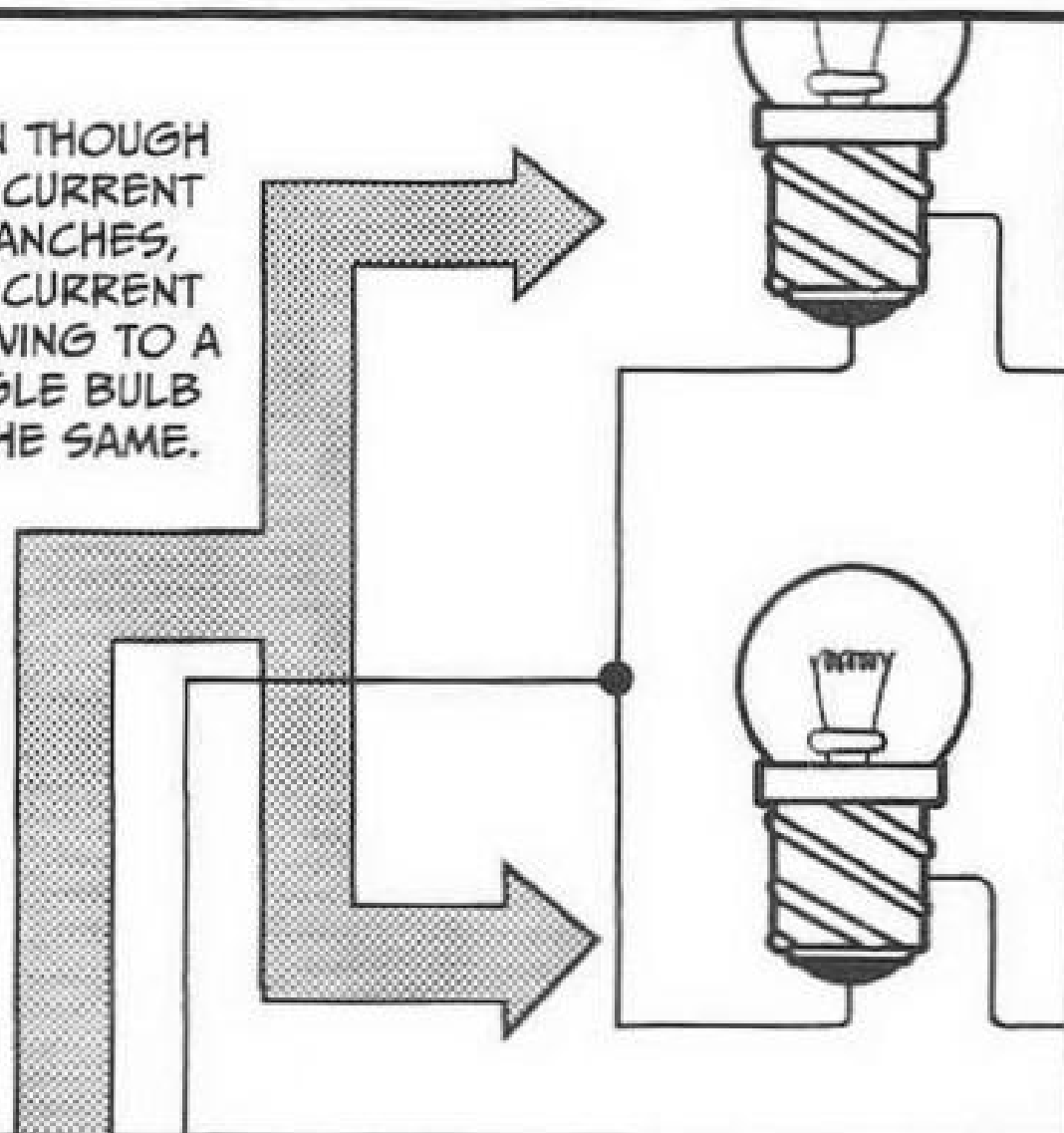
TO GET THE SAME  
BRIGHTNESS IN BOTH  
BULBS AS WHEN ONE  
BULB IS CONNECTED,  
WE MUST DOUBLE  
THE VOLTAGE.

CLICK



IF WE CONNECT THE BULBS IN PARALLEL, THE SAME VOLTAGE IS APPLIED TO EACH BULB, AND SINCE THE SAME CURRENT IS FLOWING, THE BRIGHTNESS DOES NOT CHANGE. HOWEVER, THE TOTAL CURRENT IS DOUBLED.

EVEN THOUGH THE CURRENT BRANCHES, THE CURRENT FLOWING TO A SINGLE BULB IS THE SAME.

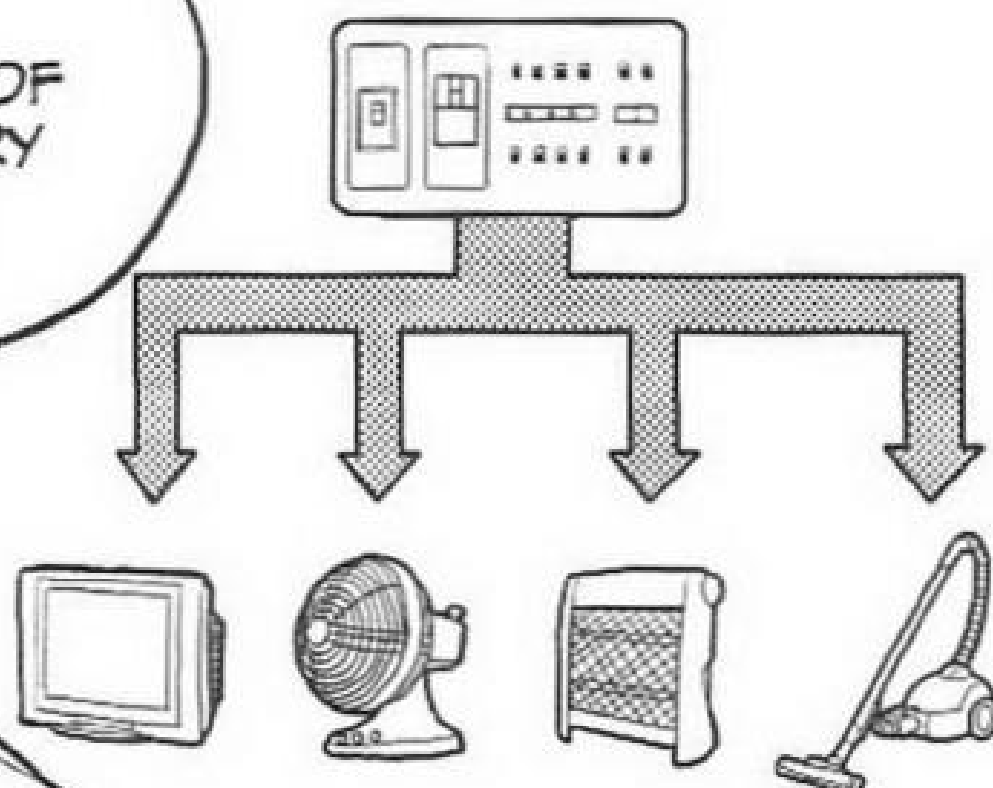


IN OTHER WORDS, WE NEED A POWER SUPPLY THAT MAKES TWICE AS MUCH CURRENT FLOW.

THESE CONNECTION METHODS EACH HAVE SPECIAL CHARACTERISTICS, DON'T THEY?

A HOUSEHOLD ELECTRIC APPLIANCE ALSO ACTS AS A RESISTANCE. WE CAN CONNECT MANY OF THEM IN PARALLEL TO A 120V POWER SUPPLY FROM THE BREAKER.

THEREFORE, A VOLTAGE OF 120V IS APPLIED TO EVERY ELECTRIC APPLIANCE.



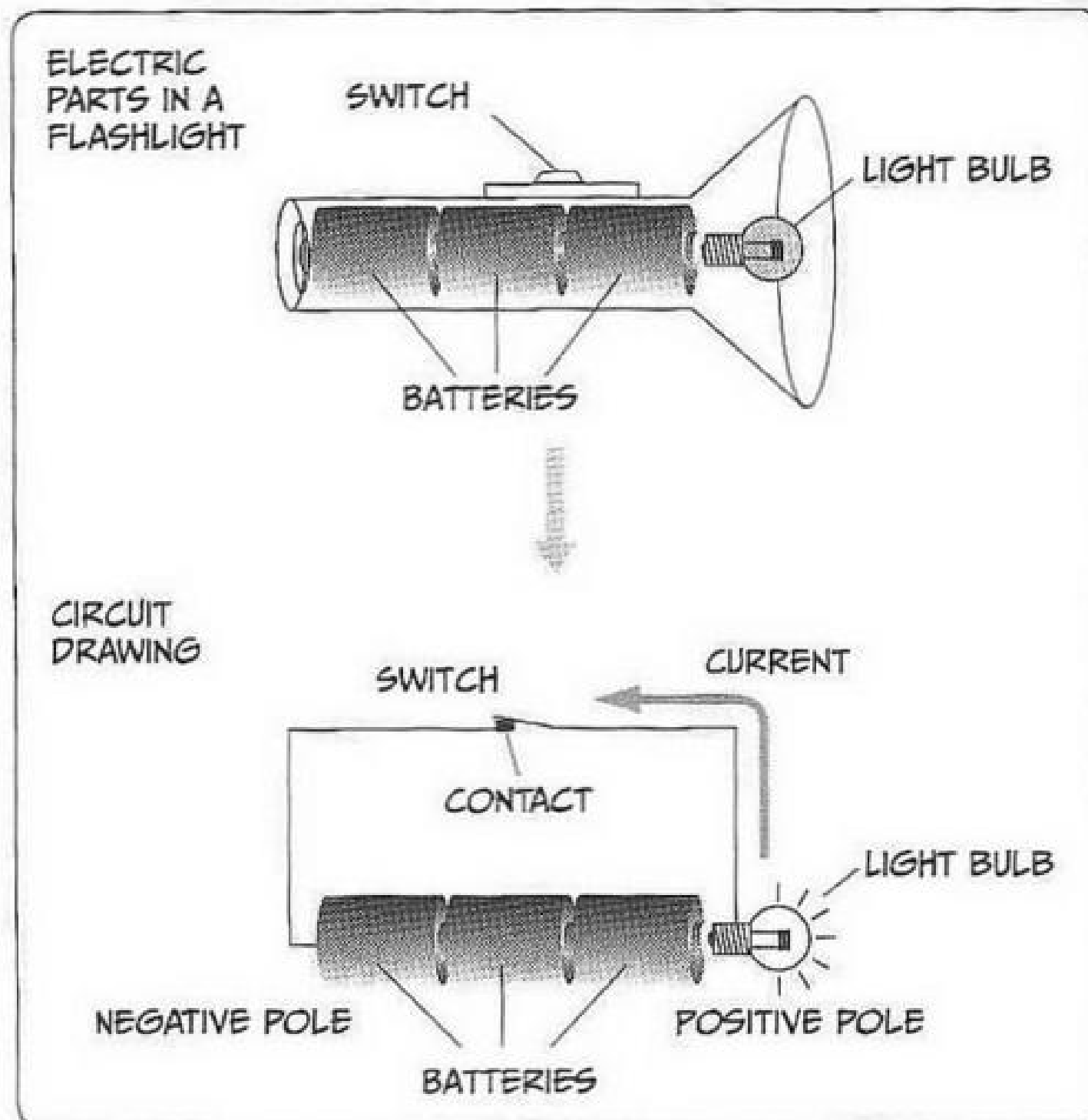
I GET IT!

ALL 120V

## ELECTRIC CIRCUITS AND CURRENT

The electrical parts that make up a flashlight are the batteries, a miniature light bulb, and a switch. A battery has the ability to make electrical current flow, so it is called the *power supply*. The light bulb is a part that emits light when current flows through it. The switch is a part that lets electricity flow or stops it according to the opening and closing of a contact.

When the switch is closed, current leaves the positive pole of the battery, passes through the light bulb and switch, and returns to the negative pole. The path through which current flows in this way is called an *electric circuit*, which always has a closed form (a *closed circuit*).



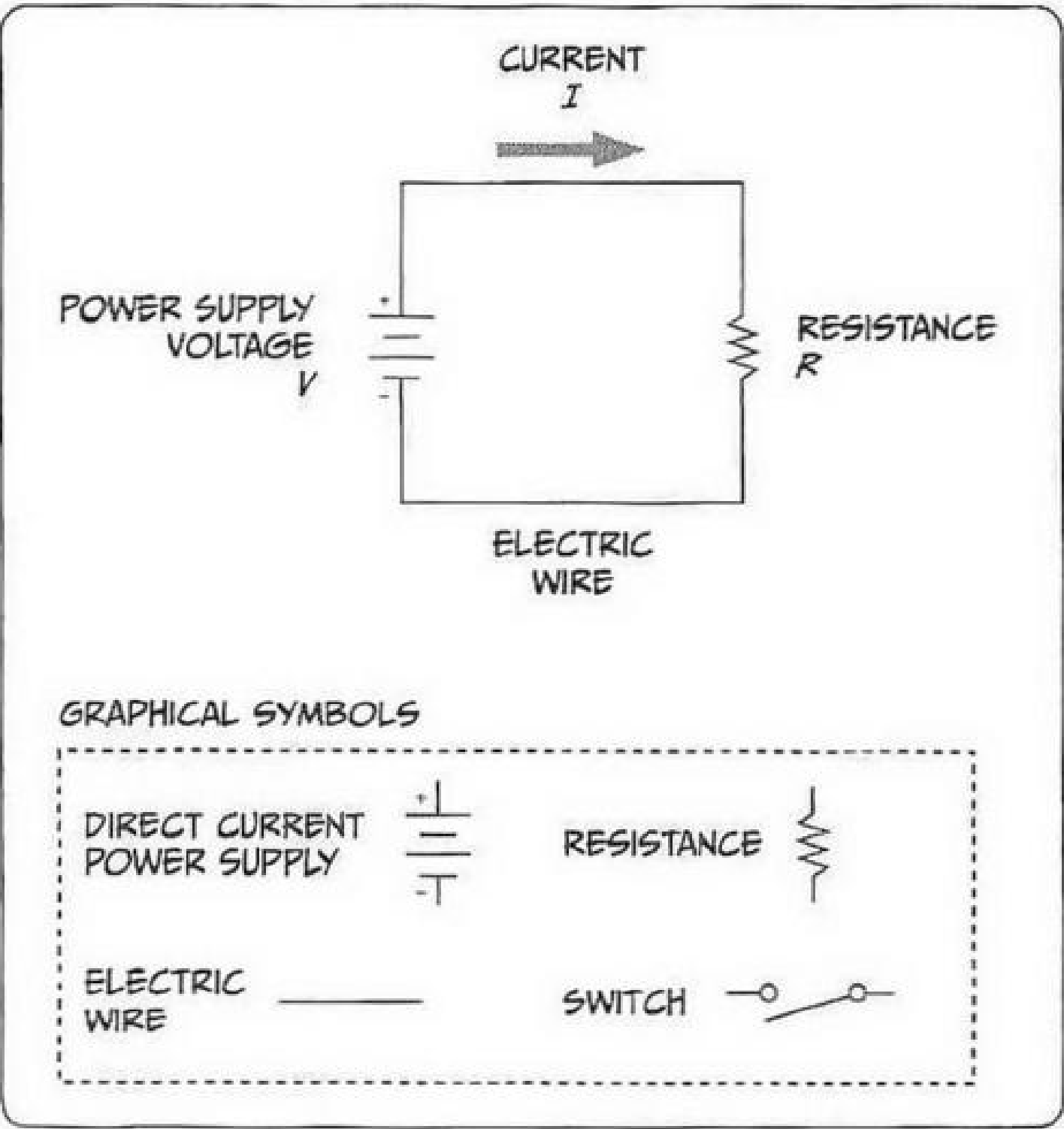
Electric circuit of a flashlight

### GRAPHICAL SYMBOLS

A basic electric circuit consists of three elements: power supply voltage, current, and electric resistance. These elements are connected by electric wires.

The power supply voltage that does the work of making current flow is called the *electromotive force*. The element that converts electric energy to light or heat when current flows is called the *load* (loads can also convert electrical energy into other things like sound or motion). The load has a property that hinders the flow of current, and this is called *electric resistance* or simply *resistance*. Resistance is represented by the symbol  $R$  and measured in *ohms* ( $\Omega$ ), which come from the name of the German physicist Georg Simon Ohm.

Creating a realistic drawing of an electric circuit takes time and effort. Therefore, *graphical symbols* are generally used to draw a representation. Using standard graphical symbols enables anyone to easily understand a circuit diagram that was drawn by someone else.



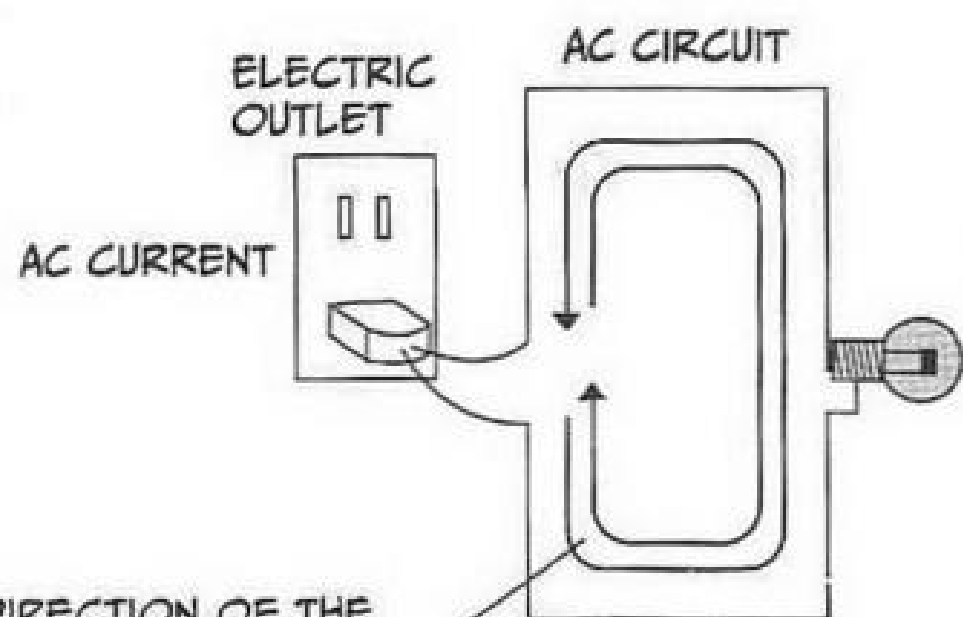
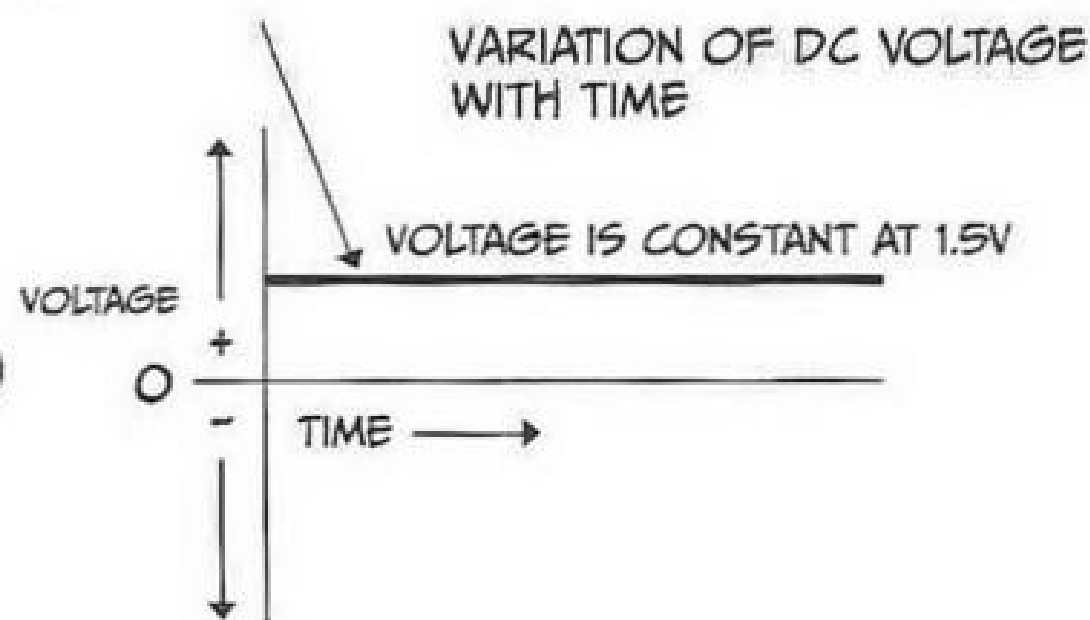
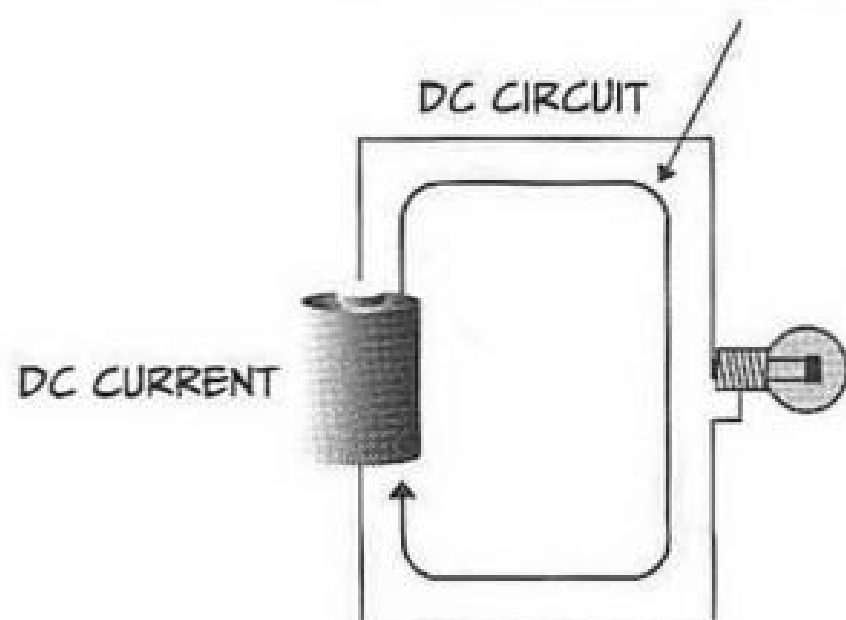
*Electric circuit and graphical symbols*

Appliances that use electric resistance include electric heaters and toasters. The electric heating element used in these appliances is the part that converts electrical energy to heat energy when current flows through the electric resistance. Note that the electric wire used in these appliances also has electric resistance; although it is only a small amount of resistance, when current flows through the electric wire, heat is generated.

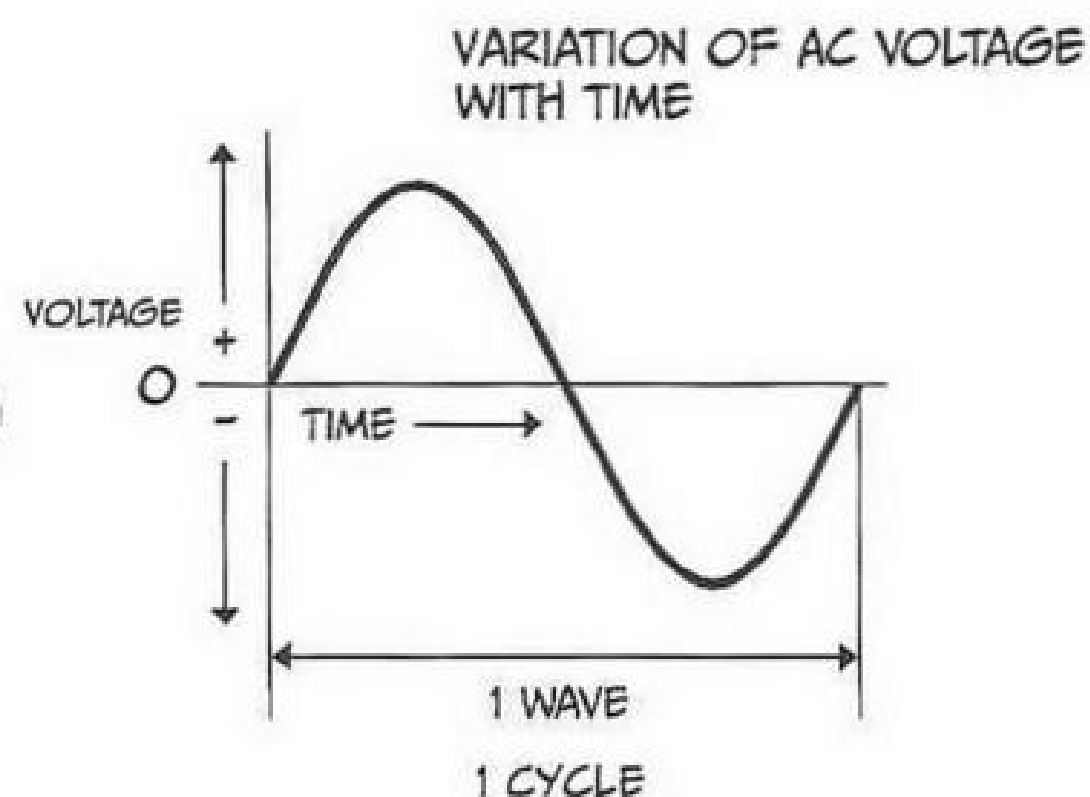
### DIRECT CURRENT CIRCUIT AND ALTERNATING CURRENT CIRCUIT

The direction the current flows in a circuit that has a battery as the power supply is fixed, and the size of the current is also constant. When the direction of the flow of current and the size of the current are fixed, we call the electricity *direct current (DC)*. A circuit in which direct current flows is called a *direct current (DC) circuit*. A power supply that sends out direct current, such as a battery, is called a *DC power supply*. A size D or size AA battery has a DC 1.5V power supply voltage.

THE DIRECTION OF CURRENT IS ALWAYS THE SAME, AND THE SIZE IS ALSO CONSTANT.



THE DIRECTION OF THE CURRENT ALTERNATES BETWEEN CLOCKWISE AND COUNTERCLOCKWISE.

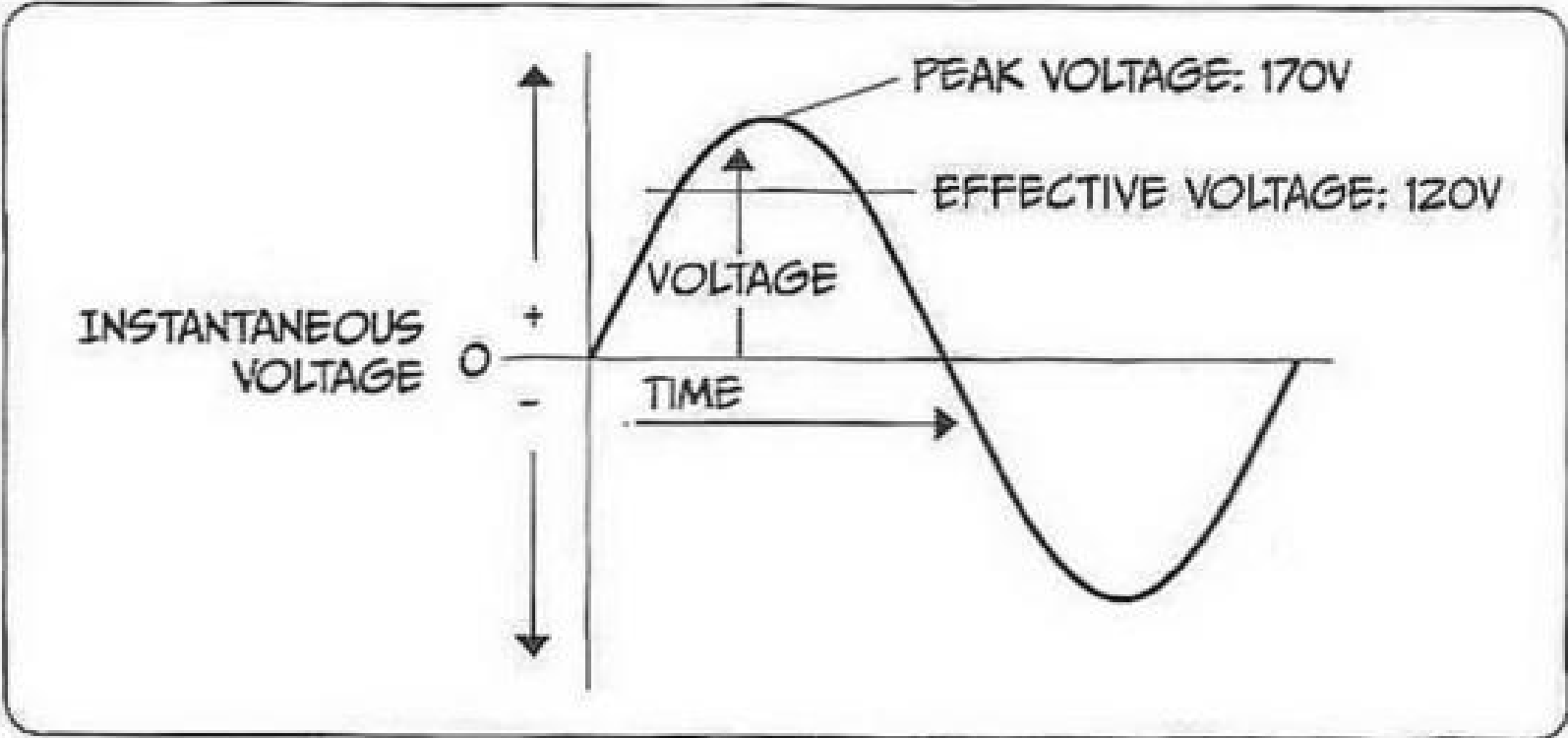


THE NUMBER OF WAVES REPEATED IN ONE SECOND IS CALLED THE FREQUENCY.

#### Direct current and alternating current

On the other hand, the direction of flow and size of the current sent from the electric power company to a home changes cyclically. This kind of electricity is called *alternating current (AC)*, and a circuit in which alternating current flows is called an *alternating current (AC) circuit*. The direction that this electricity flows changes 50 or 60 times per second, and its size also varies cyclically with time. The number of waves repeated in one second is called the *frequency*, which is represented by  $f$  and measured in *hertz (Hz)*.

The size of AC voltage at any given time is called the *instantaneous voltage*, and the largest value among the instantaneous voltages is called the *peak voltage*. The size of the AC voltage that will perform the same amount of work as a DC voltage is called the *effective voltage*. The AC voltage that comes to an electric outlet in a home is generally 120V in the United States, but this is the effective voltage. The peak voltage is approximately 170V.



Alternating current value

# OHM'S LAW

The current that flows in a circuit is directly proportional to the voltage and indirectly proportional to the resistance. This relationship is called *Ohm's law* and can be expressed in a formula as  $I = V / R$ . This is the most important and basic property in electric circuits.

For example, if a voltage of 120V is applied to a resistance of 120Ω, the current will be  $I = V / R = 120 / 120$ , and 1A of current will flow. Whenever you know two values among the current, voltage, and resistance in a circuit, you can use Ohm's law to calculate the value you don't know.

OHM'S LAW       $I = \frac{V}{R}$

IF THESE TWO VALUES ARE KNOWN,  
THE CURRENT CAN BE CALCULATED.

CALCULATION  
ACCORDING  
TO OHM'S LAW

$$I = \frac{V}{R} = \frac{120}{120} = 1A$$

Ohm's law

## RESISTIVITY AND CONDUCTIVITY

Electric wire has a very low resistance and is used to connect circuit elements. When a small amount of current flows through wire, we can consider its resistance negligible. If a larger amount of current flows through a wire than can do so safely, heat will be generated.

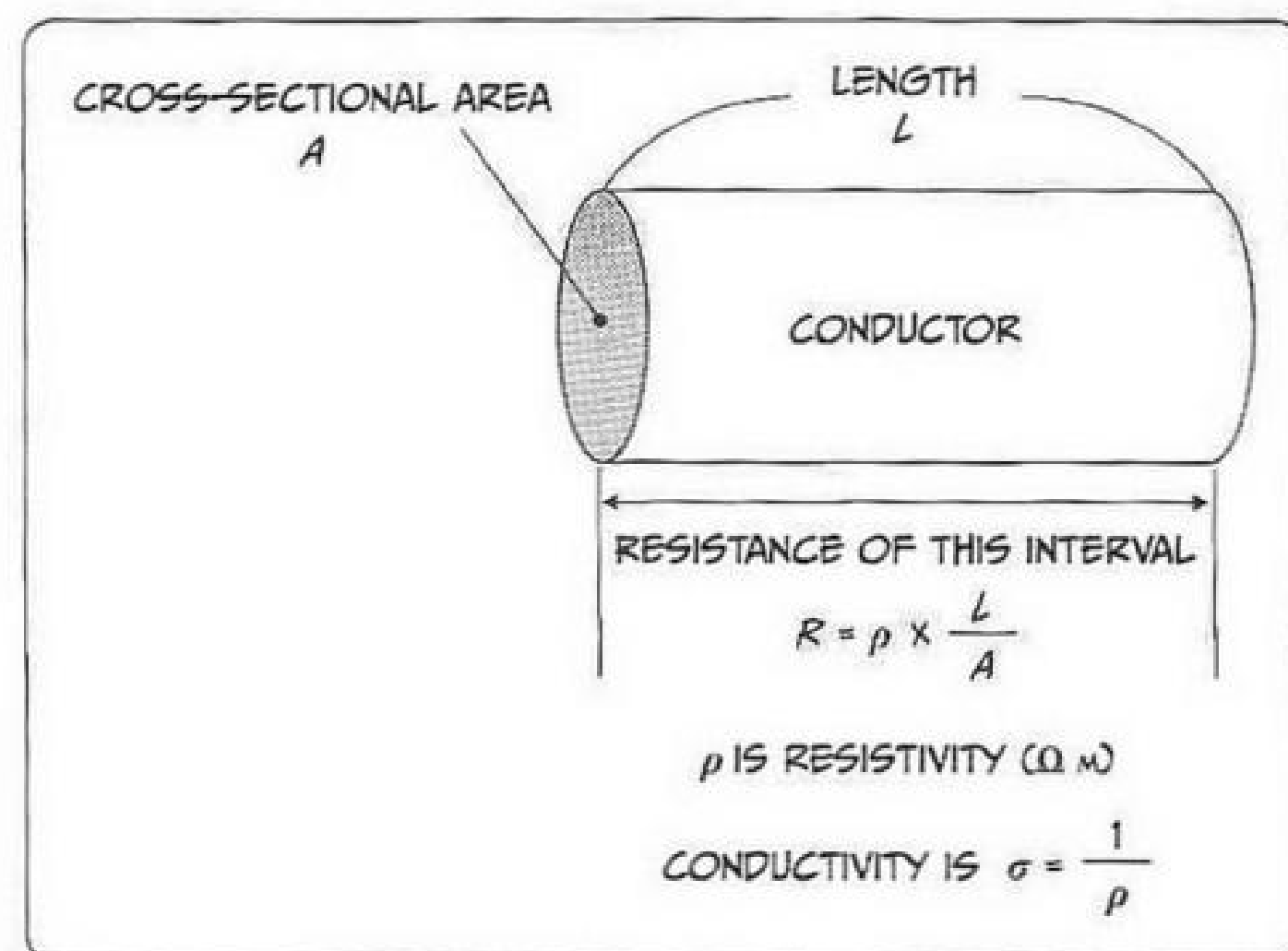
*Resistance (R)* is a measure indicating the difficulty of the flow of current. The resistance (measured in ohms) of a conductor with length  $L$  meters and cross-sectional area  $A$  square meters can be represented by  $R = \rho \times L / A$ .

*Resistivity* measures how much a material opposes the flow of current and can be used to determine a wire's resistance. Resistivity, represented by the symbol  $\rho$ , is a material-specific resistance value and is measured in *ohm meters* ( $\Omega m$ ). From this equation it is apparent that for the same material, the size of the resistance is directly proportional to the length and inversely proportional to the cross-sectional area.

### RESISTIVITY (IN $\Omega m$ ) OF VARIOUS METALS AT ROOM TEMPERATURE (68°F)

Gold	$2.22 \times 10^{-8}$
Silver	$1.59 \times 10^{-8}$
Copper	$1.69 \times 10^{-8}$
Aluminum	$2.27 \times 10^{-8}$
Nichrome	$107.5 \times 10^{-8}$

*Conductance (G)*, in contrast to resistance, is a measure indicating the ease of the flow of current and is measured in *siemens (S)*. Conductivity, represented by the symbol  $\sigma$ , is the reciprocal of resistivity, and it is measured in *siemens per meter (S/m)*. (The siemens, named for German inventor Ernst Werner von Siemens, is an inverse ohm; it is also sometimes called a *mho* and can be represented by the symbol  $\mathfrak{U}$  or  $\Omega^{-1}$ ).



Resistivity and conductivity



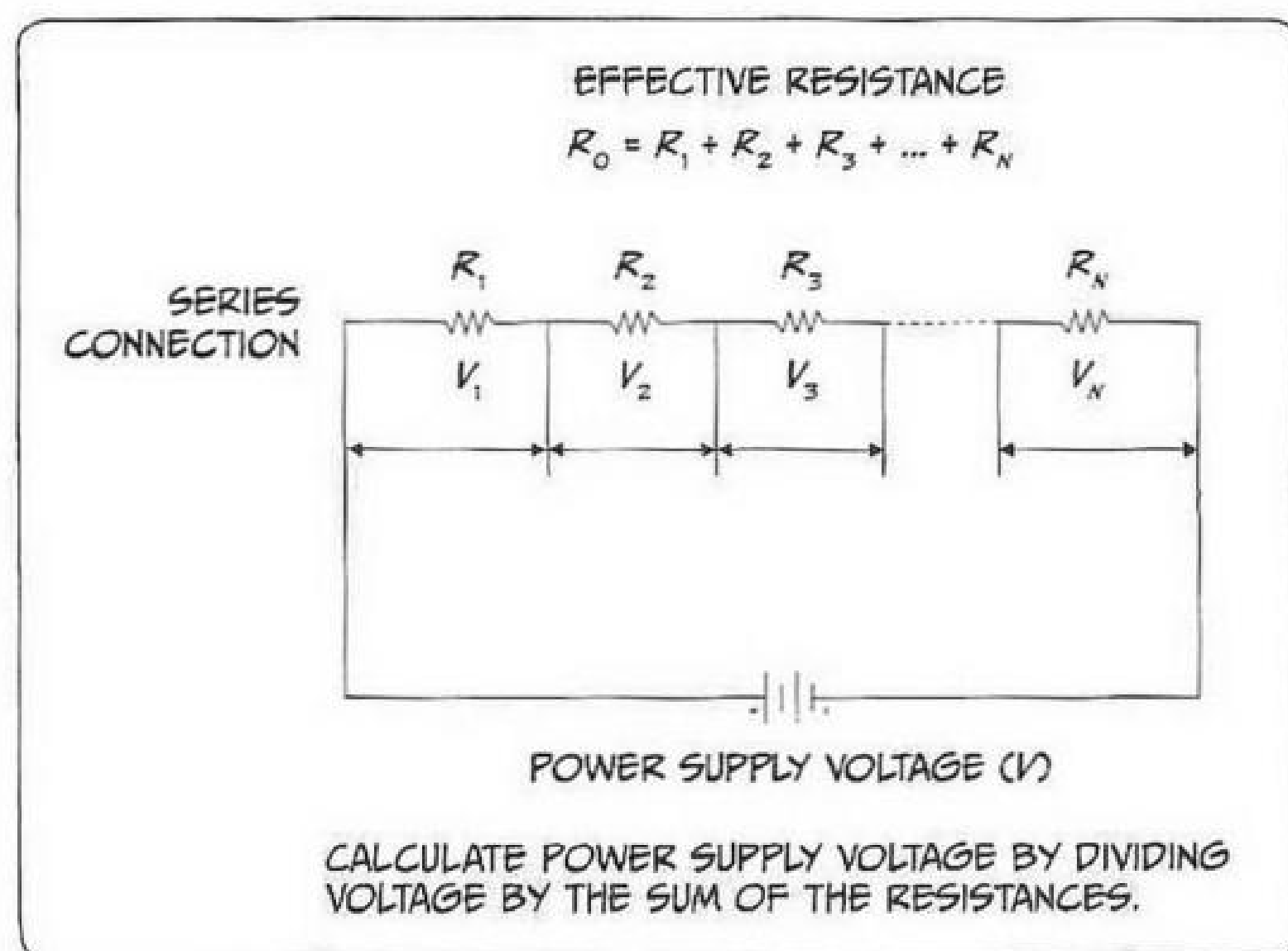
# EFFECTIVE RESISTANCE

There are two basic methods of connecting electrical components. Let's look at them both with respect to resistance. When there are multiple resistances in a circuit, we can consider them as a single *effective resistance*.

The method of connecting resistances in a line is called a *series connection*. We calculate the value of the effective resistance in a series connection by totaling the individual resistance values.

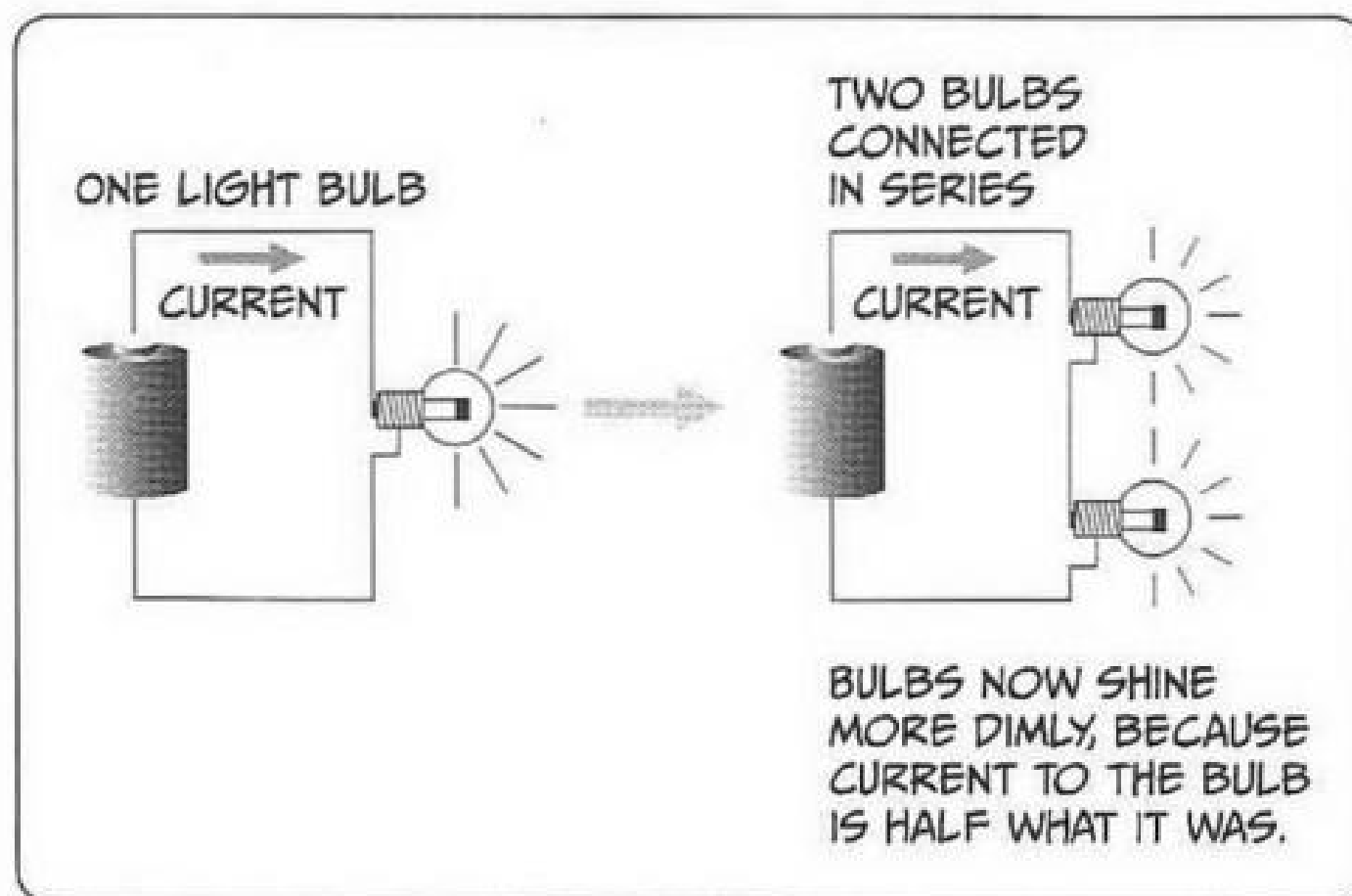
$$\text{Effective resistance} = R_0 = R_1 + R_2 + \dots + R_n$$

In this connection, the size of the current that flows in each resistance is the same. The power supply voltage is voltage divided by each resistance.



*Series connection and effective resistance*

If two light bulbs of the same size are connected in series to a power supply, the current will be halved, and the brightness of each bulb will be dimmer than it was when just a single bulb was connected, because the effective resistance is doubled. At this time, the voltage at both sides of each light bulb will be half the value of the power supply voltage.



Series connection of light bulbs

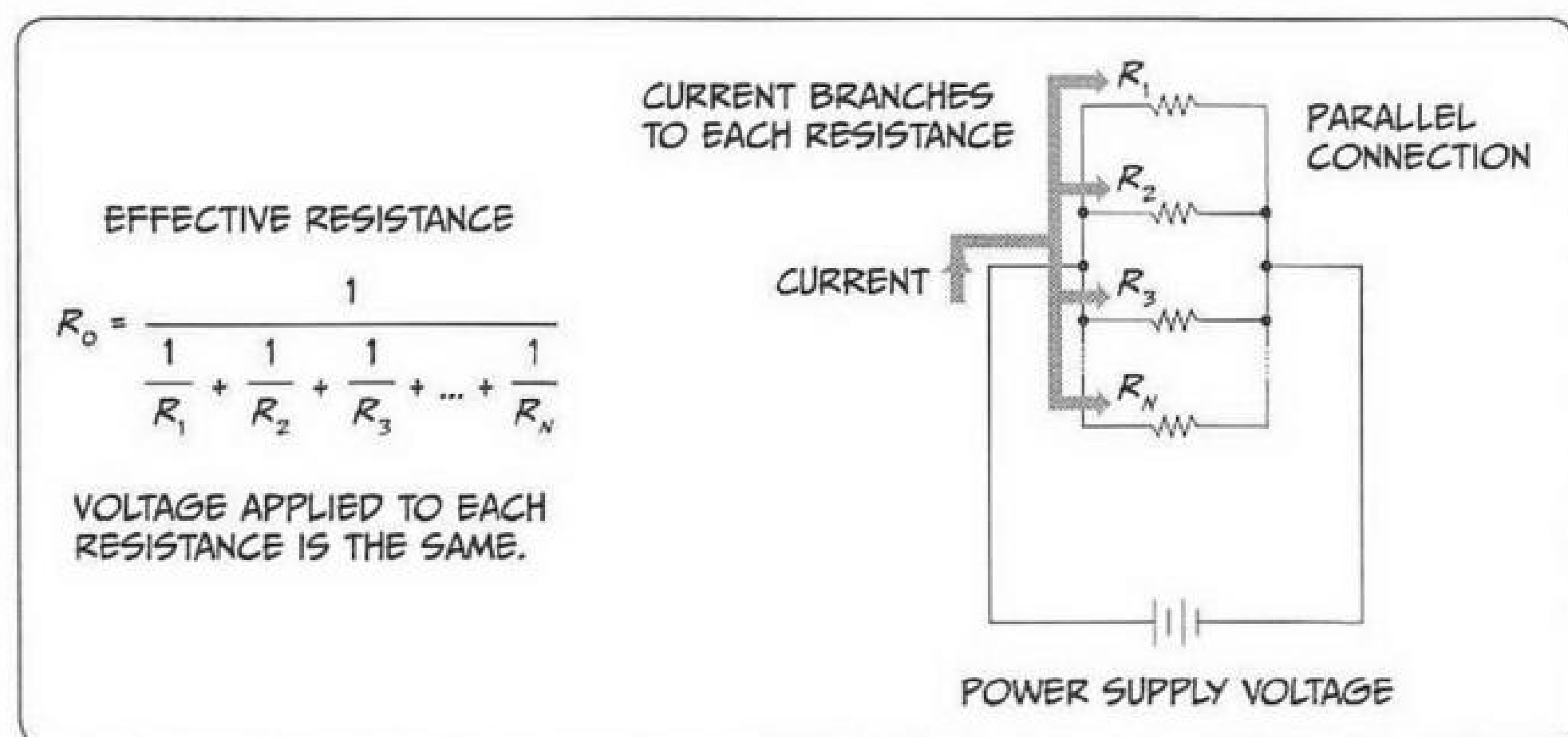
The other basic method of connecting resistances is called a *parallel connection*. At this time, the value of the effective resistance can be obtained by calculating the reciprocal of the sum of the reciprocals of each resistance.

$$\text{Effective resistance} = R_0 = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}}$$

The total resistance when two resistances are connected in parallel can be obtained as follows.

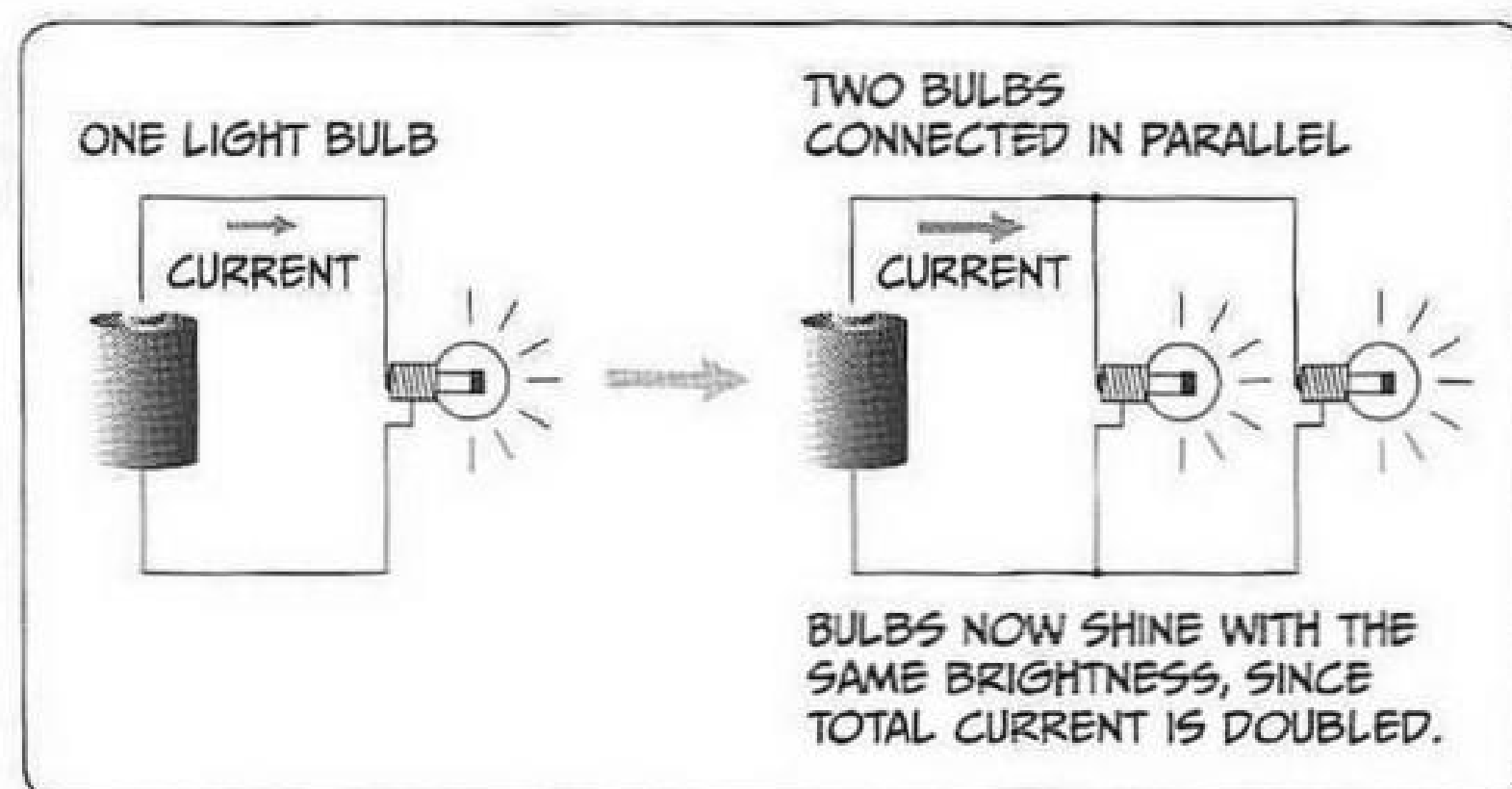
$$\text{Effective resistance} = R_0 = \frac{R_1 \times R_2}{R_1 + R_2} \quad (\text{Product over sum})$$

In a parallel circuit, the voltage applied to each resistance is the same, because the current branches and flows to each resistance.



Parallel connection and effective resistance

If two light bulbs of the same size are connected in parallel to a power supply, the brightness of each bulb is the same as it is when there is only one bulb. Since the current flowing to each bulb is the same as the current flowing when only one bulb is connected, the total current is doubled.



*Series connection of light bulbs*

The 120V electric appliances that we use in our homes are connected in parallel to a 120V power supply. If we increase the number of electric appliances connected to the power supply, the total current flowing also increases.

3

HOW DOES ELECTRICITY WORK?



WHY DOES ELECTRICITY  
PRODUCE HEAT?

SO, HOW'S  
IT GOING?

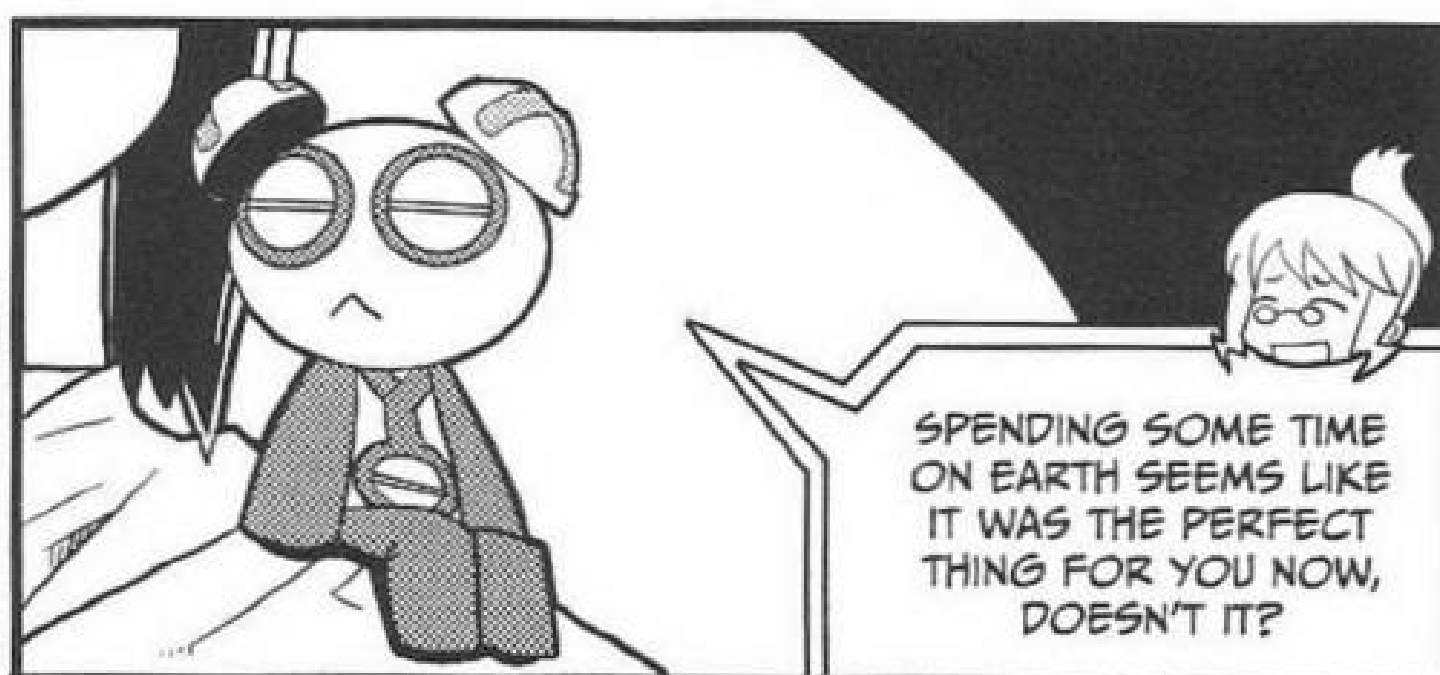
ARE THE  
LESSONS  
GOING WELL?



THEY'RE  
GREAT!



HIKARU SENSEI  
AND I HAVE REALLY  
HIT IT OFF!



SPENDING SOME TIME  
ON EARTH SEEMS LIKE  
IT WAS THE PERFECT  
THING FOR YOU NOW,  
DOESN'T IT?



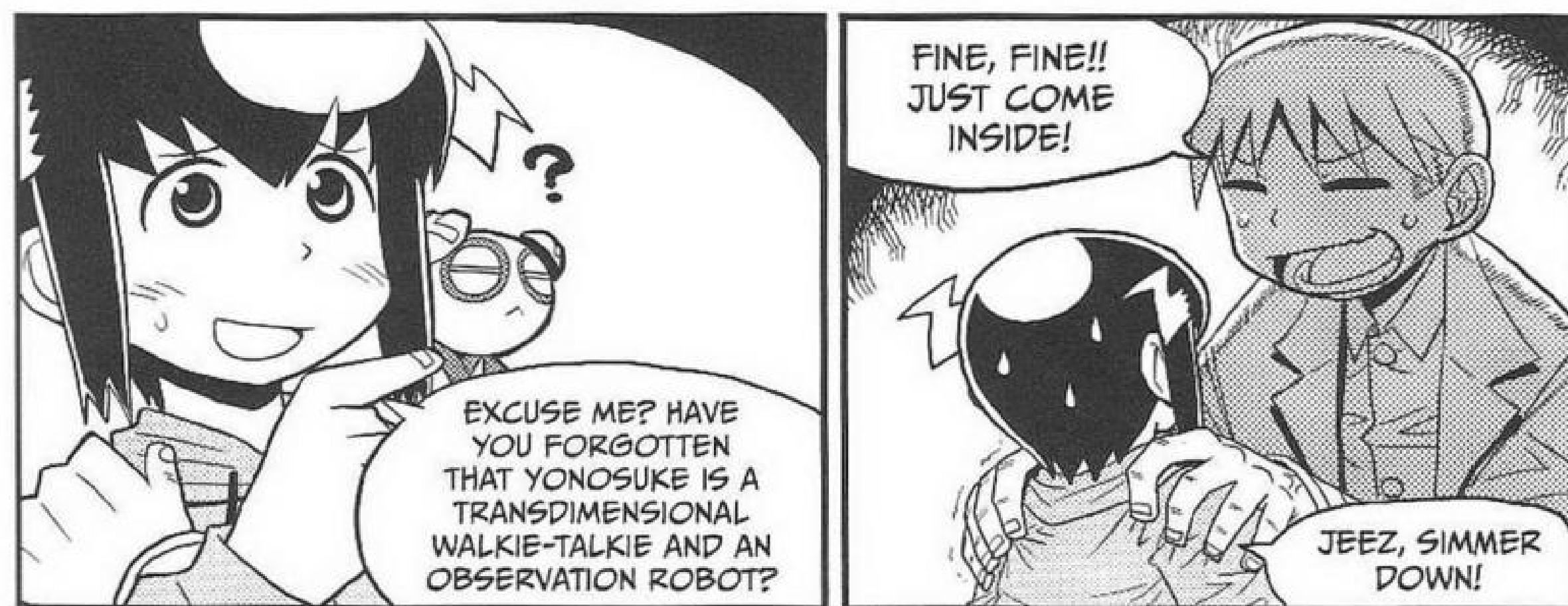
YES! BY  
PROPERLY  
REVIEWING THE  
BASICS HERE,  
I WILL REGAIN  
MY HONOR IN  
ELECTOPIA!

REGAIN?



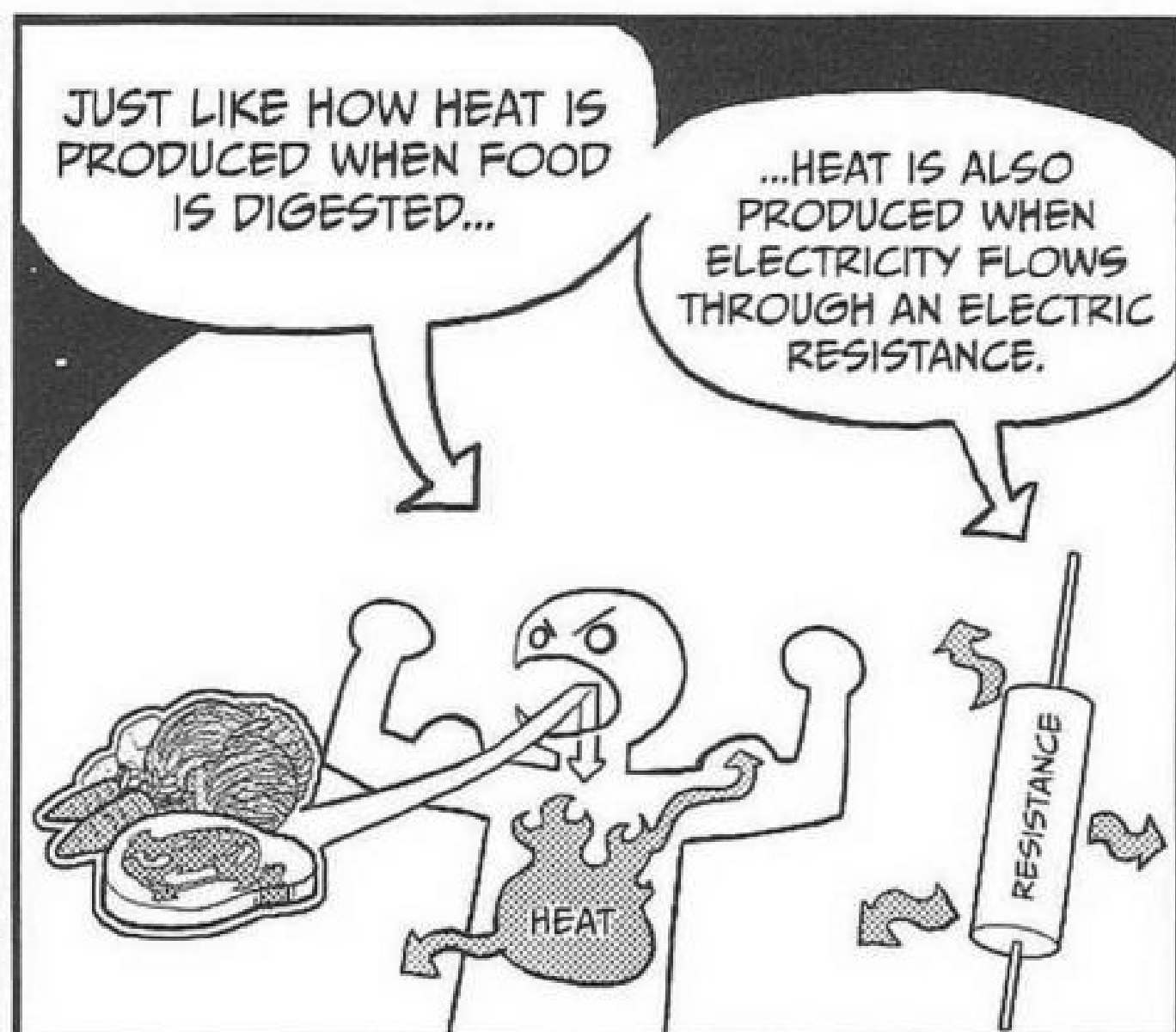
YOU NEVER  
HAD ANY  
HONOR IN  
THE FIRST  
PLACE!

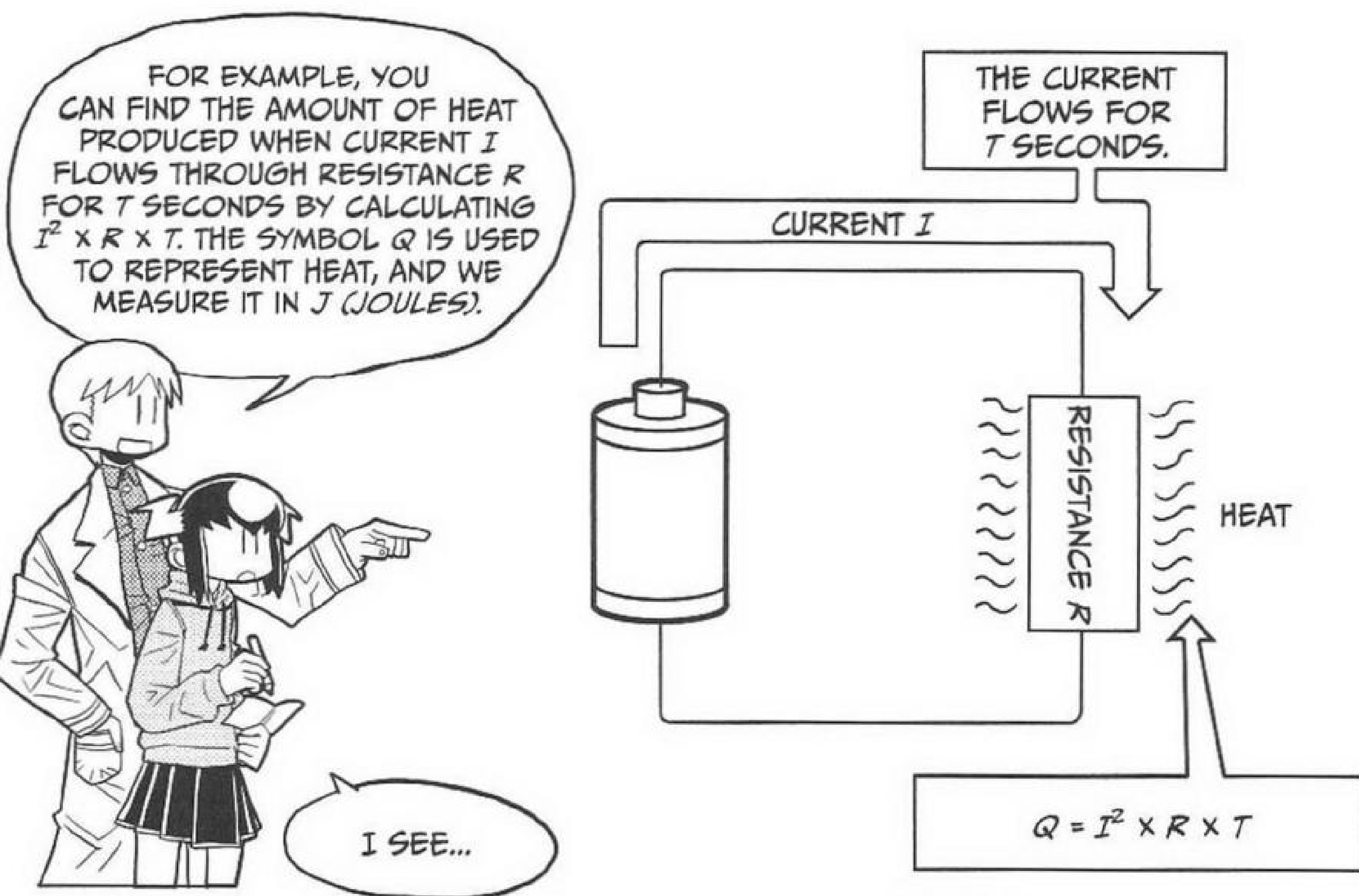
JEEZ! THAT  
WAS ROUGH.



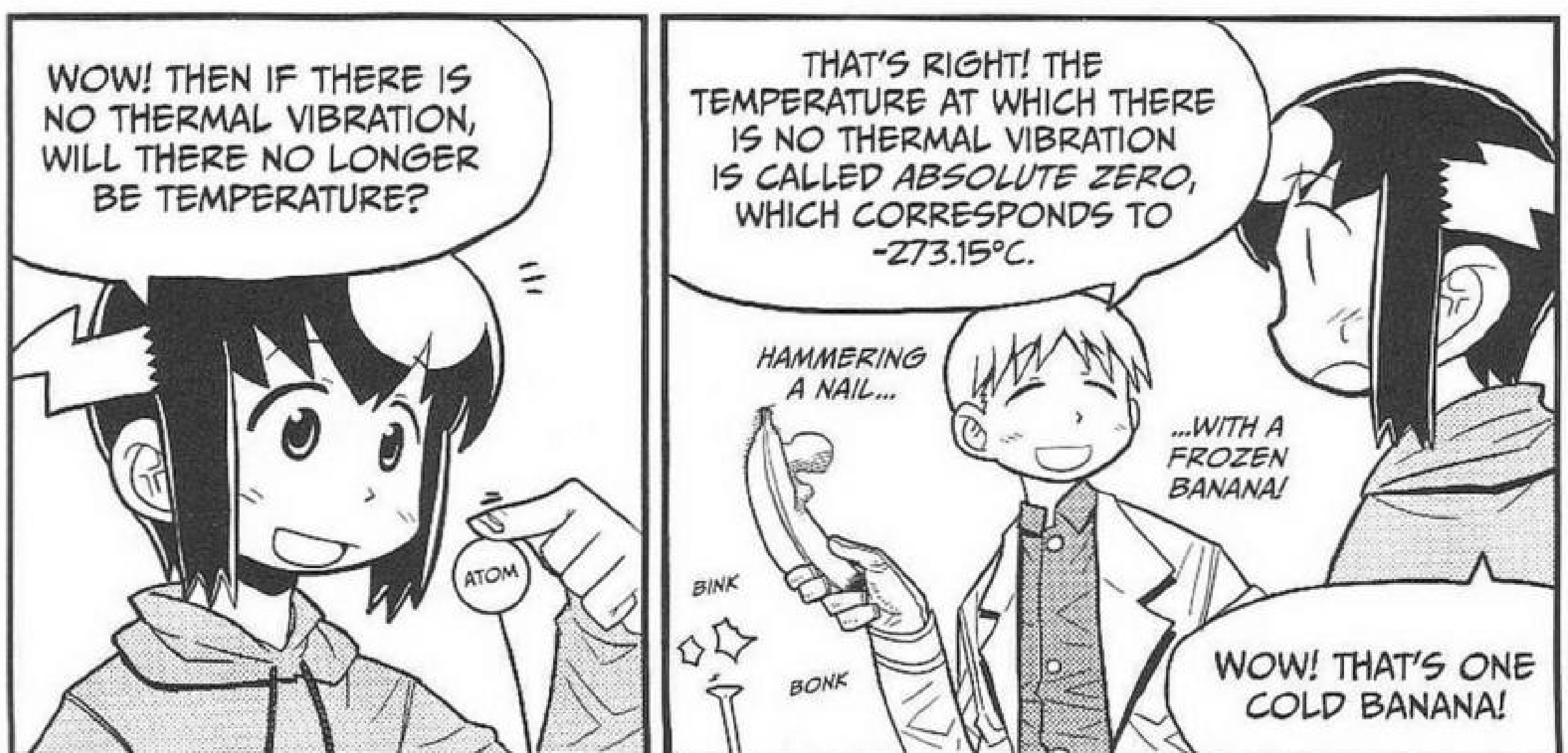
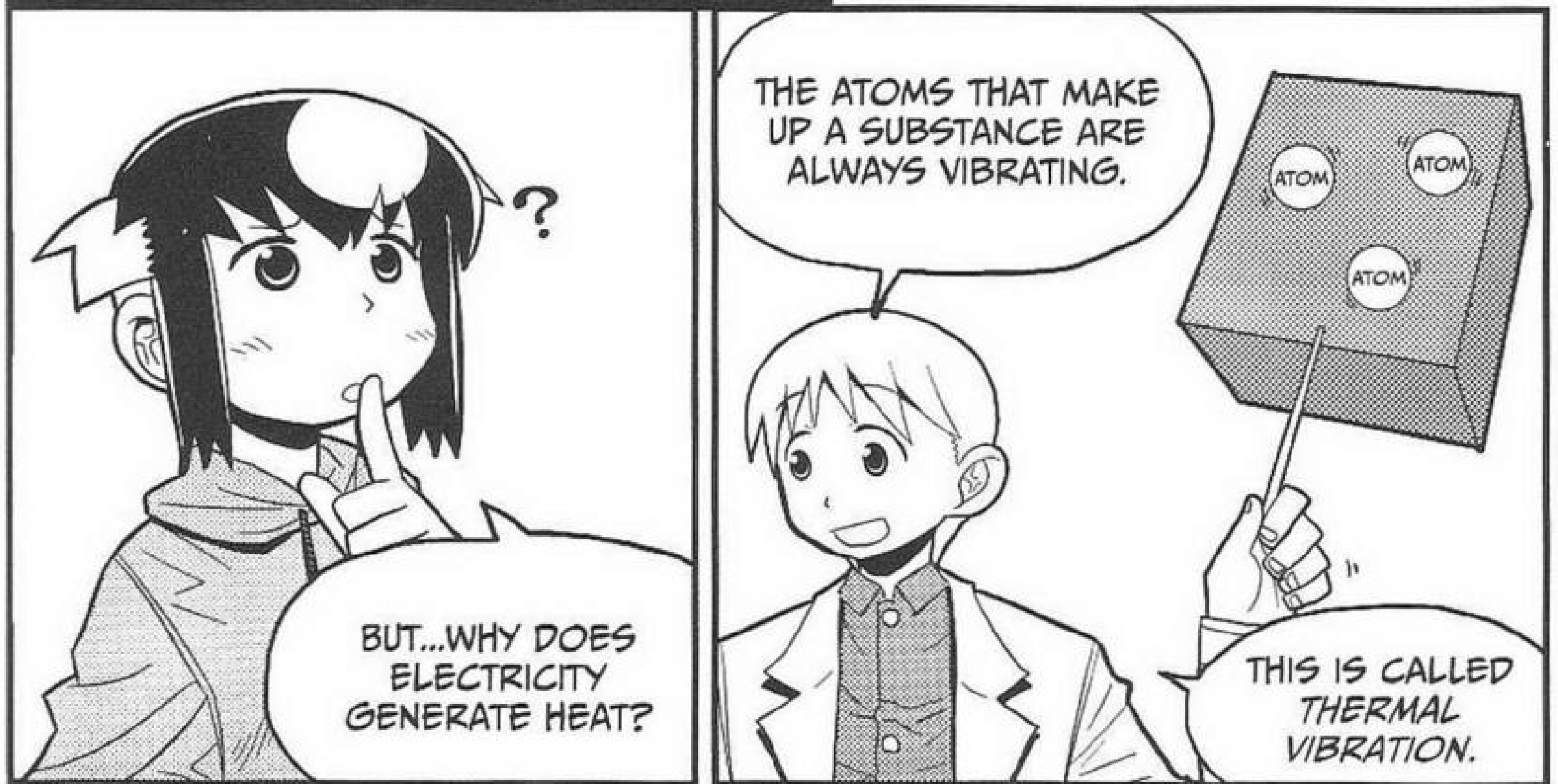






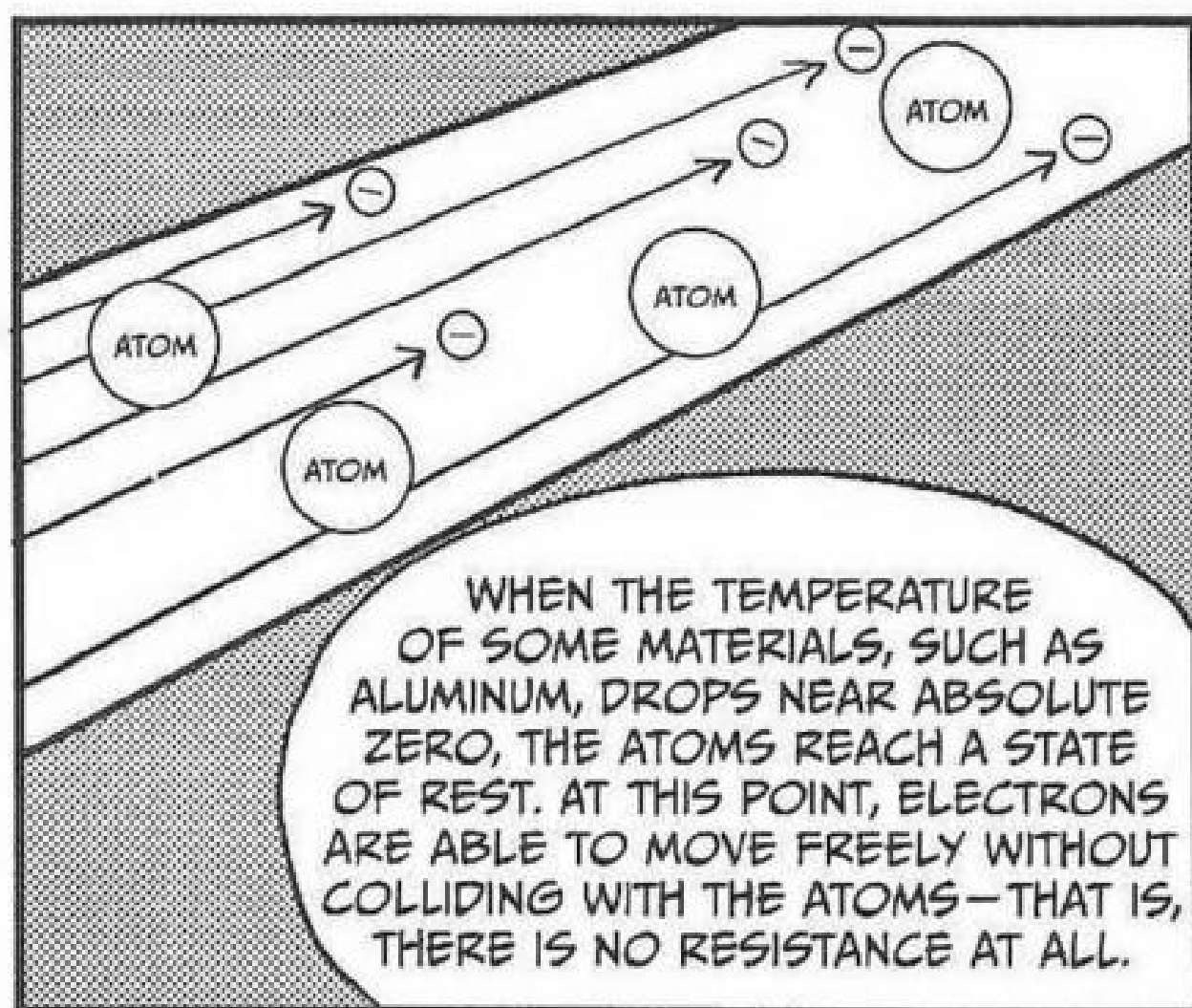
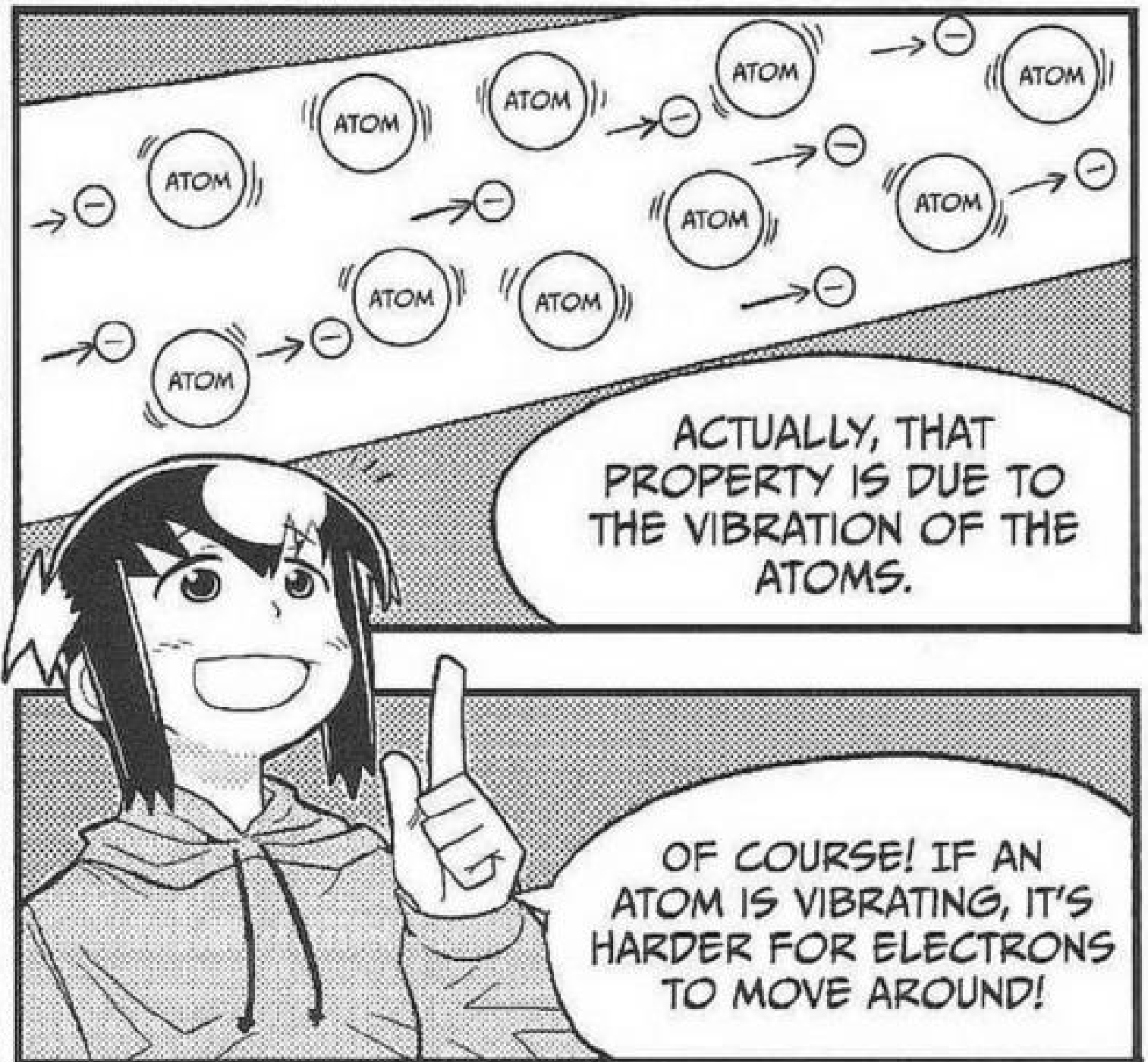


## HOW IS HEAT GENERATED BY CURRENT?

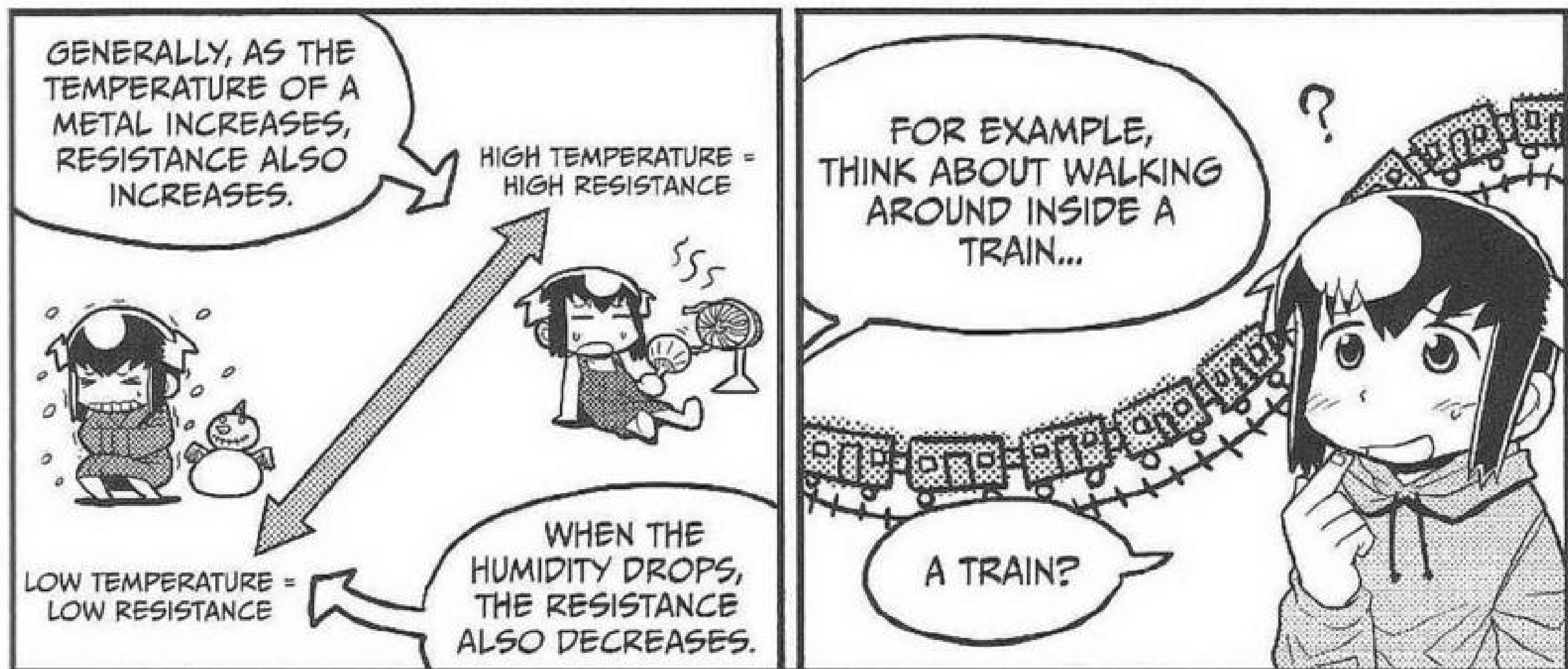
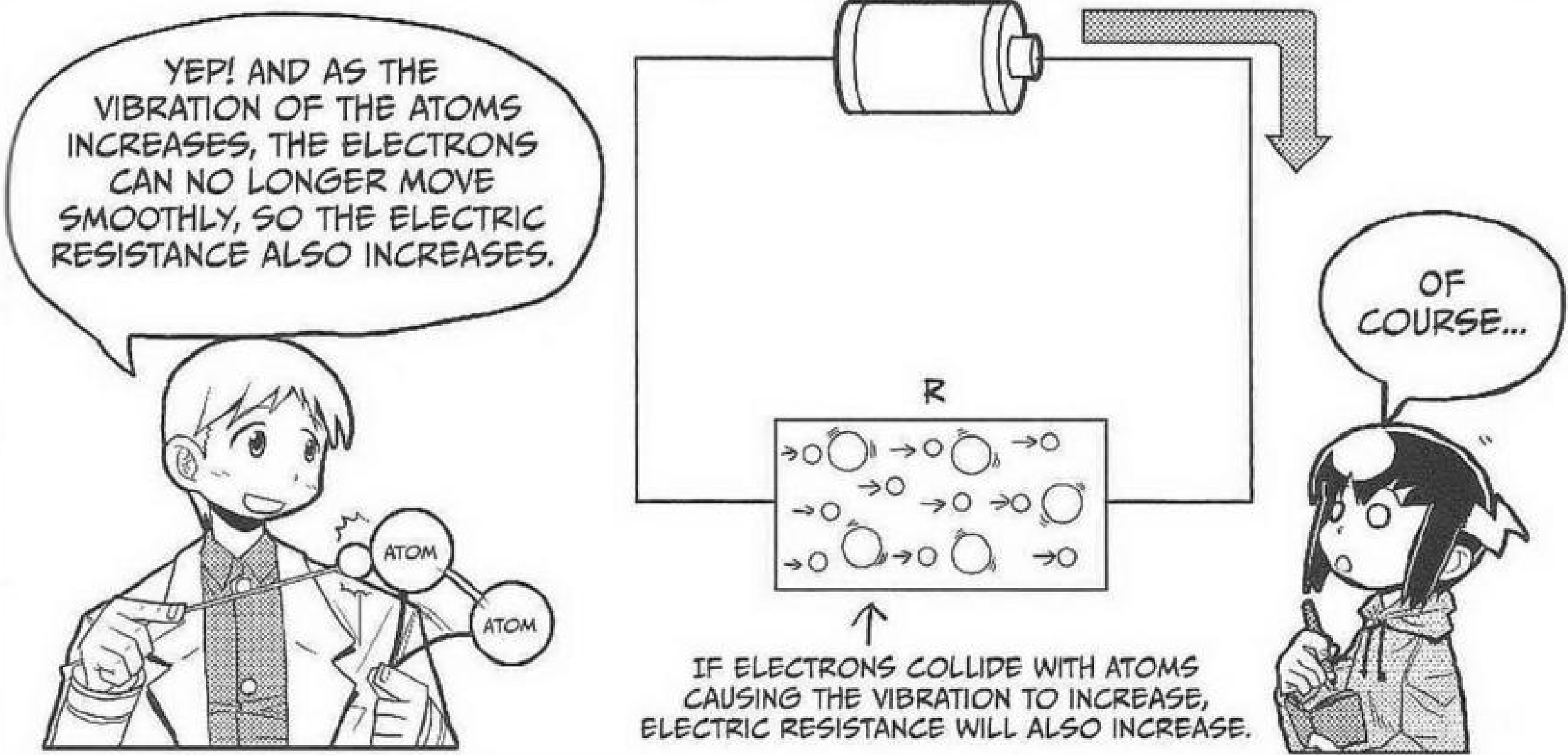
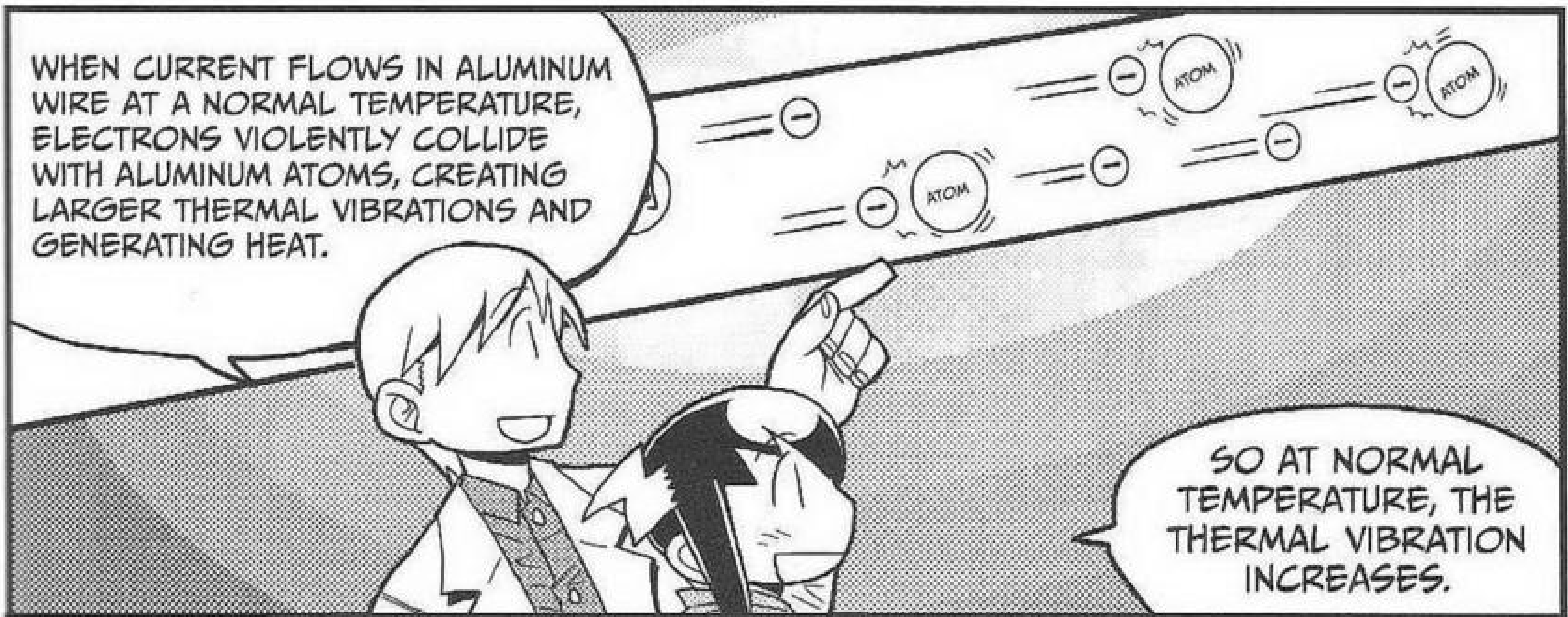




\* SEE PAGE 61.

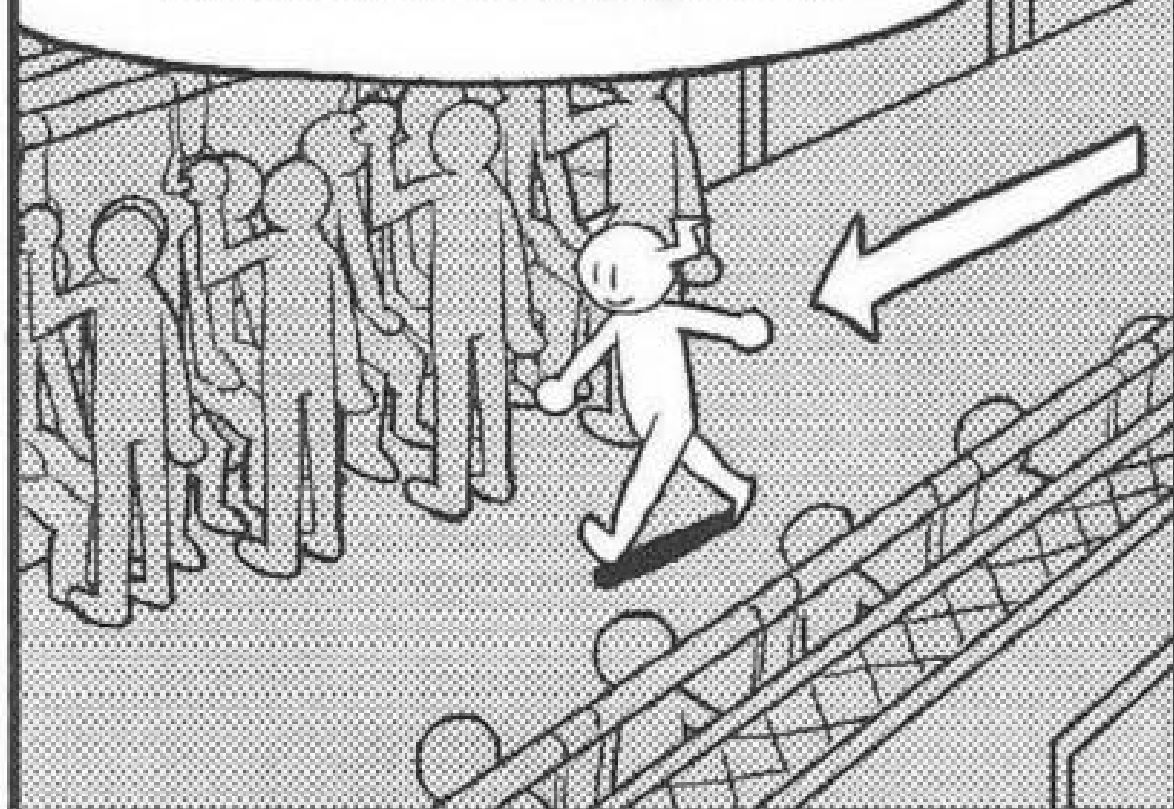




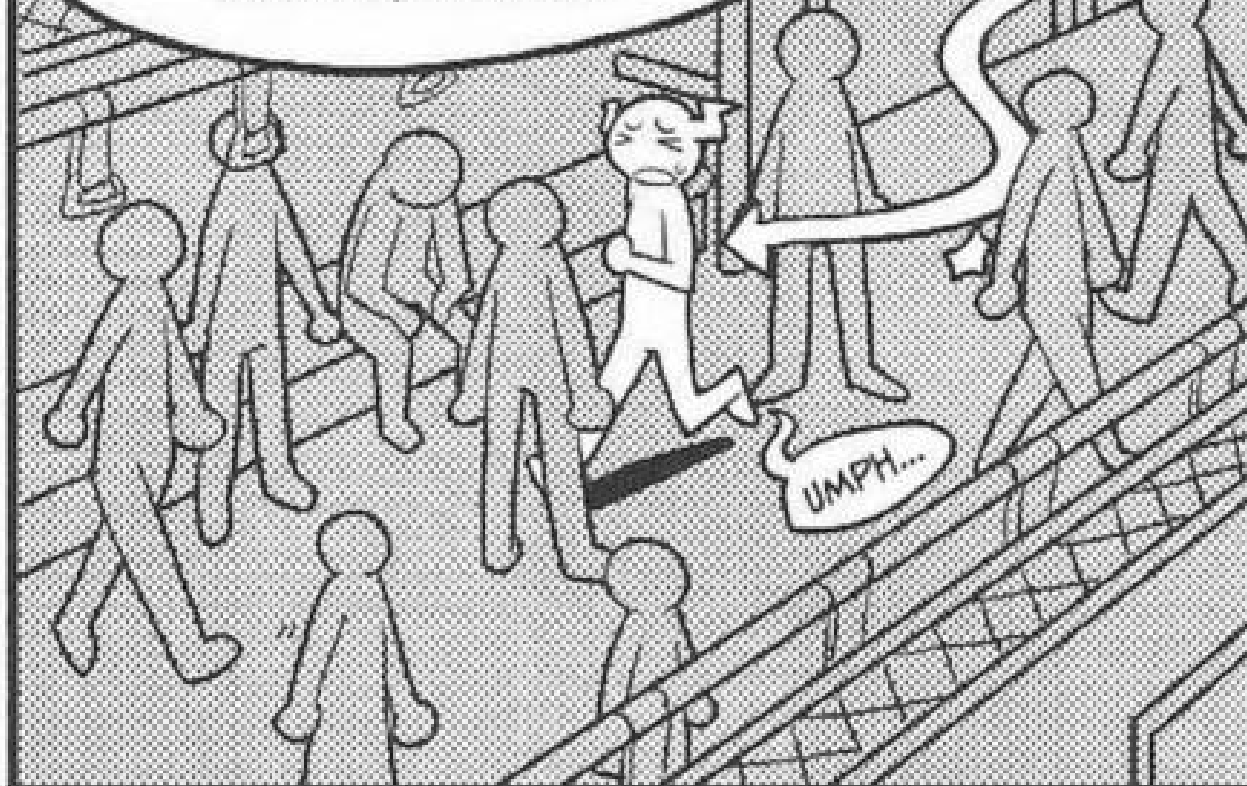




IF THE PEOPLE AROUND YOU  
ARE STANDING STILL WHEN  
YOU ARE TRYING TO WALK, YOU  
CAN MOVE EASILY, BUT...



...IF EVERYONE AROUND YOU  
IS ALSO MOVING, YOU WILL  
BUMP INTO THEM, AND YOU  
WON'T BE ABLE TO MOVE  
EASILY, RIGHT?

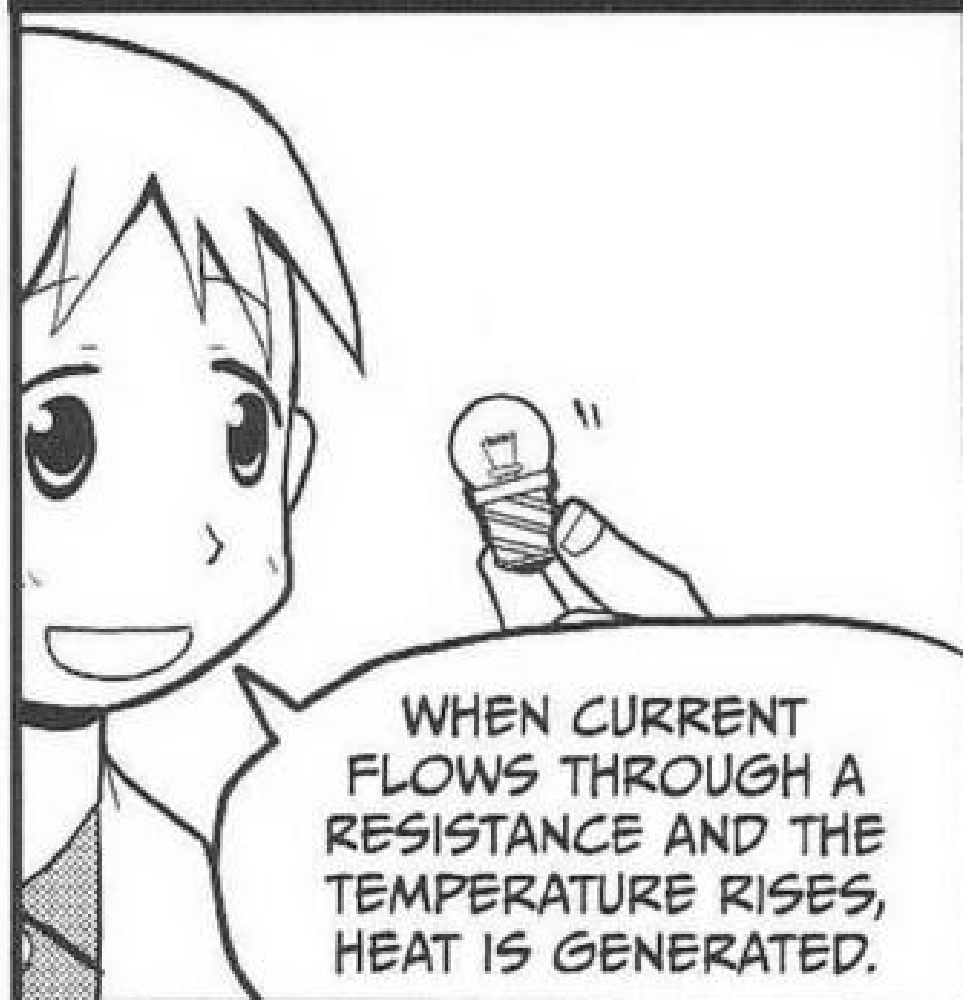


I'M THE ELECTRON, AND  
THE PEOPLE AROUND  
ME ARE THE ATOMS,  
AREN'T THEY?

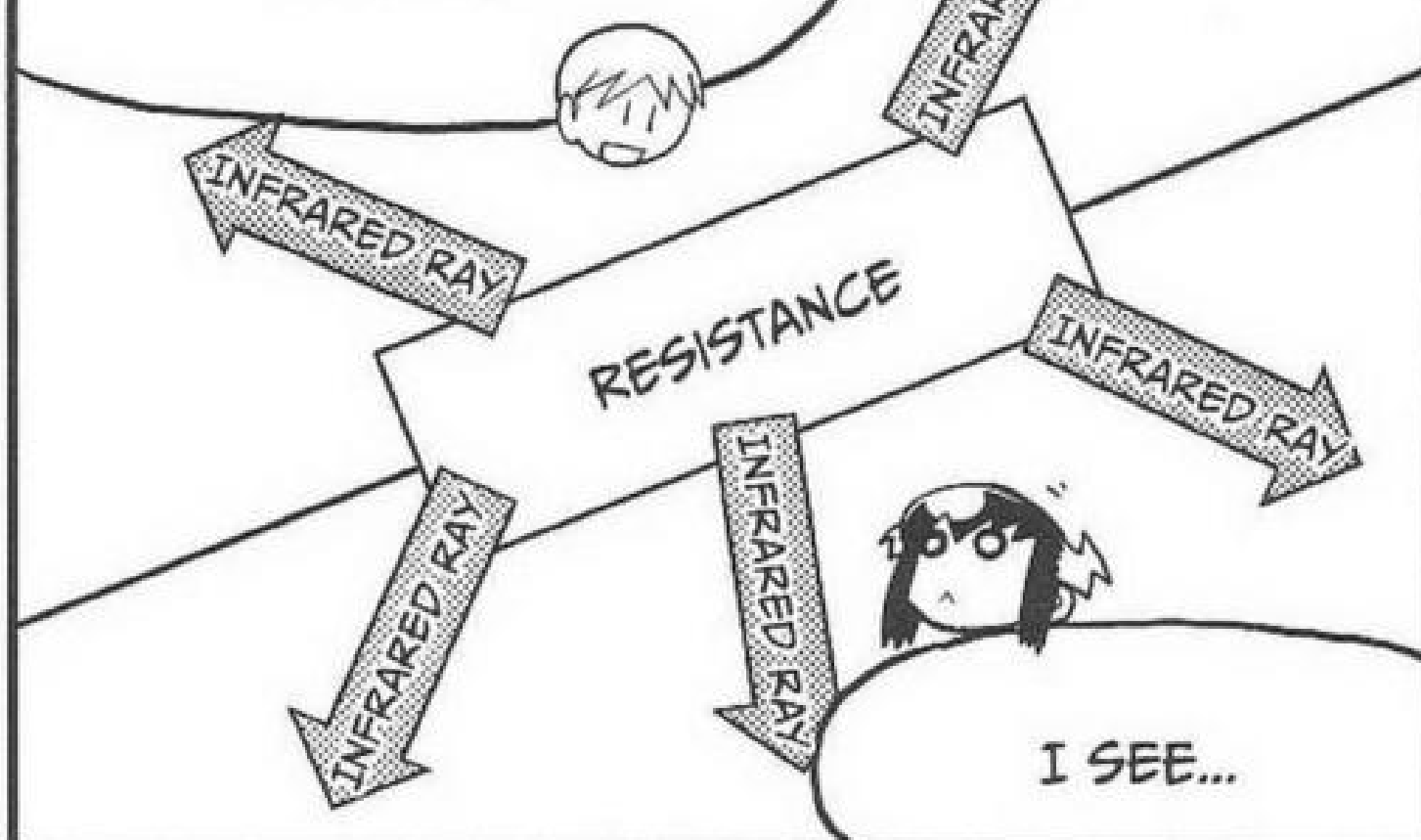


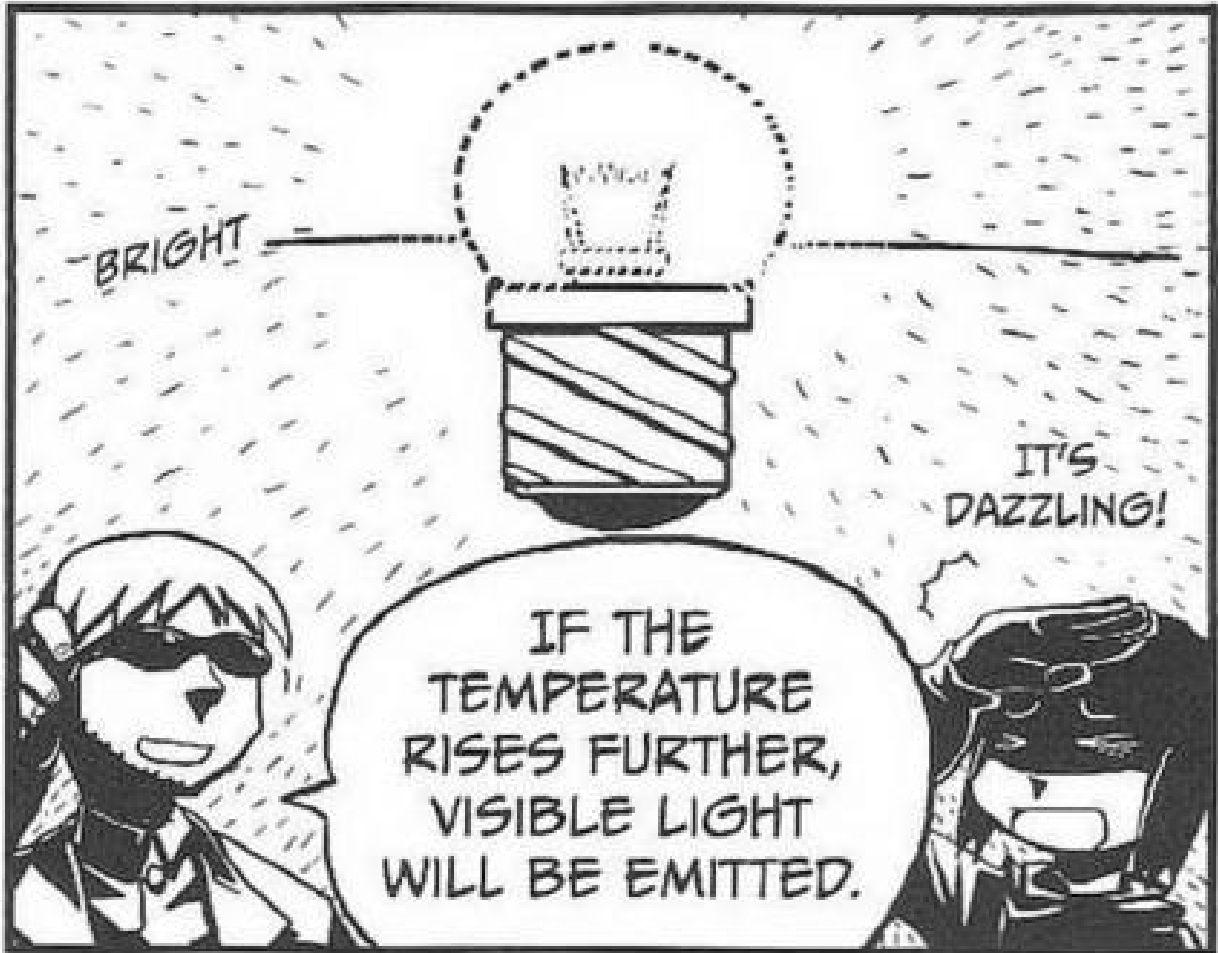
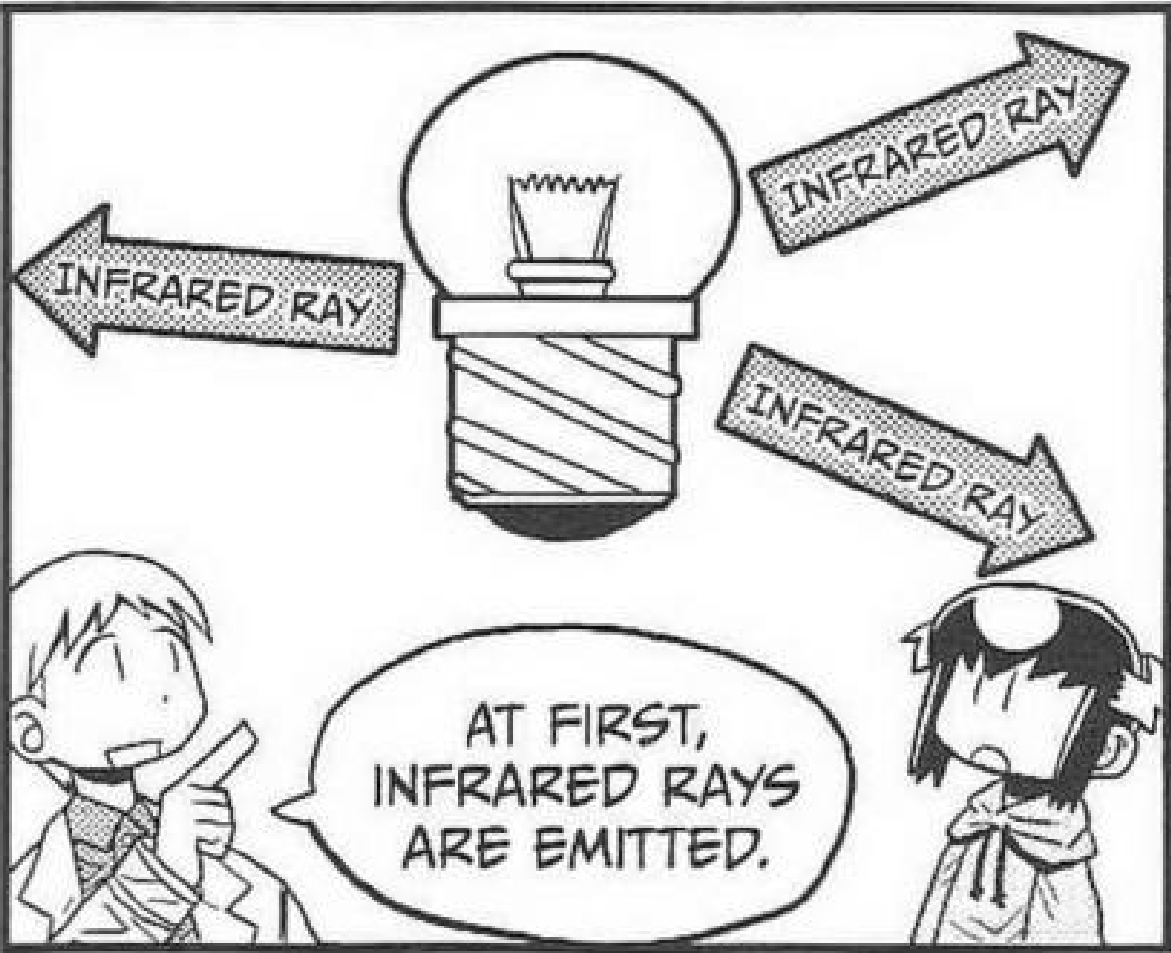
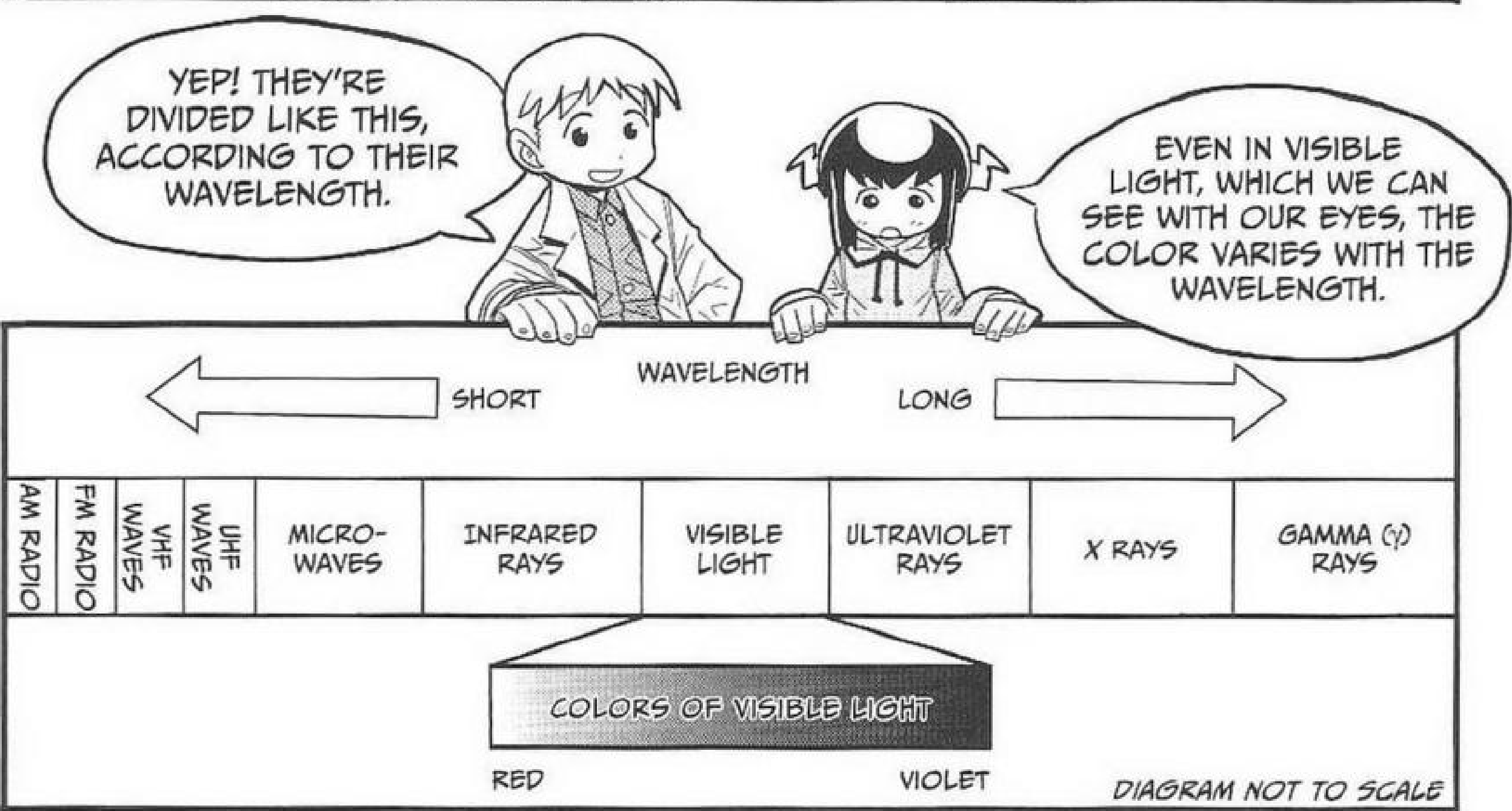
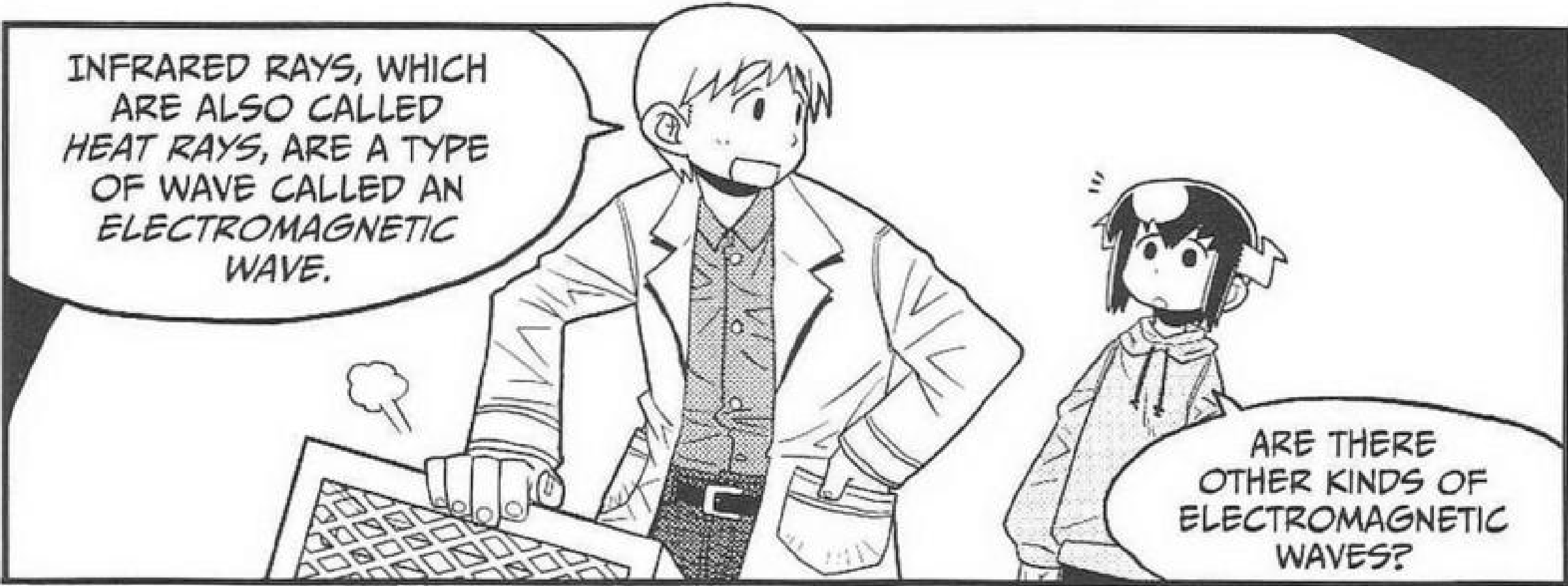
EXACTLY!  
IF YOU TRY TO KEEP  
MOVING WHEN THE  
PEOPLE AROUND YOU ARE  
ALSO MOVING, YOU WILL  
BUMP INTO THEM, MAKING  
EVERYONE MOVE AROUND  
EVEN MORE!

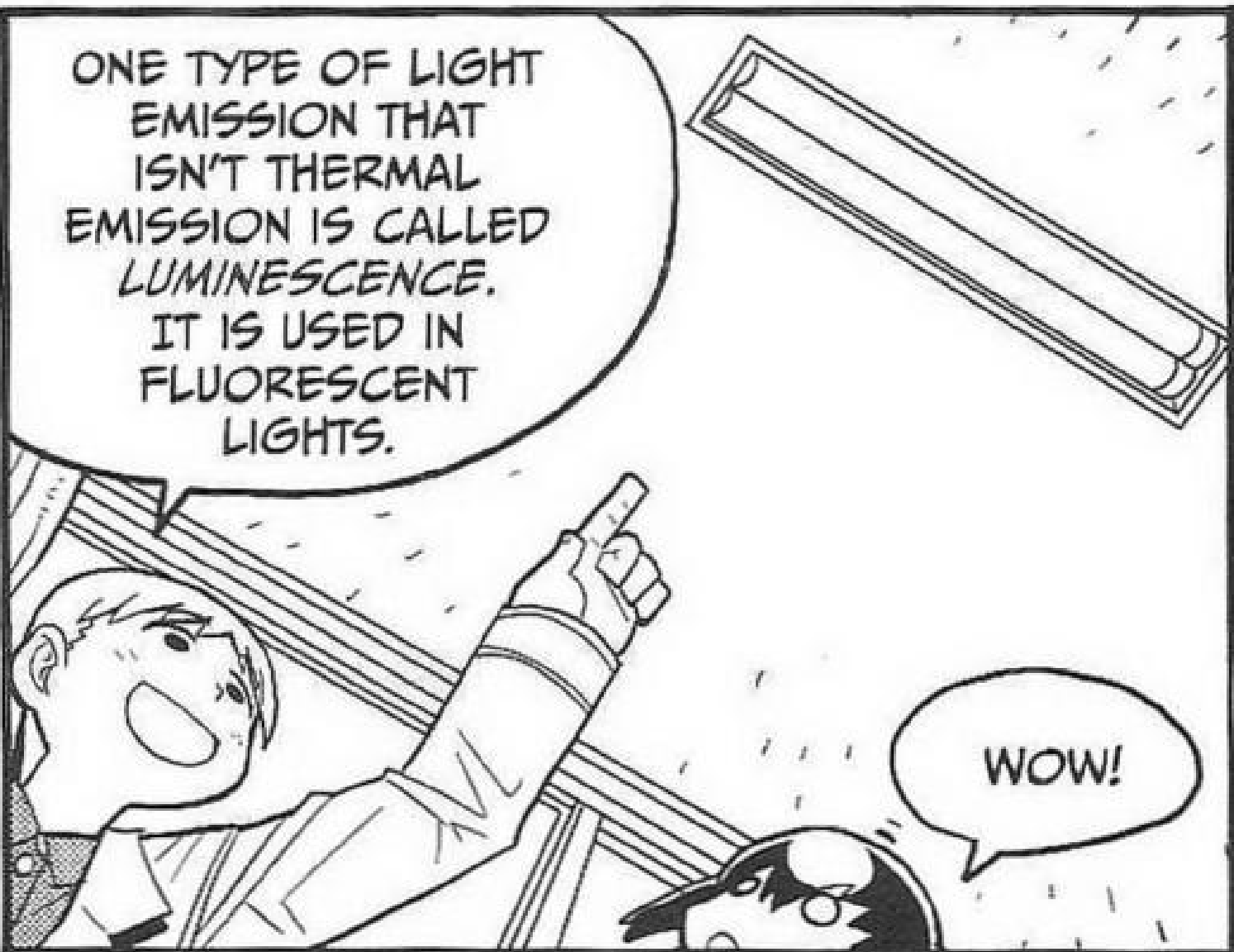
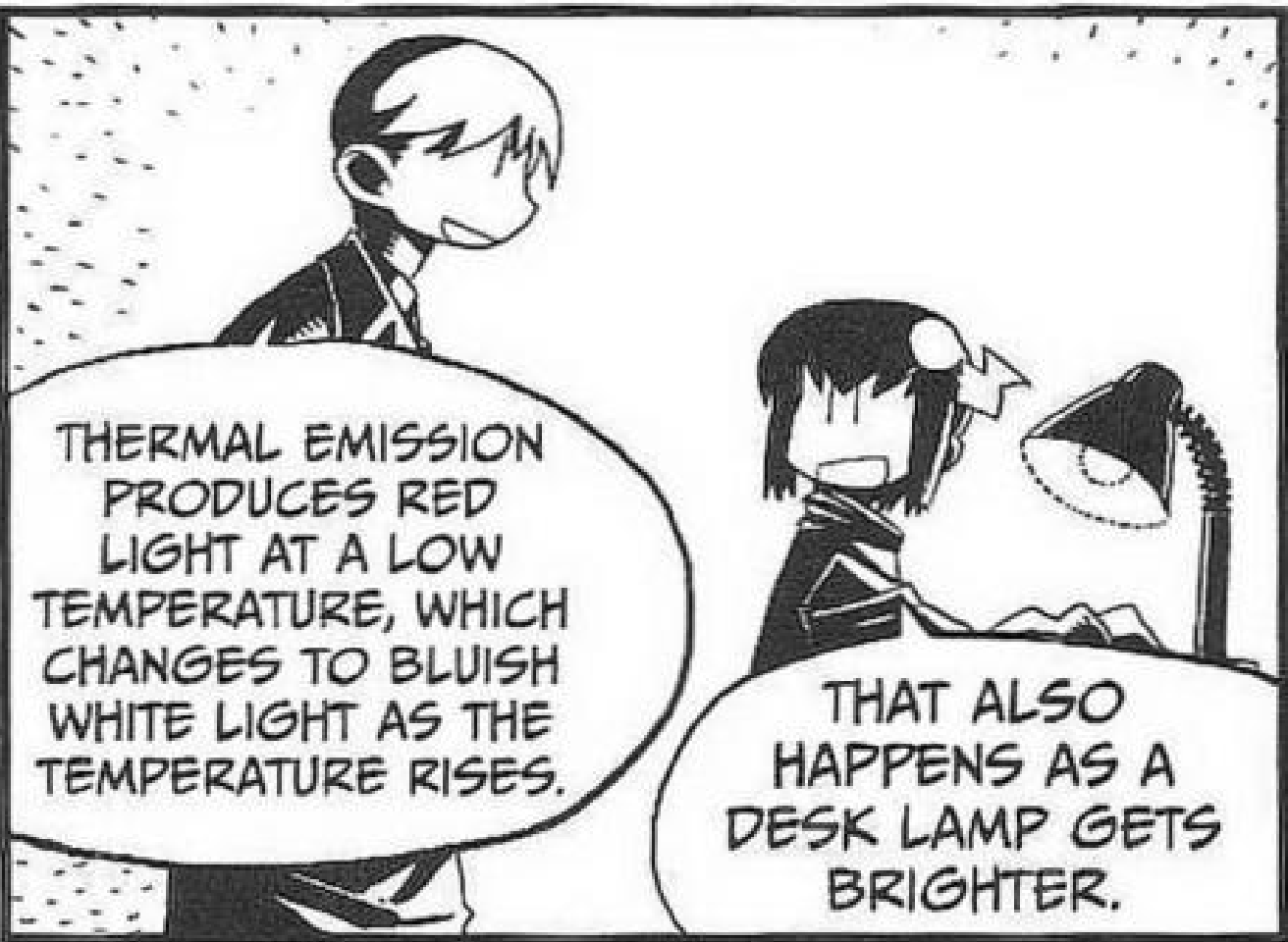
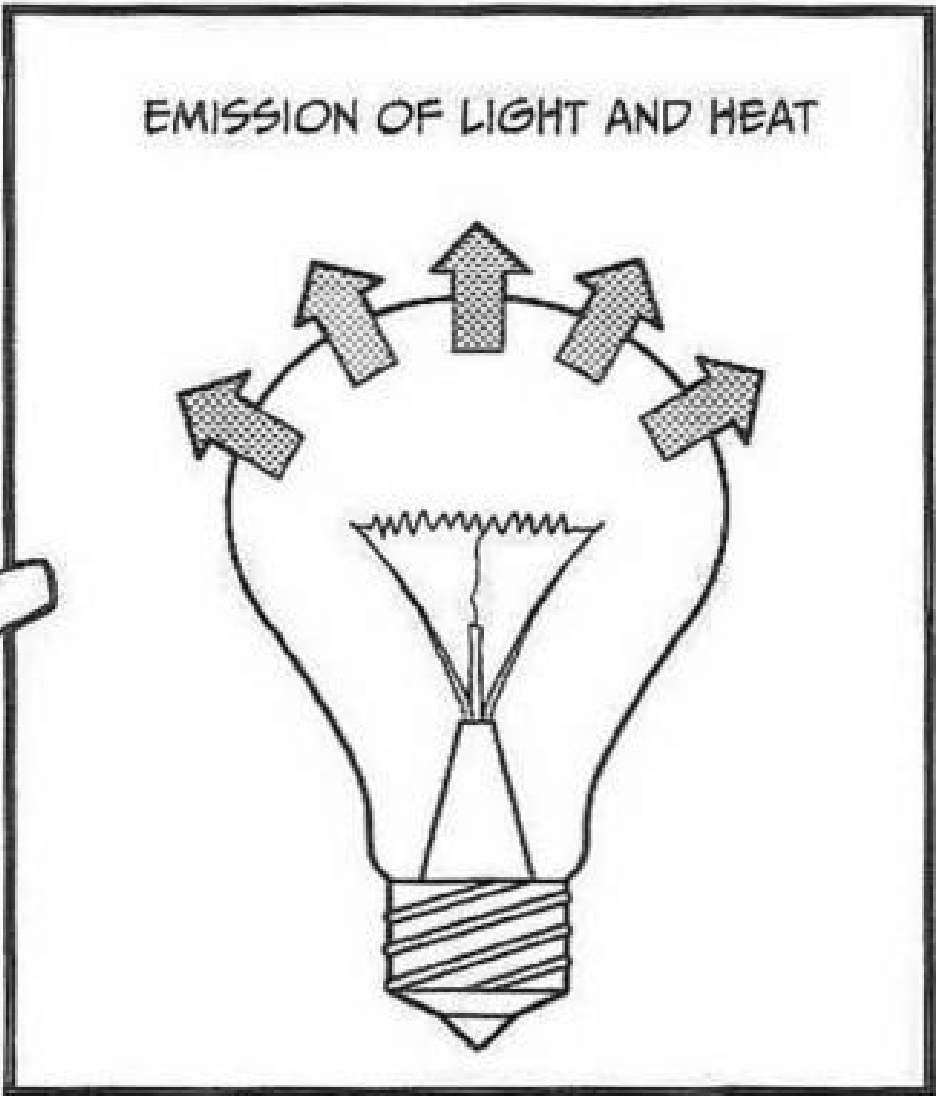
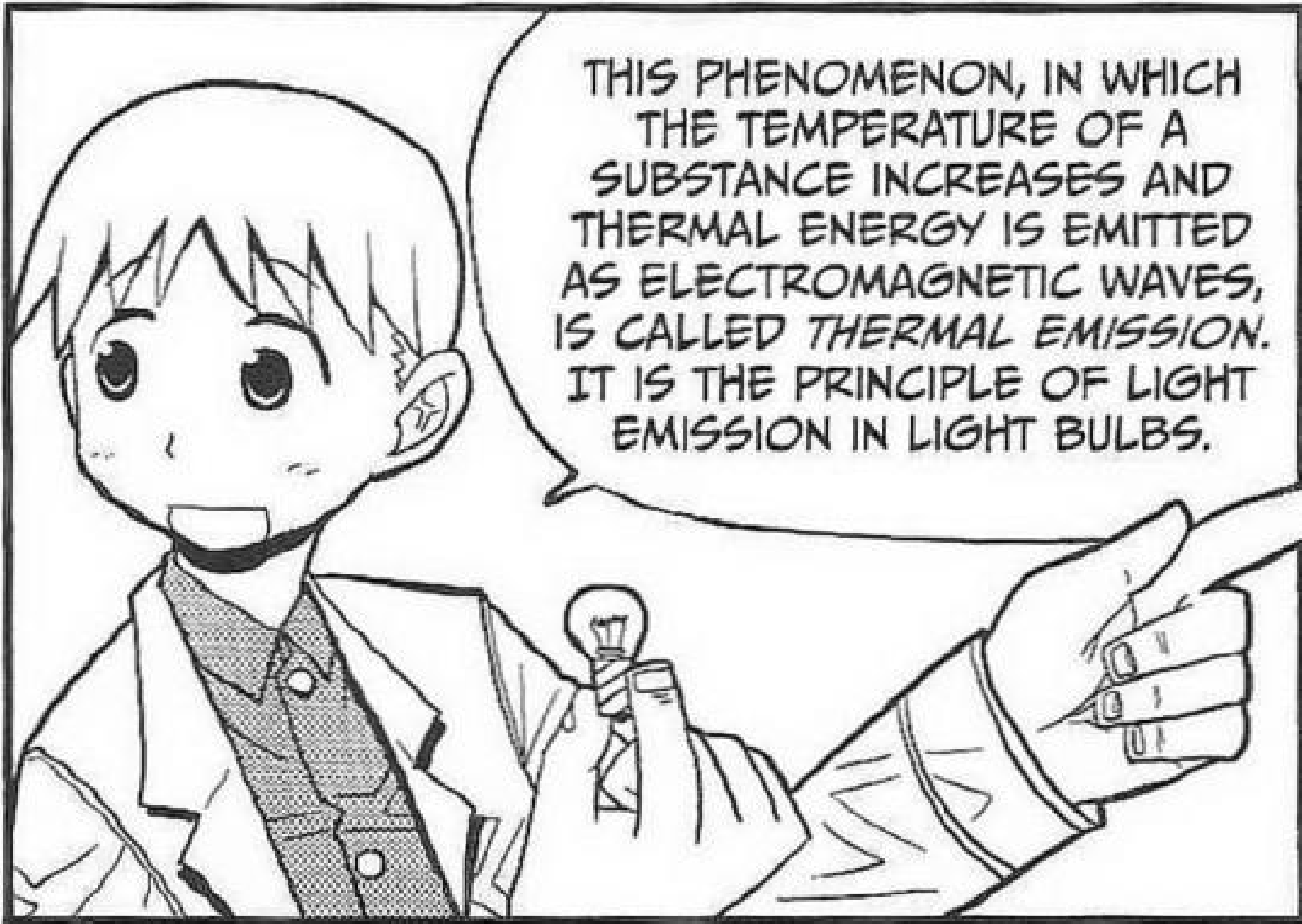
## THERMAL EMISSION AND LUMINESCENCE

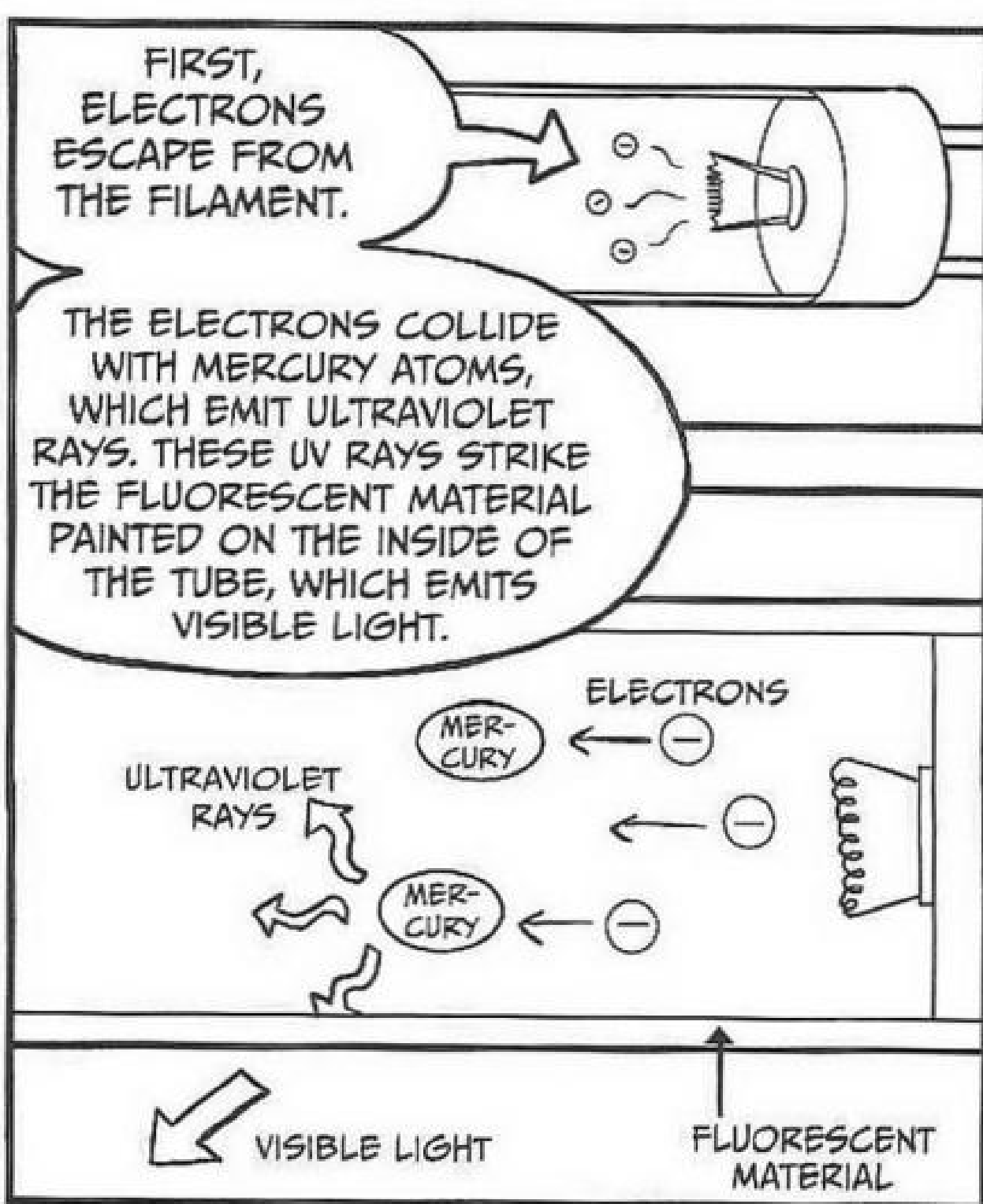


AT THIS TIME, INFRARED  
RAYS THAT ARE INVISIBLE  
TO THE NAKED EYE ARE  
EMITTED.

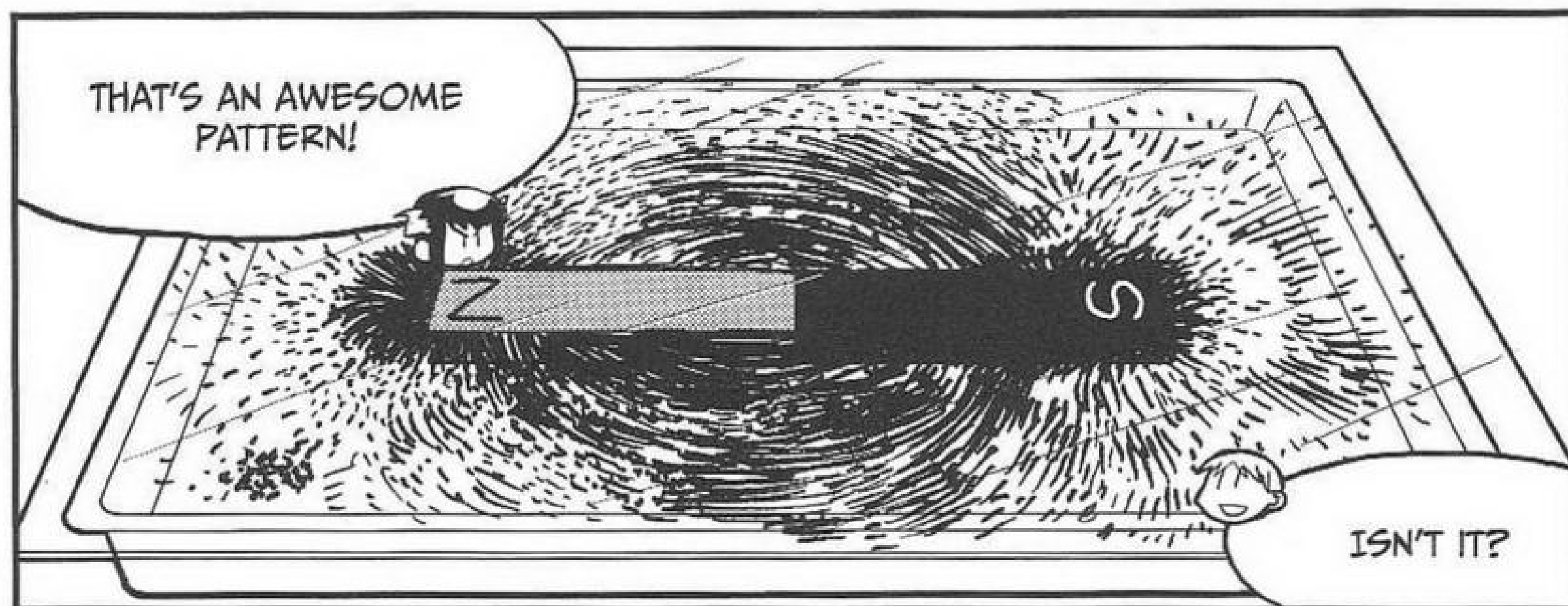




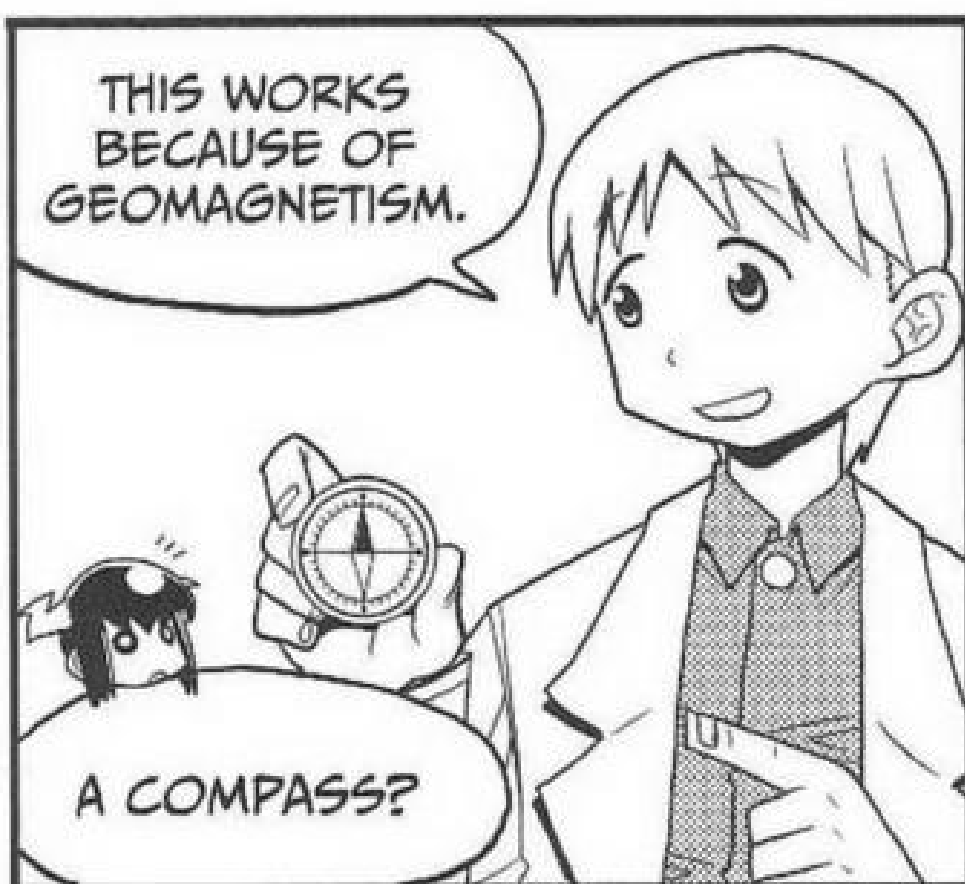
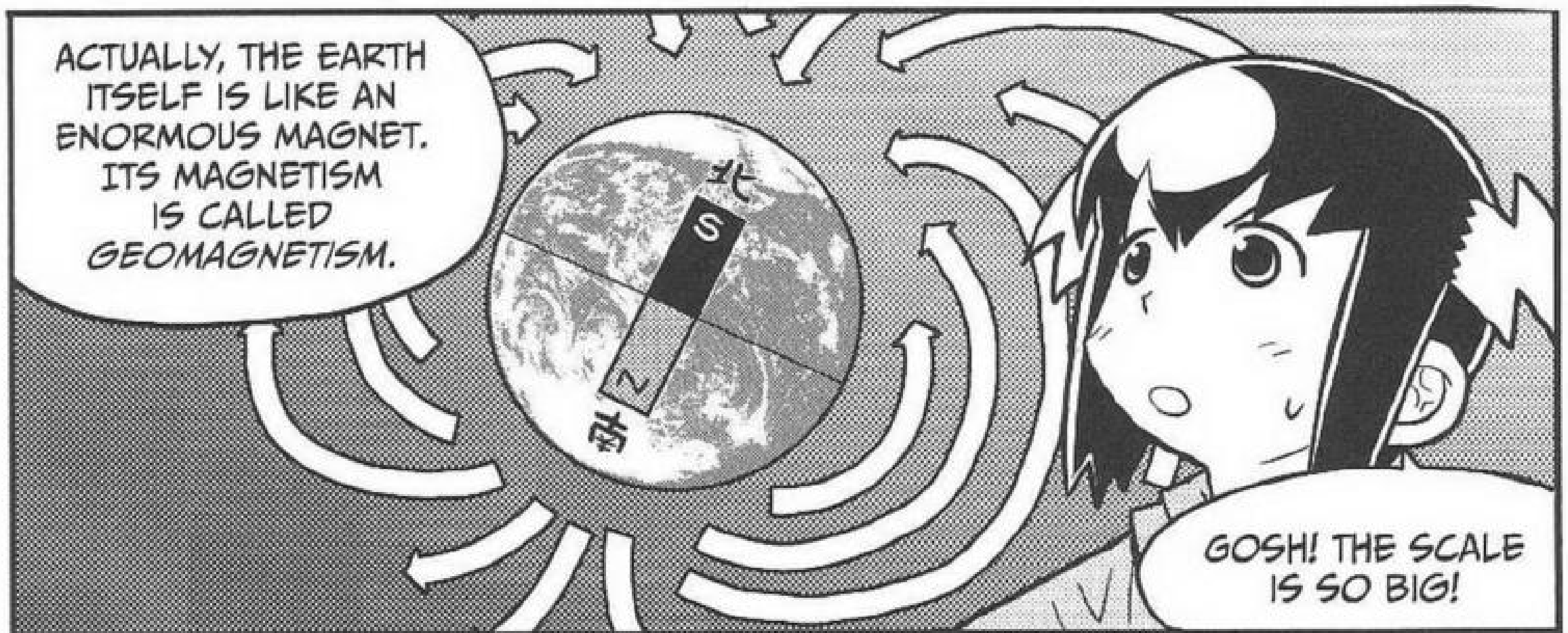
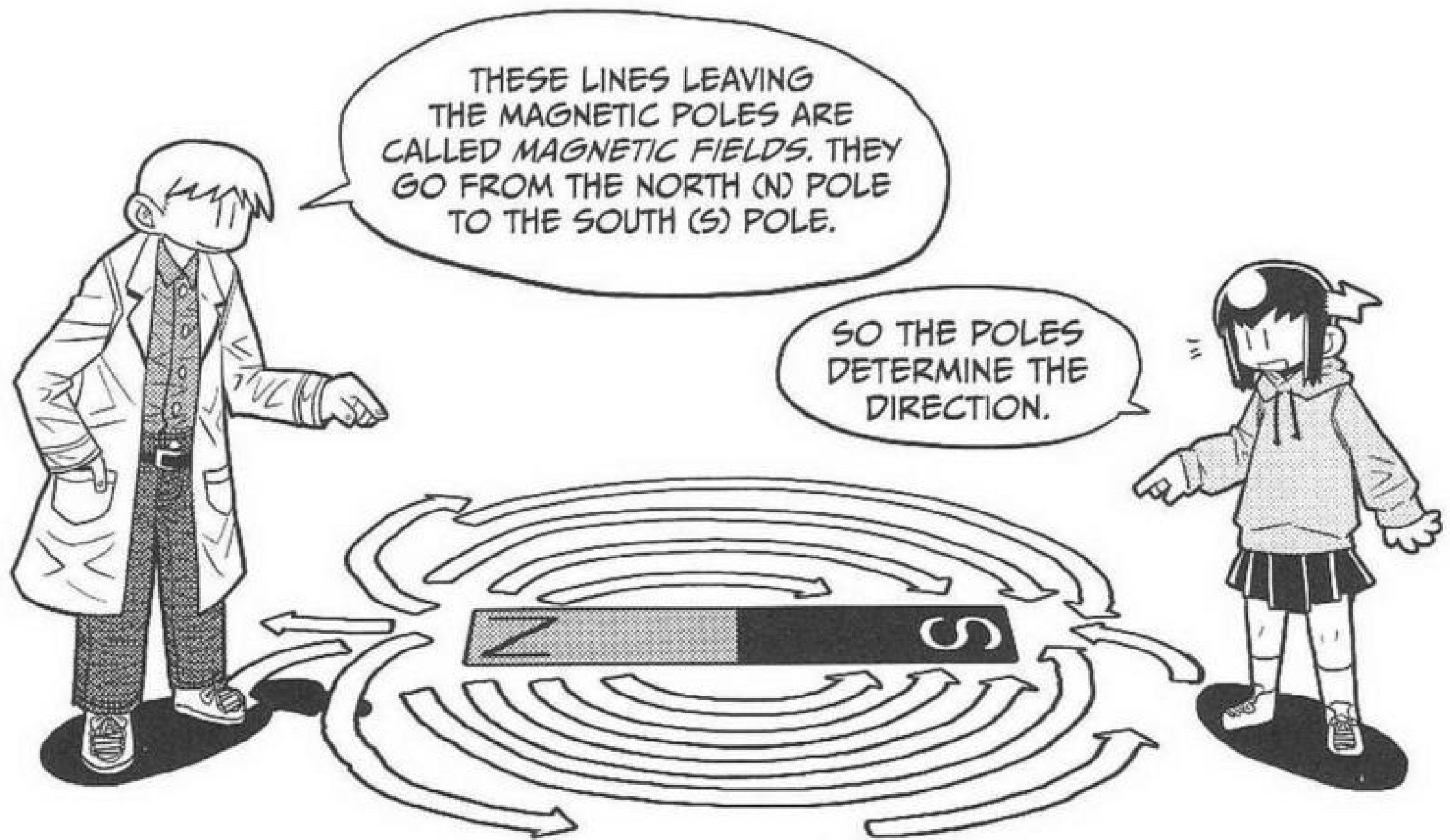


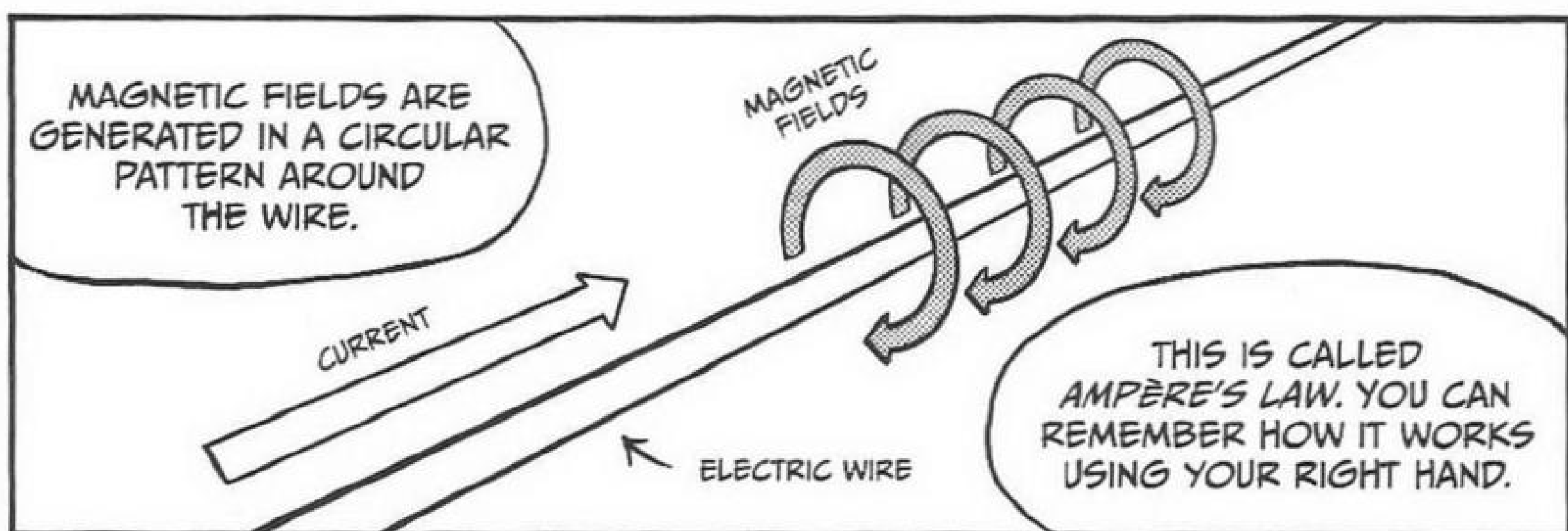
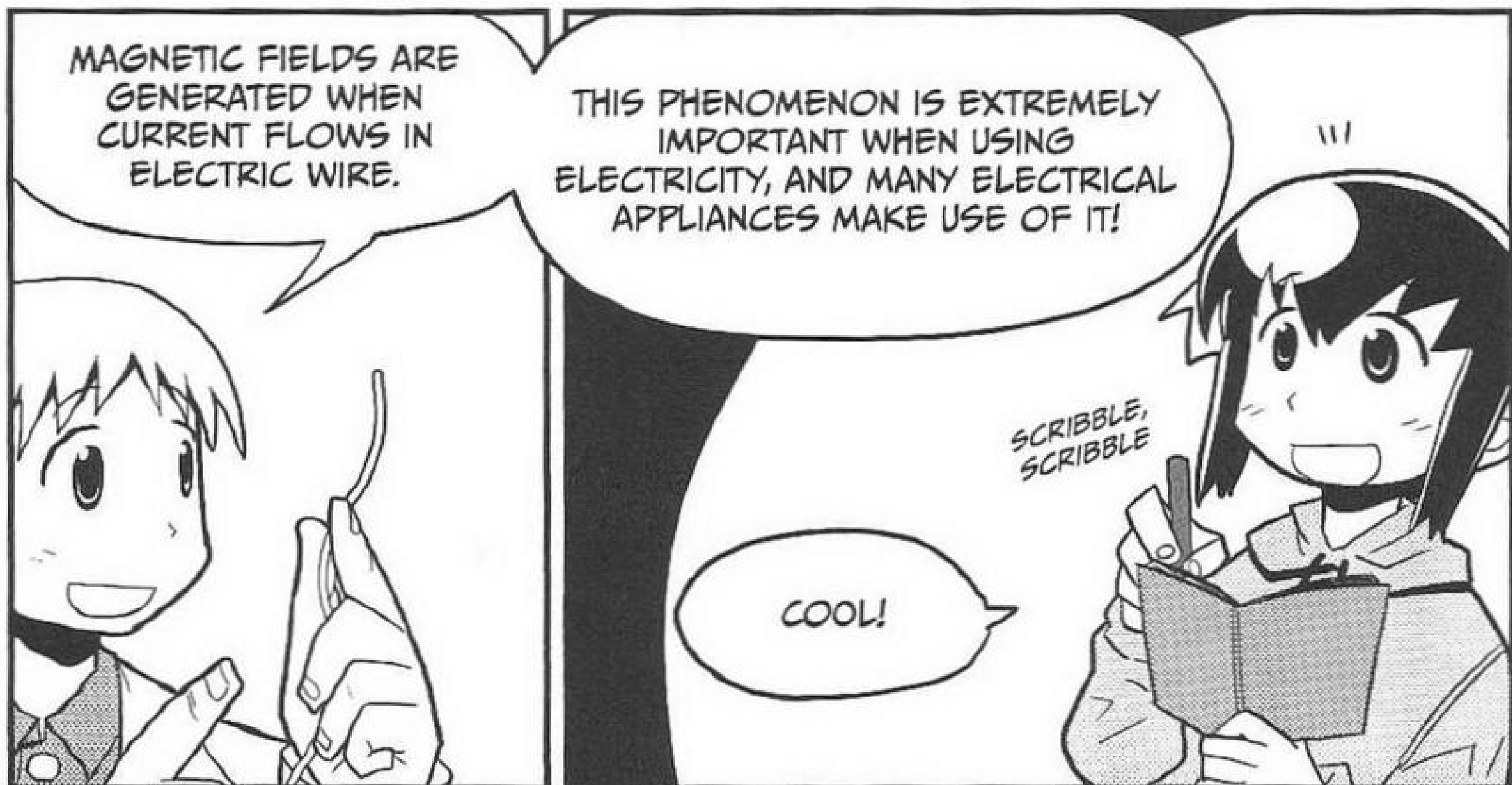


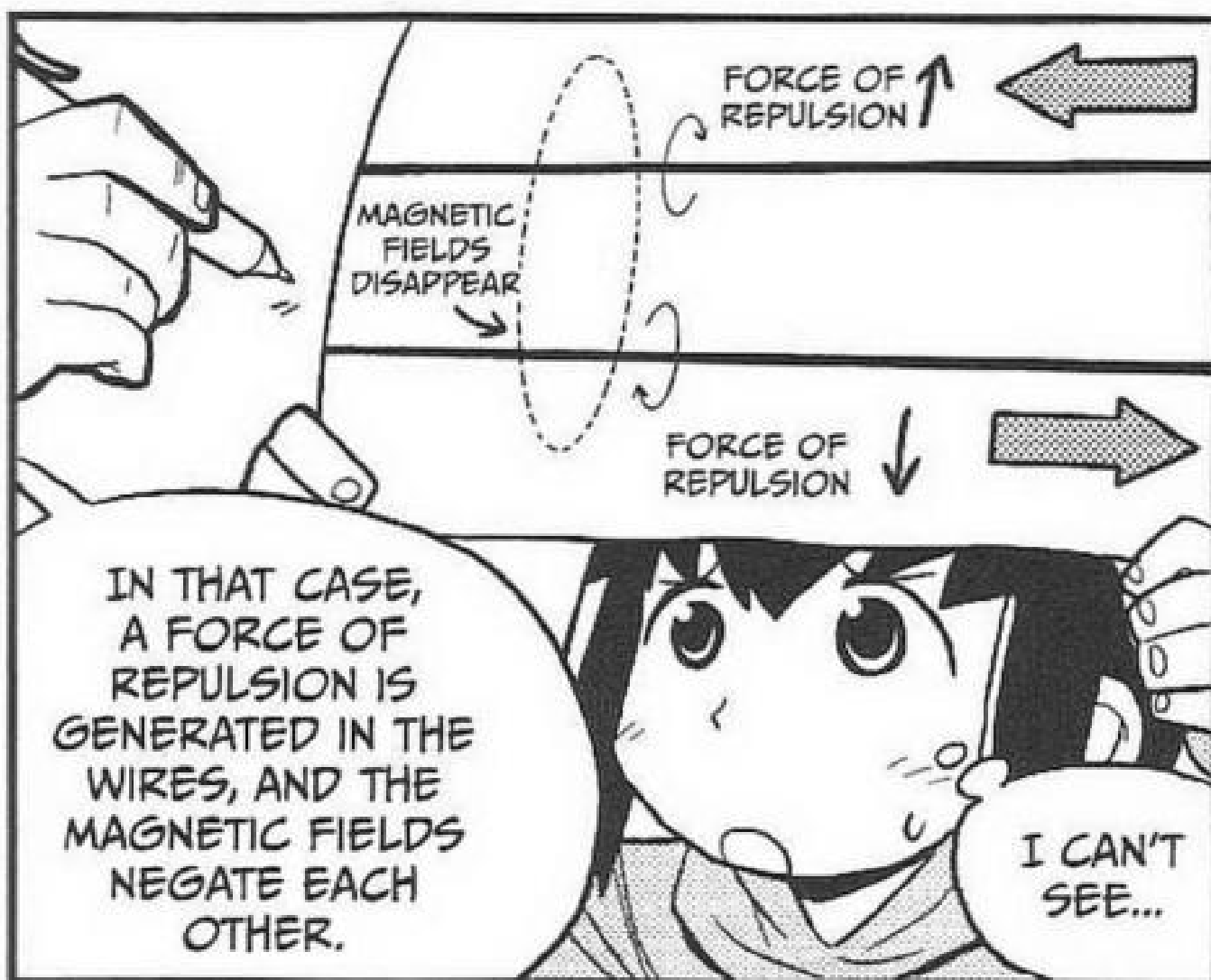
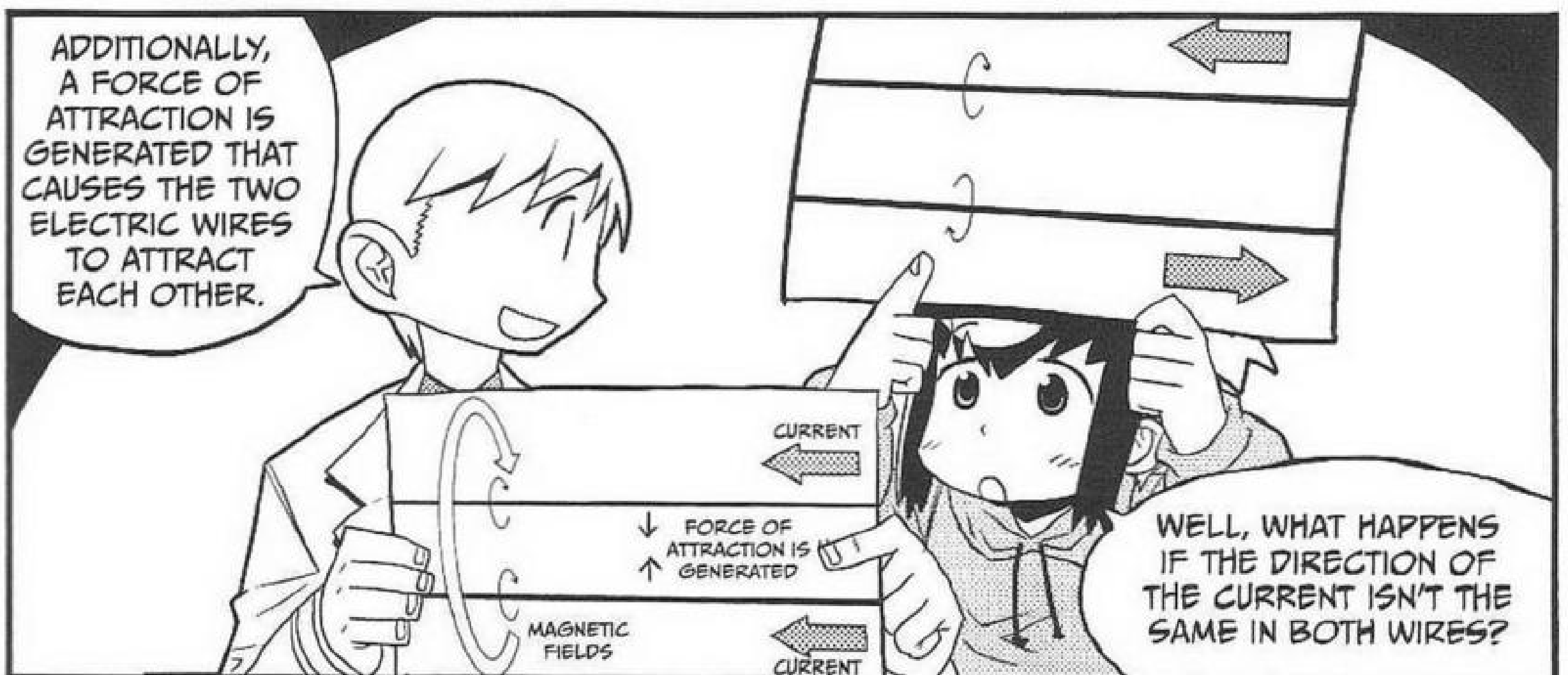
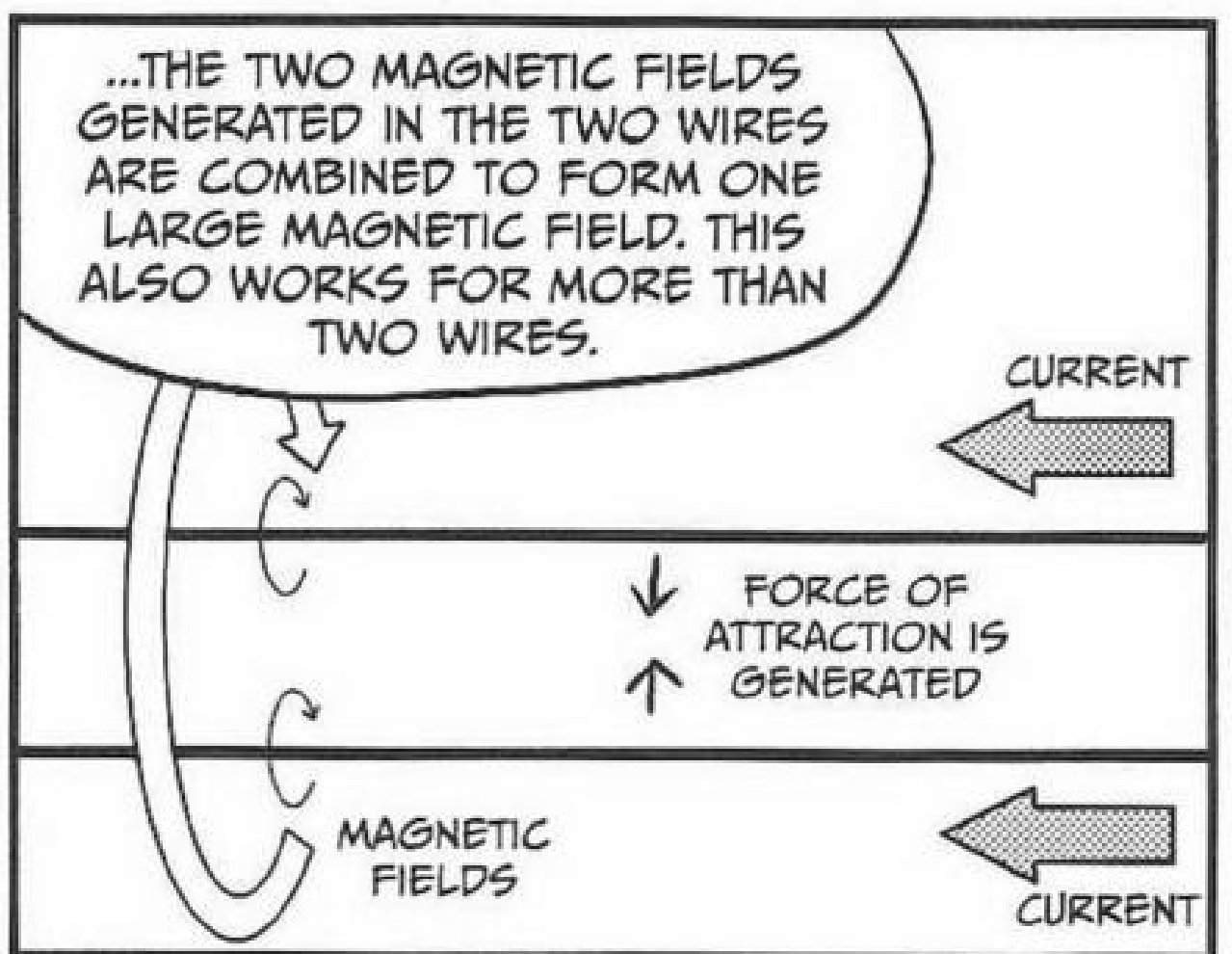
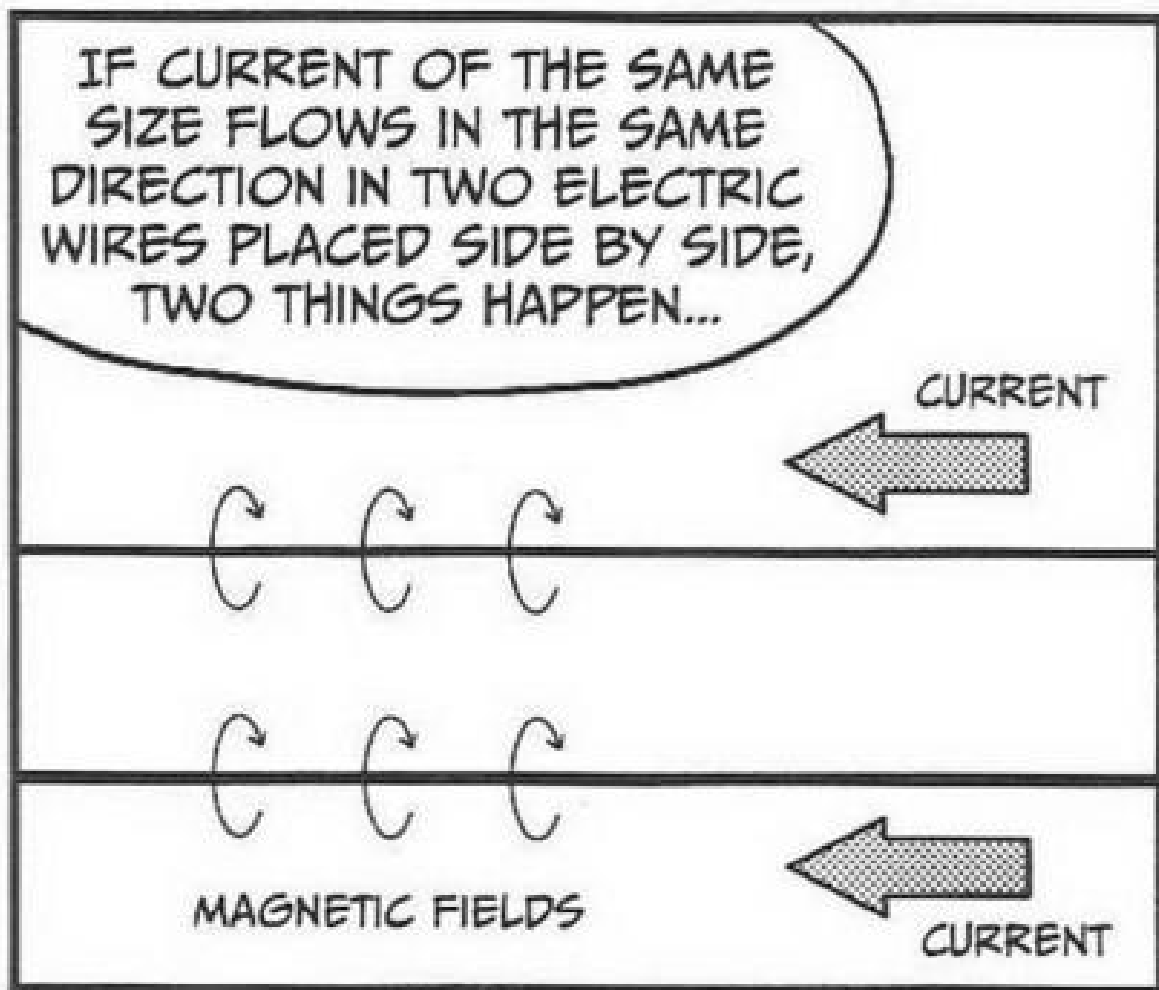
## CURRENT AND MAGNETIC FIELDS



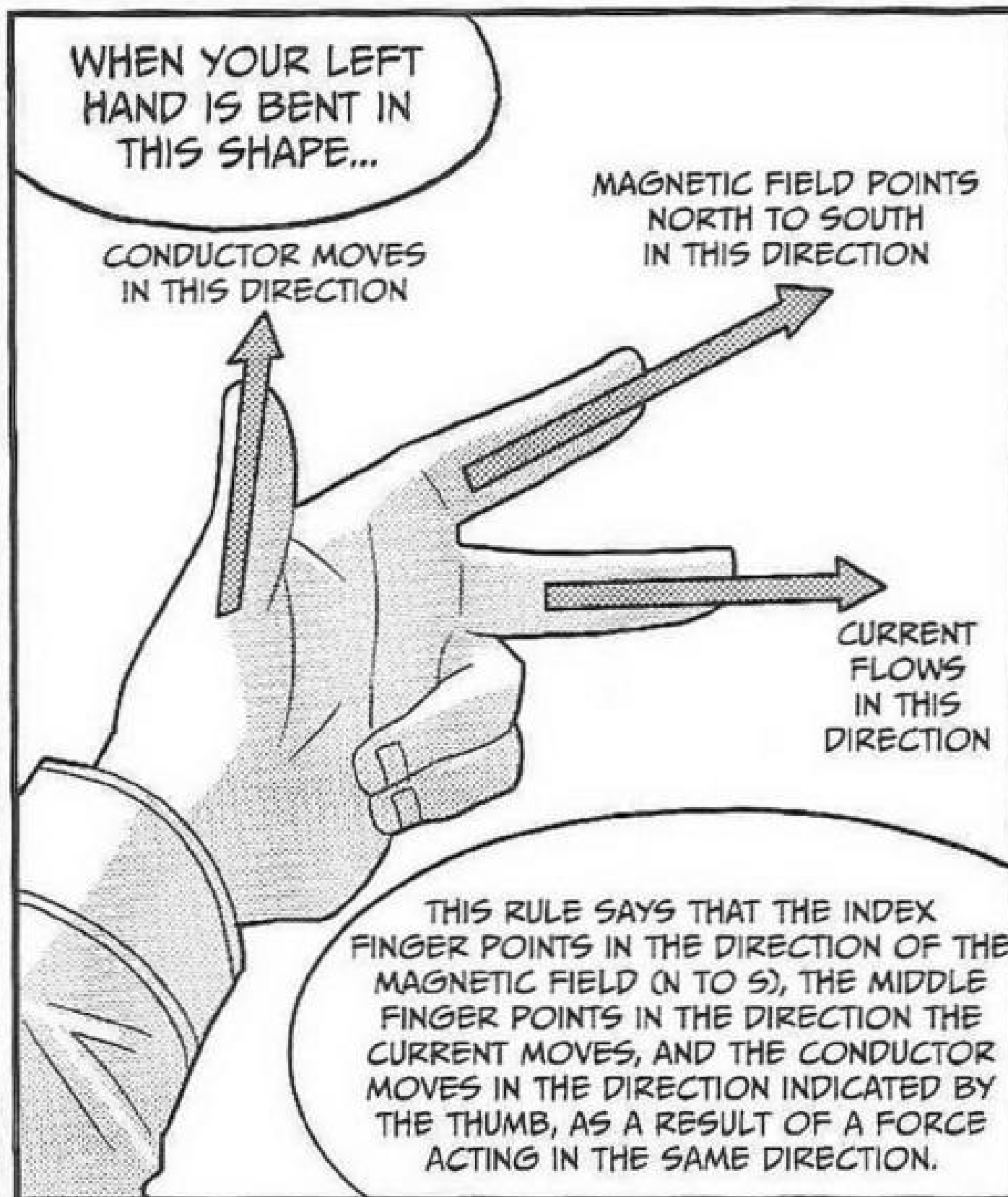
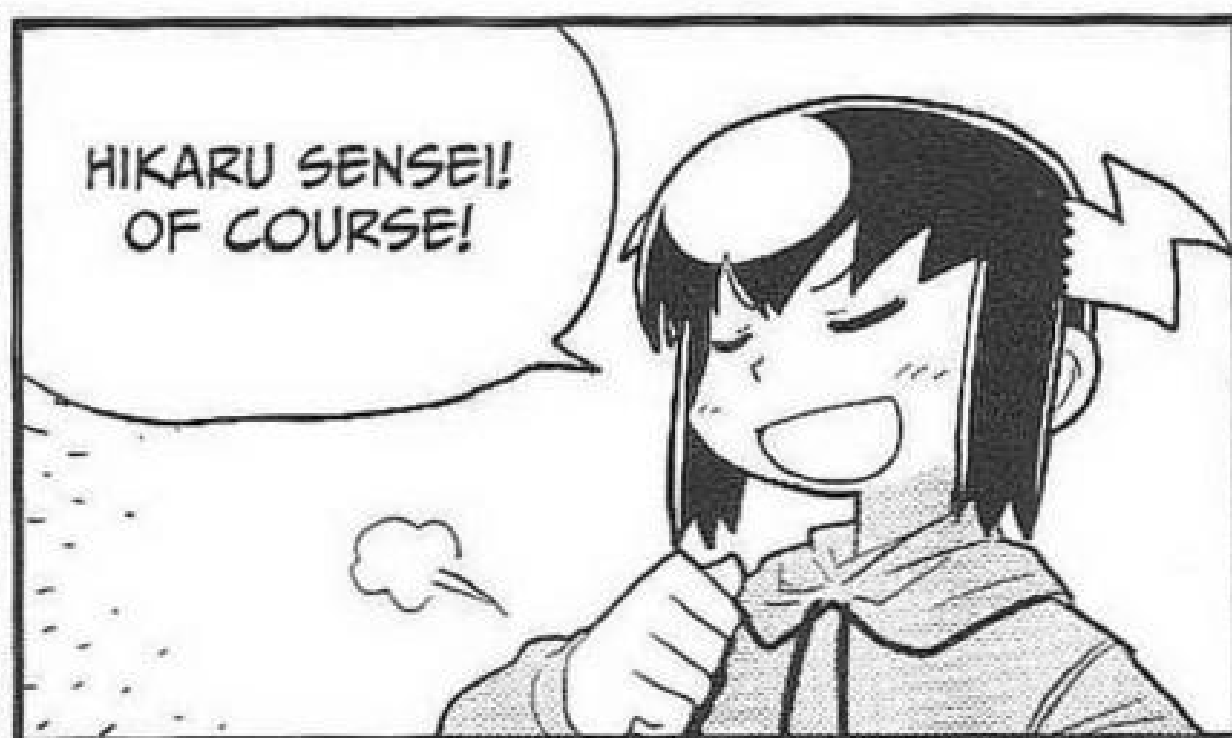


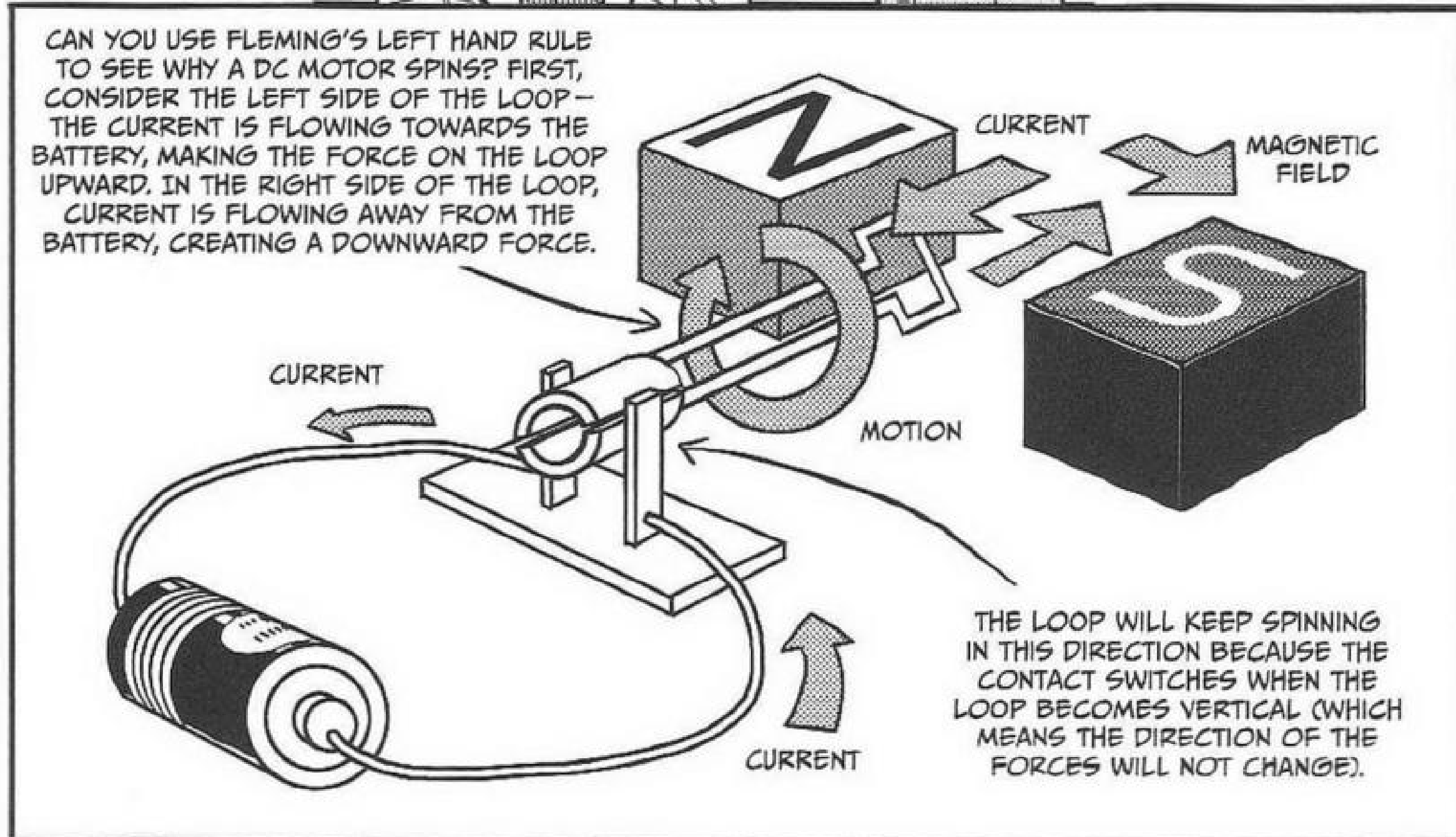
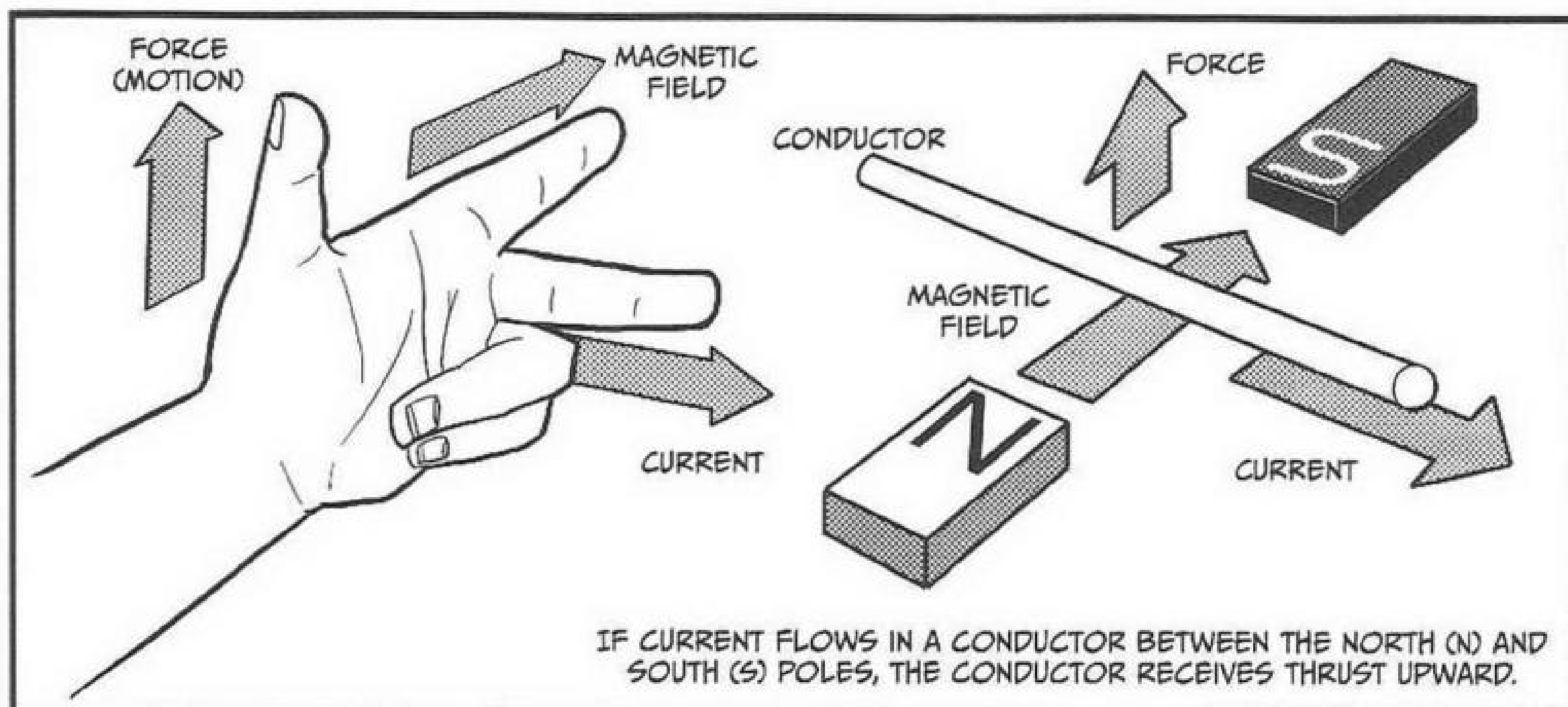






FLEMING'S LEFT-HAND RULE  
(FOR DC MOTORS)







## FLEMING'S RIGHT-HAND RULE (FOR GENERATORS)

FLEMING ALSO HAS A  
RIGHT-HAND RULE!

WHAT DOES THAT  
RULE SAY?

IF A CONDUCTOR  
MOVES BETWEEN THE  
POLES OF A MAGNET,  
THE CONDUCTOR  
CROSSES THROUGH A  
MAGNETIC FIELD.

MOTION  
OF THE  
CONDUCTOR

CONDUCTOR

MAGNETIC  
FIELD

OKAY...

AN ACTION THAT CAUSES  
ELECTRICITY TO FLOW, WHICH IS  
CALLED THE *ELECTROMOTIVE  
FORCE*, IS GENERATED IN THE  
CONDUCTOR AT THIS TIME, AND  
CURRENT FLOWS.

MAGNETIC  
FIELD

N-TO-S MAGNETIC  
FIELD POINTS IN  
THIS DIRECTION

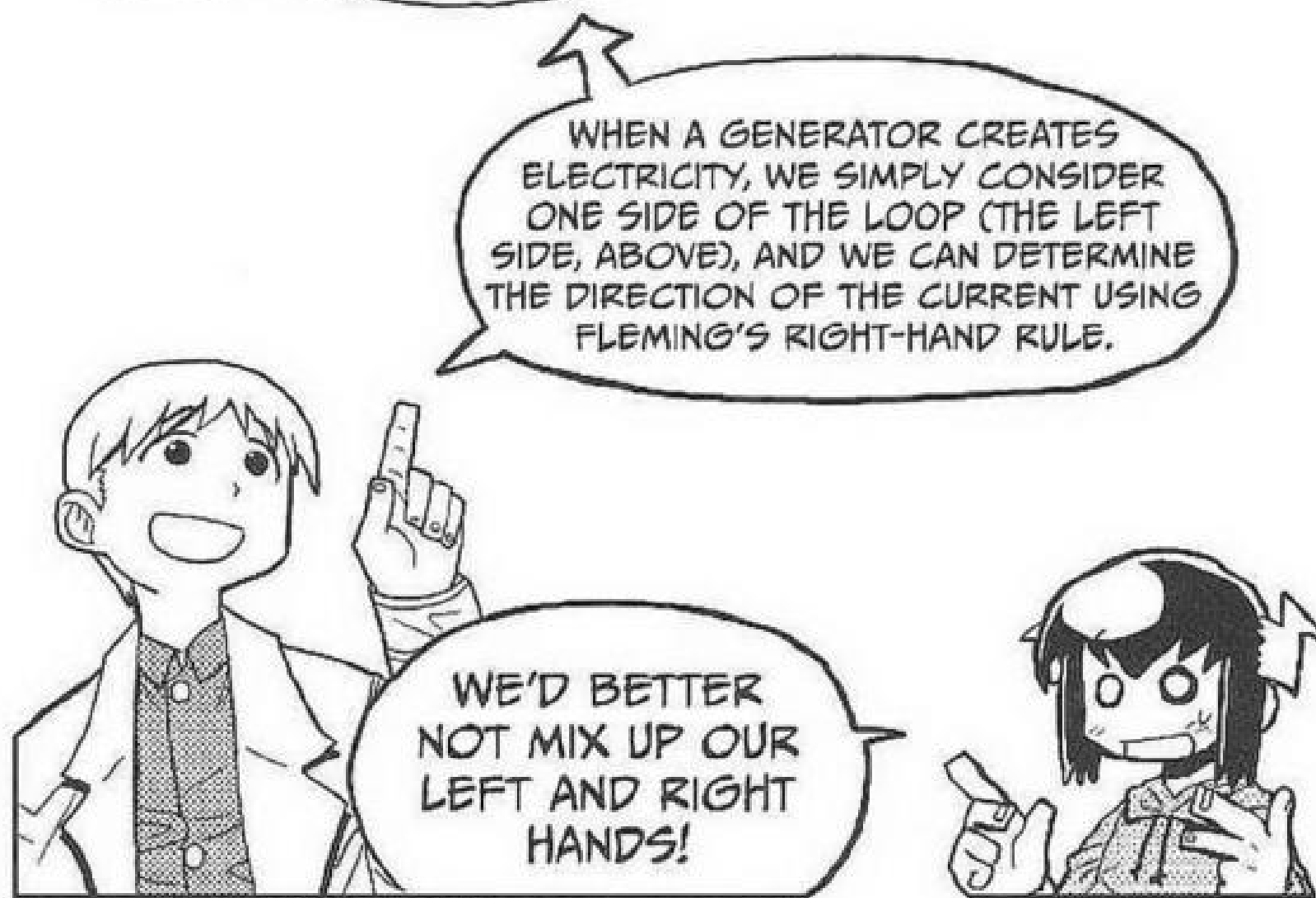
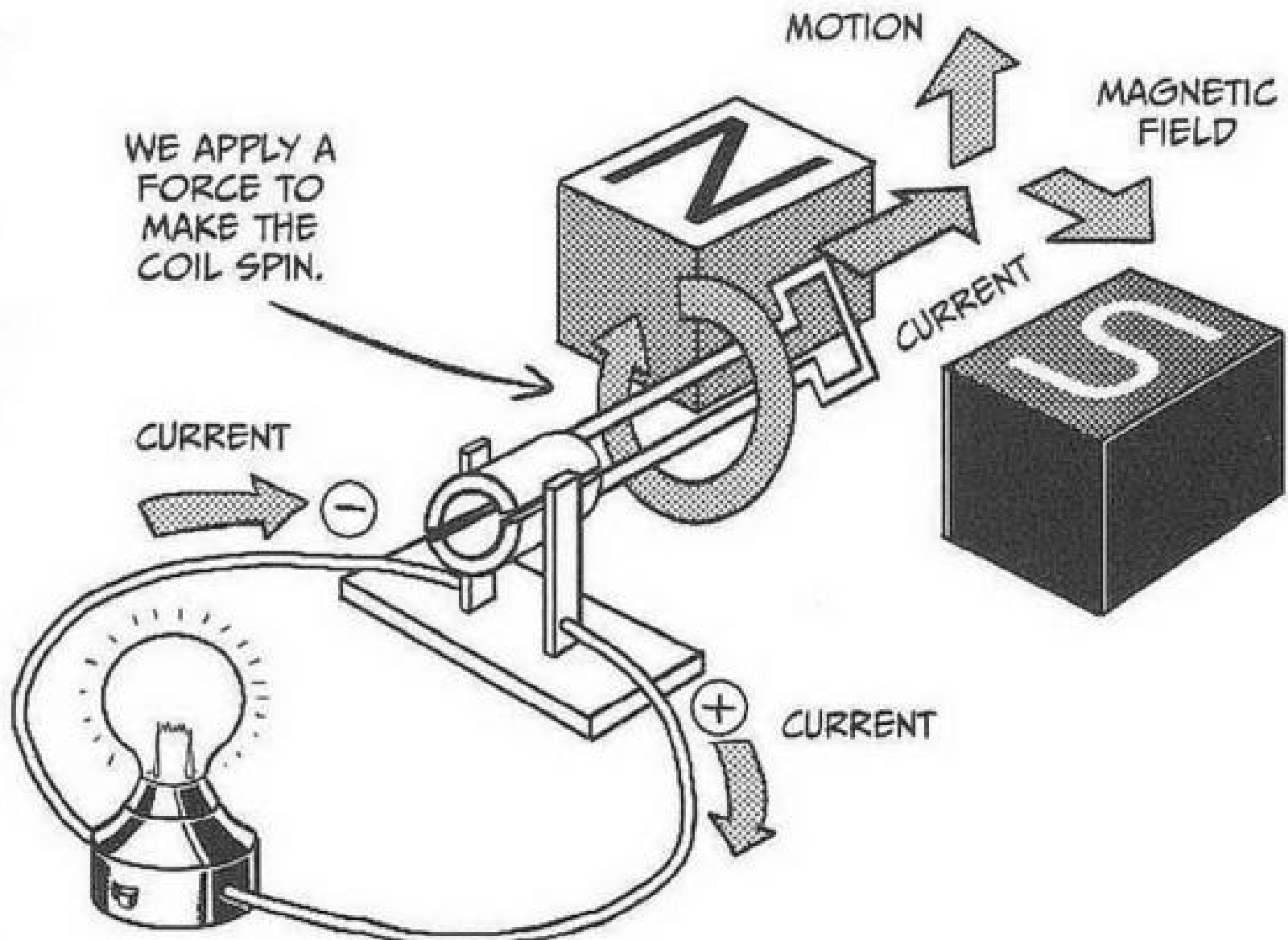
CONDUCTOR  
MOVES IN THIS  
DIRECTION

CURRENT  
MOVES IN THIS  
DIRECTION

MOTION

CURRENT

THE FLOW OF THAT CURRENT  
IS IN THE DIRECTION OF THE  
MIDDLE FINGER OF THE RIGHT HAND,  
THE DIRECTION OF THE MAGNETIC FIELD  
IS THE DIRECTION OF THE INDEX FINGER,  
AND THE DIRECTION OF MOVEMENT OF  
THE ELECTRIC WIRE IS THE DIRECTION  
OF THE THUMB.

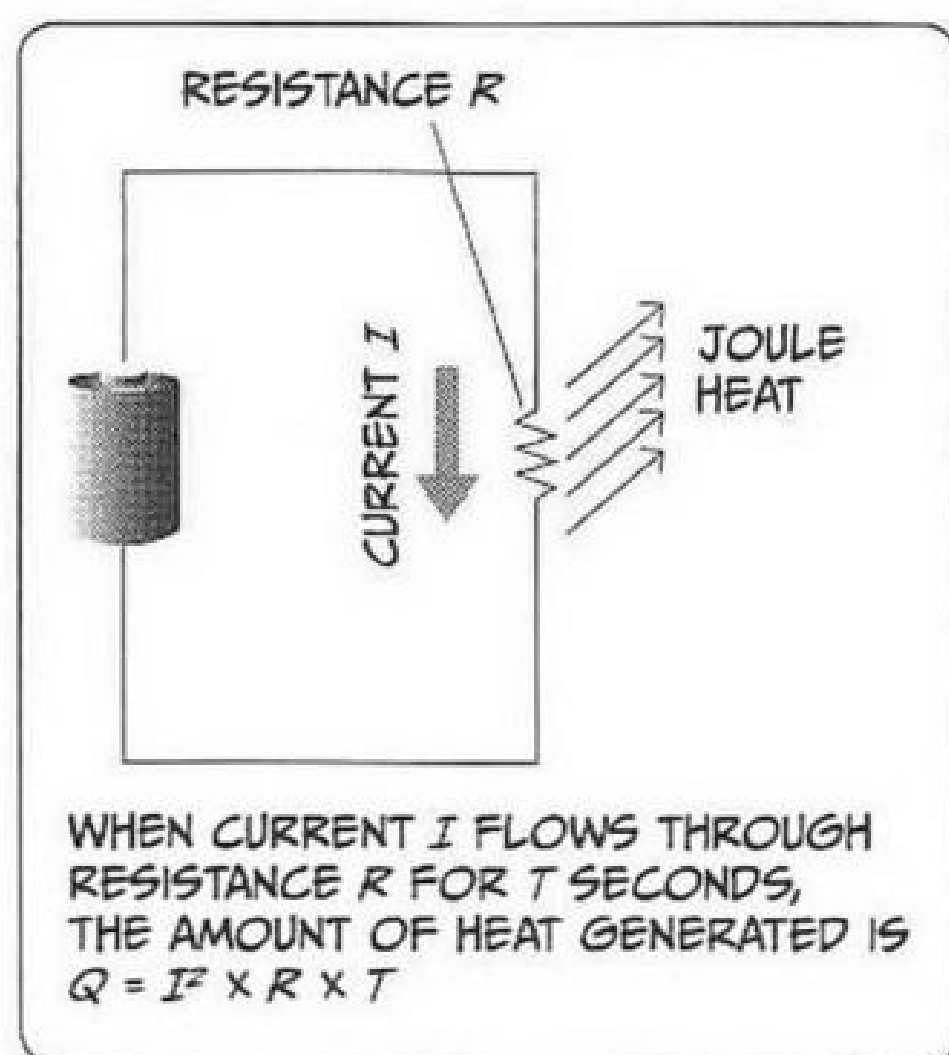






## JOULE HEAT

Heat that is produced when current flows through an electric resistance is called *joule heat*. For example, the amount of heat produced when current  $I$  flows through resistance  $R$  for  $t$  seconds can be obtained by calculating  $I^2 \times R \times t$ . The amount of heat is represented by the symbol  $Q$  and is measured in *joules (J)*, which are named after the English physicist James Prescott Joule. One joule corresponds to the electric power consumption of 1Ws (watt second)—and one joule is equivalent to a  $\text{kg} \times \text{m}^2 / \text{s}^2$ . The amount of heat required to raise 1 gram of pure water from  $14.5^\circ\text{C}$  to  $15.5^\circ\text{C}$  at 1 atmosphere of pressure is approximately 4.2J, and this is equivalent to 1 *calorie (cal)*.



Resistance and joule heat

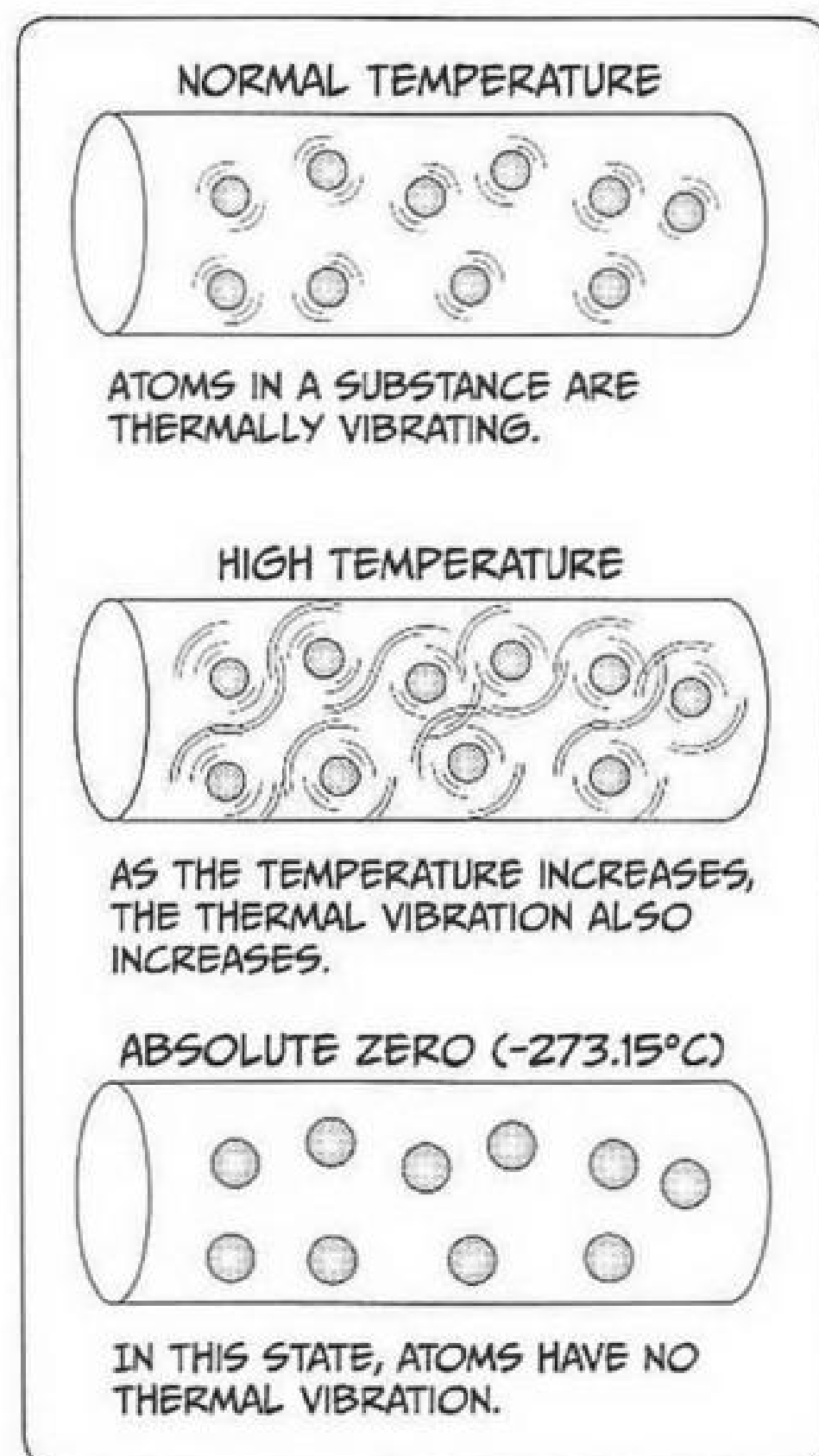
## THERMAL VIBRATION

What is heat? The atoms that make up a substance are always vibrating, and this is called *thermal vibration*. The magnitude of the thermal vibration in a substance is directly related to the magnitude of the temperature of that substance—this thermal vibration of atoms is the true nature of heat.

If the atoms in a substance are not vibrating, that substance will have no temperature—that temperature is called *absolute zero*, which is equal to  $-273.15^\circ\text{C}$ .

Even when copper wire, which is used for electric wire because of its low resistance, is at normal temperatures, the vibration of the copper atoms resists the movement of electrons, creating additional heat and additional resistance.

However, if the temperature of a material drops to near absolute zero, the vibrations of the atoms become very small. In such a state, electrons can travel much more easily—in other words, the material's resistance decreases. In some materials, such as aluminum, if the temperature becomes low enough, the electrons can move without

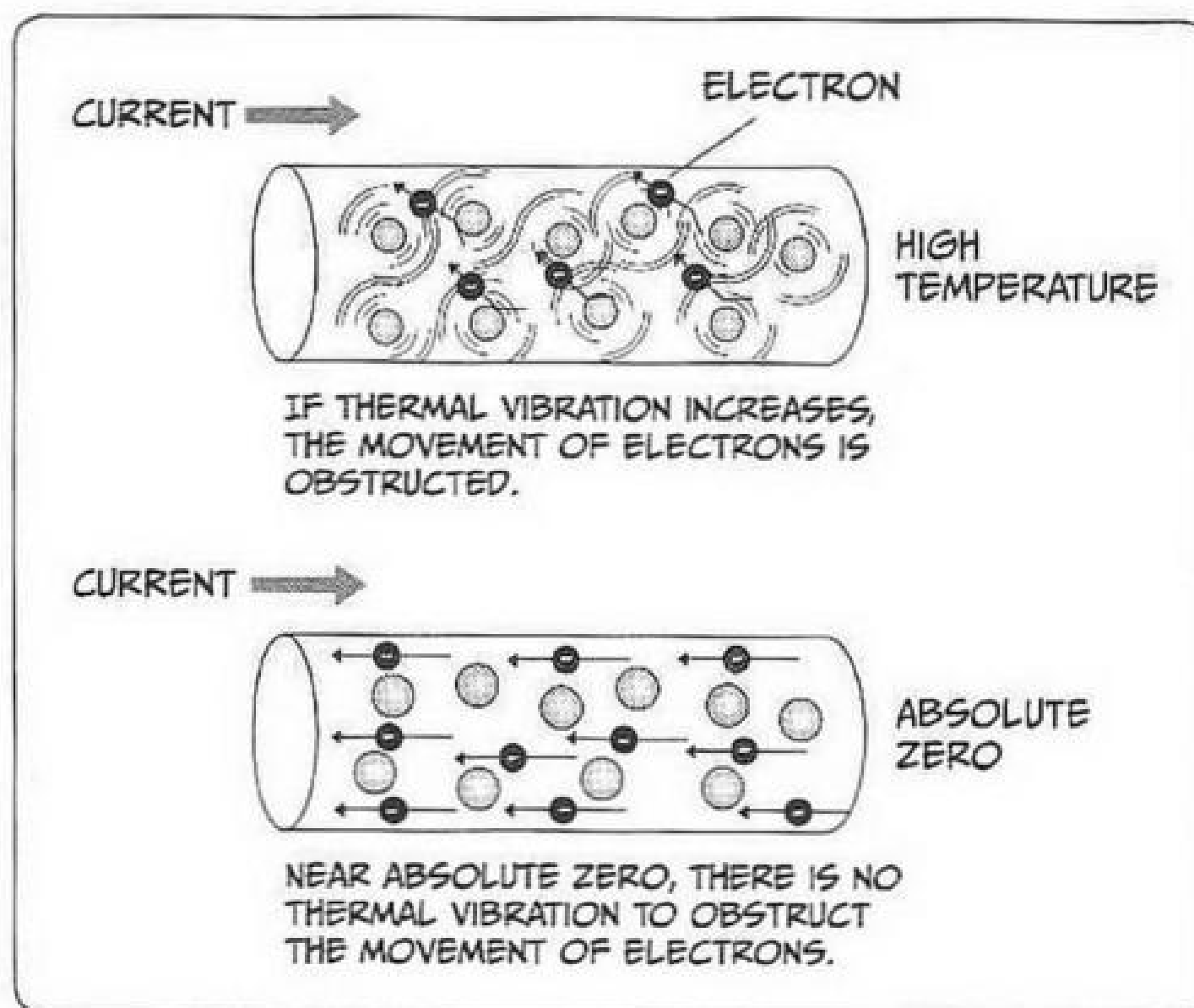


Thermal vibration and temperature



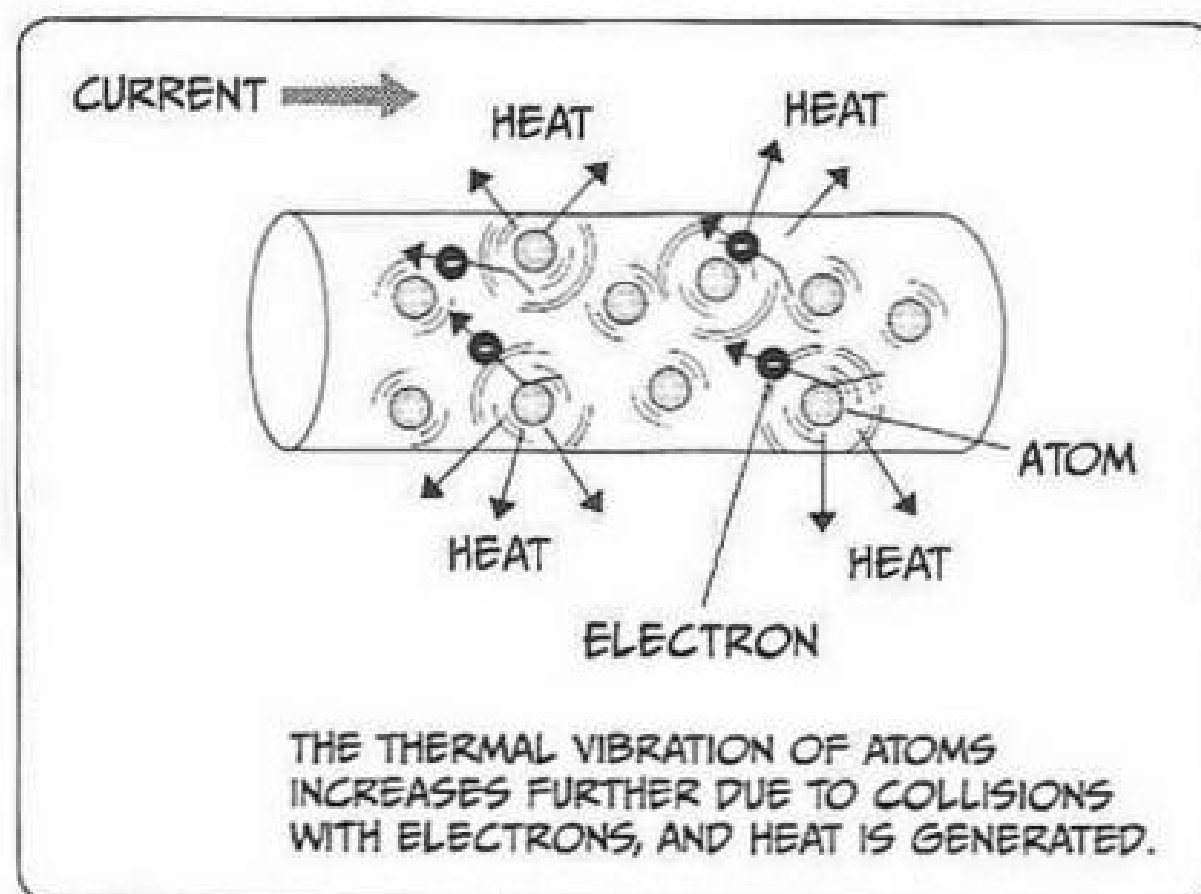
being obstructed by the atoms at all! When a material's resistance becomes zero, we call the phenomenon *superconductivity*.

Many metals are found to naturally superconduct when they are cold enough, but most need to be near absolute zero. However, since it is extremely difficult to actually lower a substance's temperature near absolute zero, research is being conducted on superconductivity phenomena that occur at temperatures much higher than absolute zero, a field called *high-temperature superconductors*. Someday, materials like these may be used to send electricity to homes everywhere without current loss due to joule heating.



*Superconductivity and current*

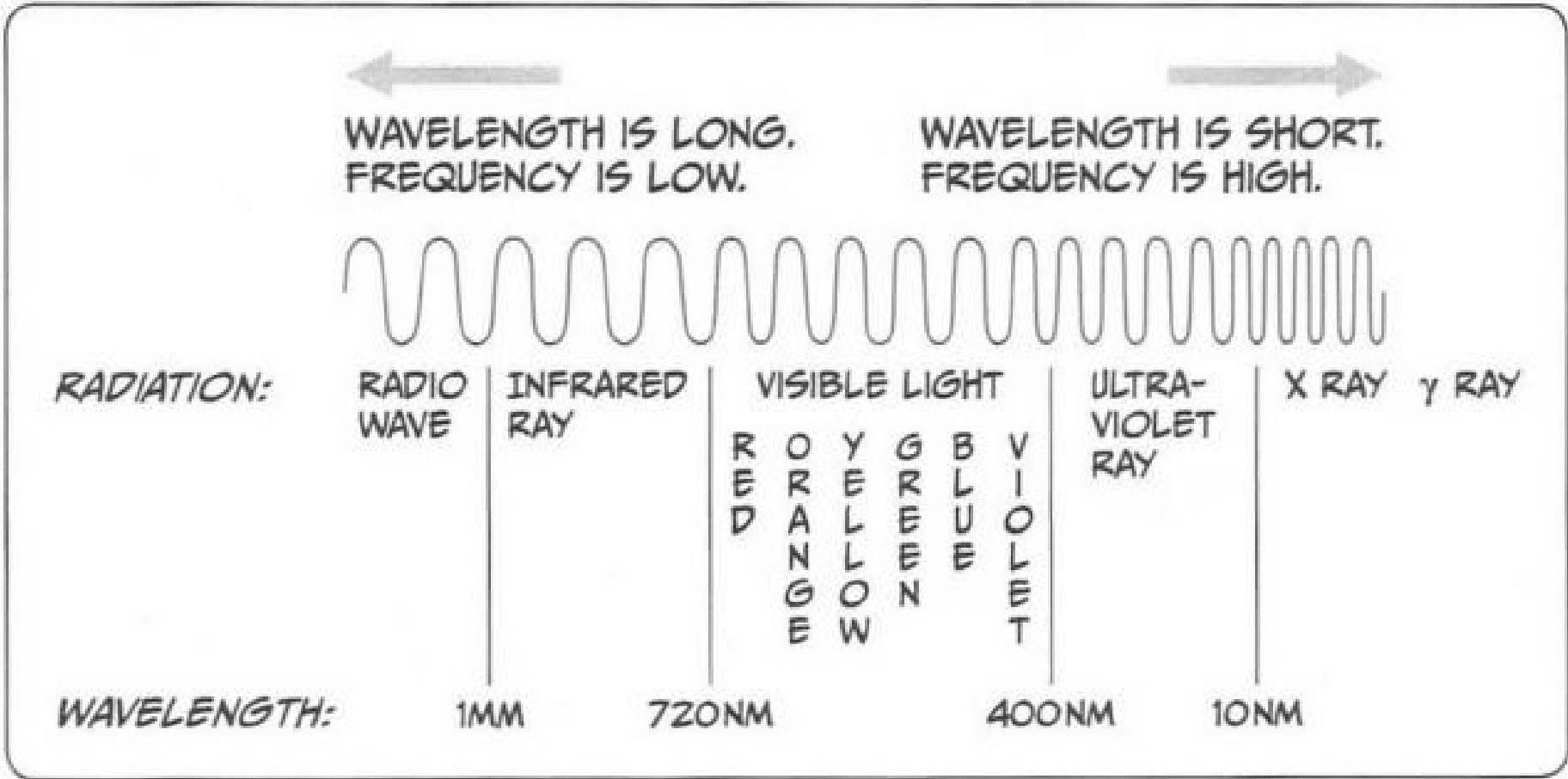
In wires at normal temperatures, electrons will violently collide with other atoms, which creates even more thermal vibrations—that is, more heat. As a wire heats up, its resistance increases. Conversely, as its temperature decreases, electric resistance decreases.



*Collisions with electrons and generation of heat*

# ELECTROMAGNETIC WAVES

When current flows through a resistance and the temperature rises, heat is generated. At first, infrared rays that are invisible to the naked eye are emitted. *Infrared rays*, which are also called *heat rays*, are a type of *electromagnetic wave*—a wave that has thermal energy. Electromagnetic waves (in order of decreasing wavelength) include radio waves, infrared rays, visible light, ultraviolet rays, and X rays, among others. Radio waves are used for TV or radio broadcasting and communication for ships. The color of visible light varies with the wavelength—red light has the longest wavelength, and violet light has the shortest.

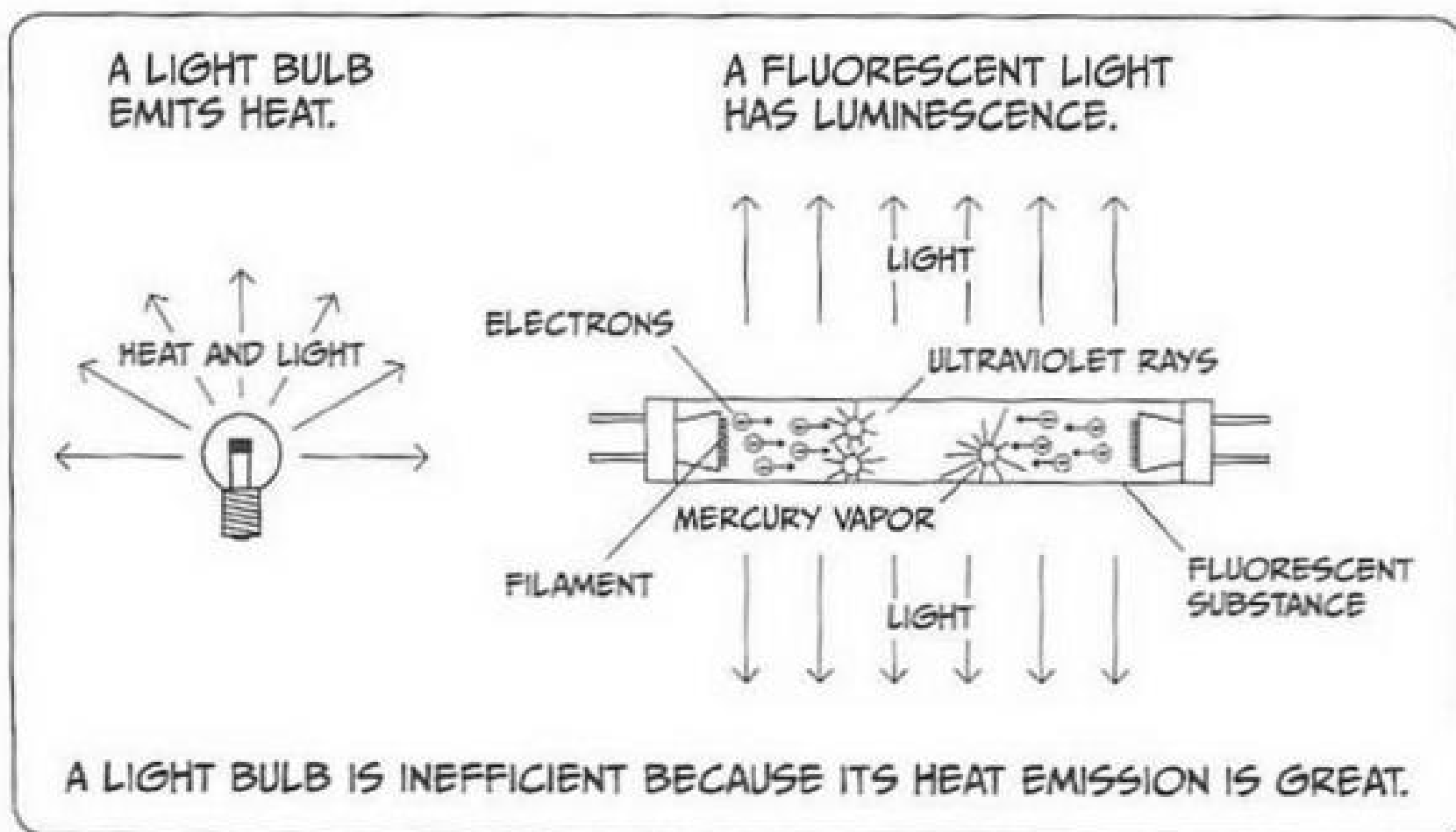


Wavelength and classification of electromagnetic waves

After infrared rays are emitted from a substance, visible light will be emitted if the temperature continues to rise. This phenomenon in which thermal energy is emitted as electromagnetic waves as the temperature of a substance increases is called *thermal emission*. This is the principle of light emission in light bulbs. Thermal emission produces red light at a low temperature, which changes to bluish white light as the temperature rises.

Light emission due to thermal emission mostly ends up becoming heat, so it is inefficient to use it as light. Light emission in which the emitter does not need to be heated is called *luminescence*; it is the principle used in fluorescent lights. In a fluorescent light, electrons that escape from the filament collide with mercury vapor inside the fluorescent tube; the ultraviolet rays that are generated at that time excite the fluorescent substance on the inner surface of the fluorescent tube and become visible light. The light emission of a fluorescent light is very efficient—for the same electric power consumption, it emits more than four times the light that a regular light bulb emits.

Light-emitting phenomena include thermal emission and luminescence, as shown here.



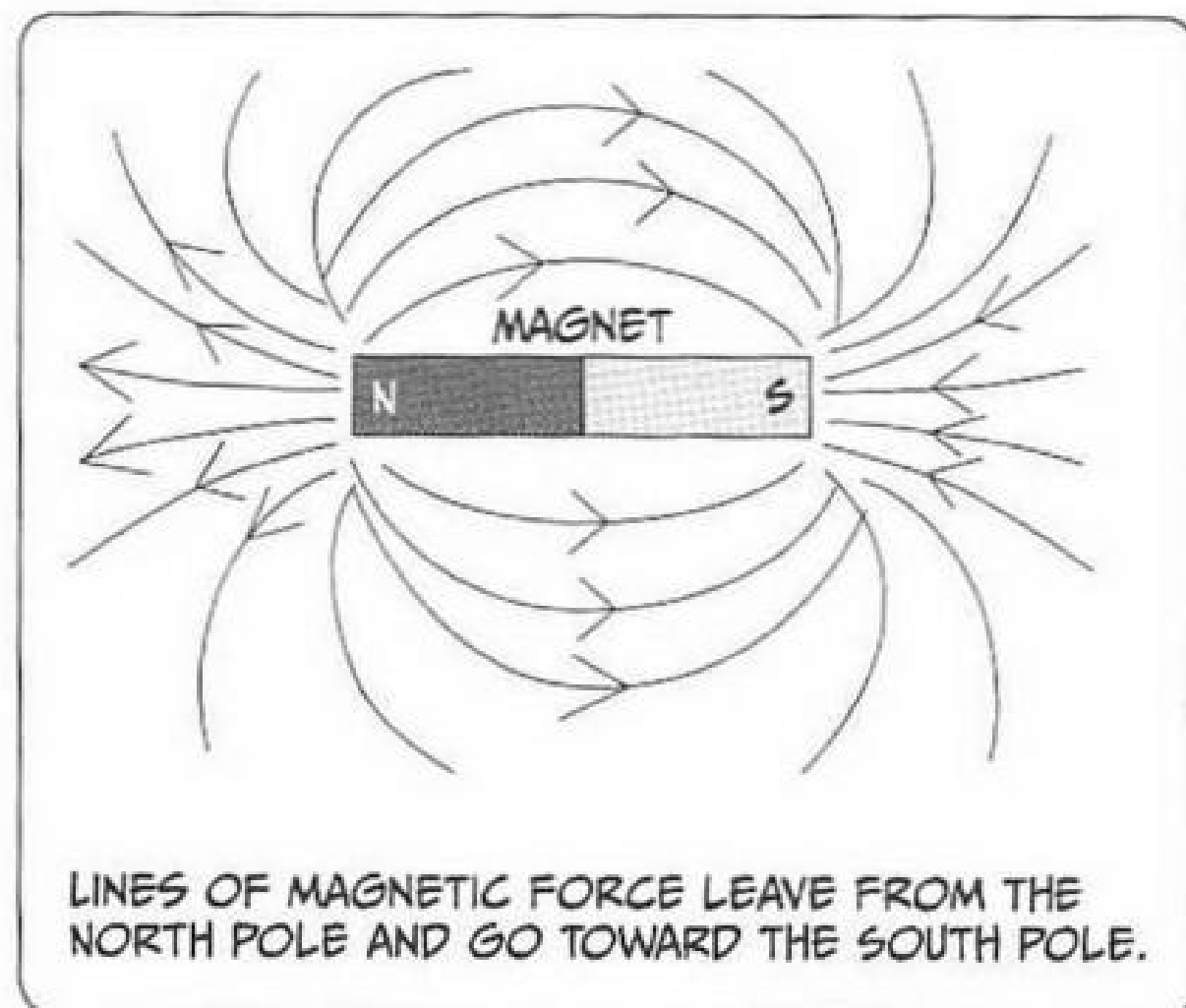
Light emission of a light bulb and a fluorescent tube

## ELECTRICITY AND MAGNETISM

If iron filings are sprinkled on a sheet of paper placed over a bar magnet, a pattern of lines is produced. These lines originate from the north (N) pole and lead toward the south (S) pole; they are called a *magnetic field*.

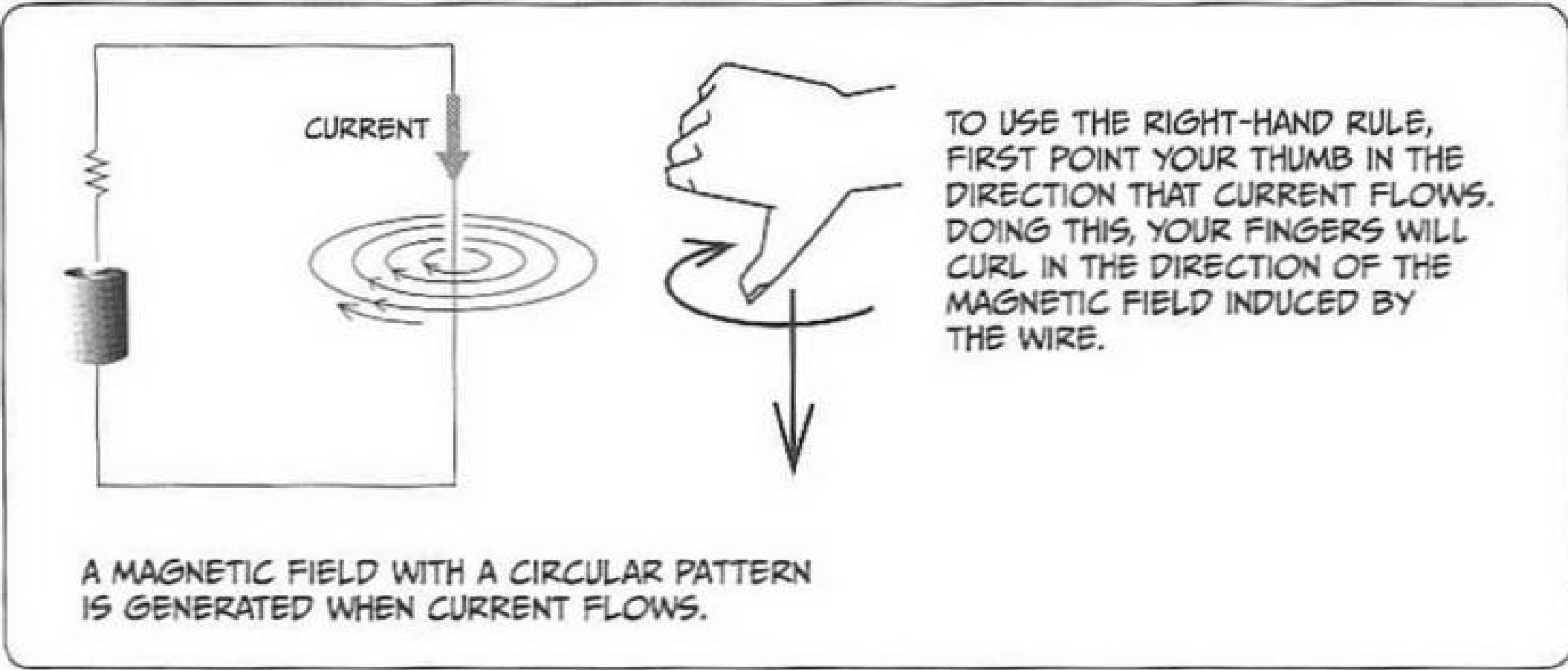
Magnetic fields are also generated when current flows. This phenomenon is extremely important when using electricity, and many common electrical appliances make use of it.

When current flows in an electric wire, a magnetic field with a circular pattern is generated around that wire. This is called *Ampère's law*. The magnitude of this magnetic field varies according to the strength of the current; if the direction of the current changes, the direction of the magnetic field also changes.

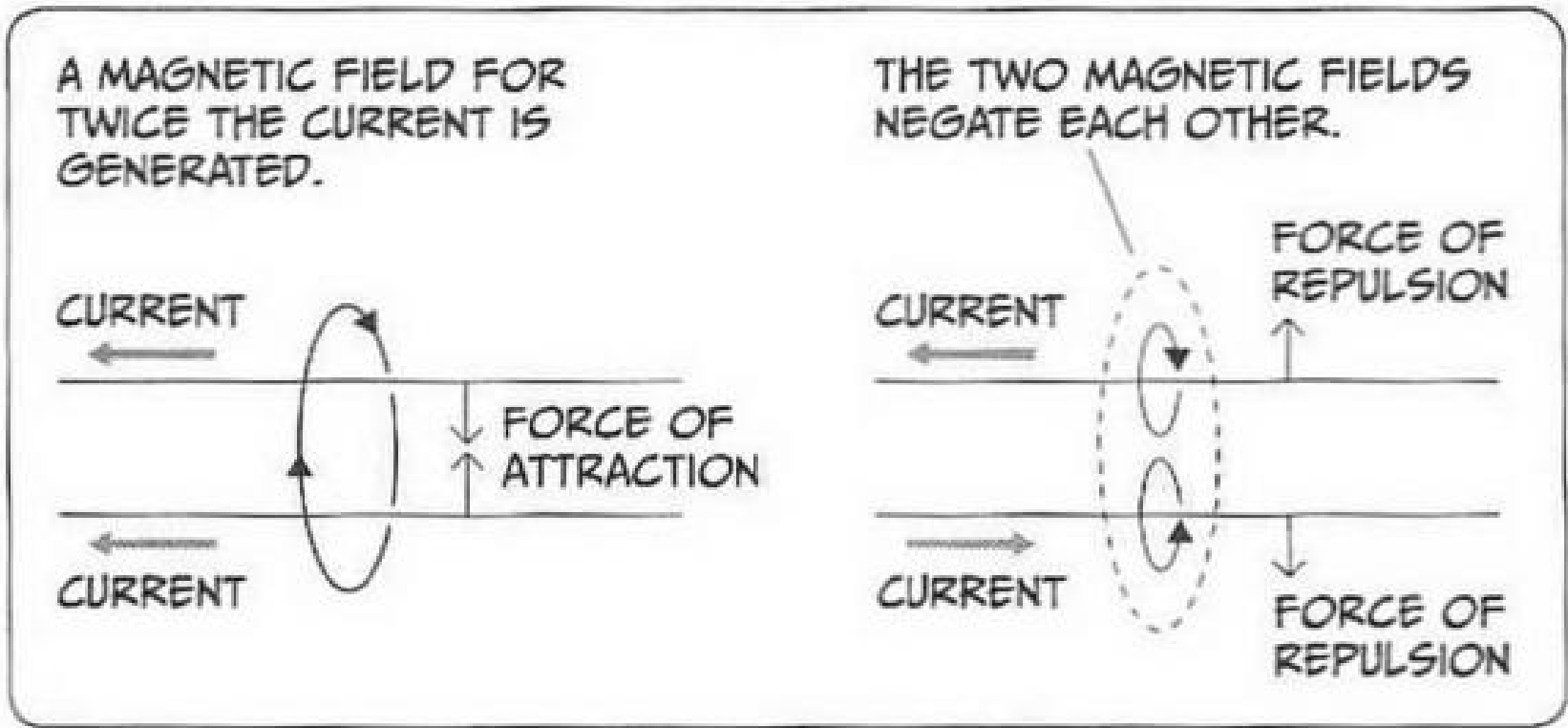


A magnet and magnetic fields

If current of the same magnitude flows in the same direction in two electric wires placed side by side, the magnetic fields generated in each wire are combined to generate a magnetic field of twice the current around both conductors. At this time, a force of attraction is generated between the two electric wires. If current is flowing in opposite directions in two wires, a force of repulsion is generated between the wires. In this case, the magnetic fields around the wires negate each other and become smaller.



Ampère's law

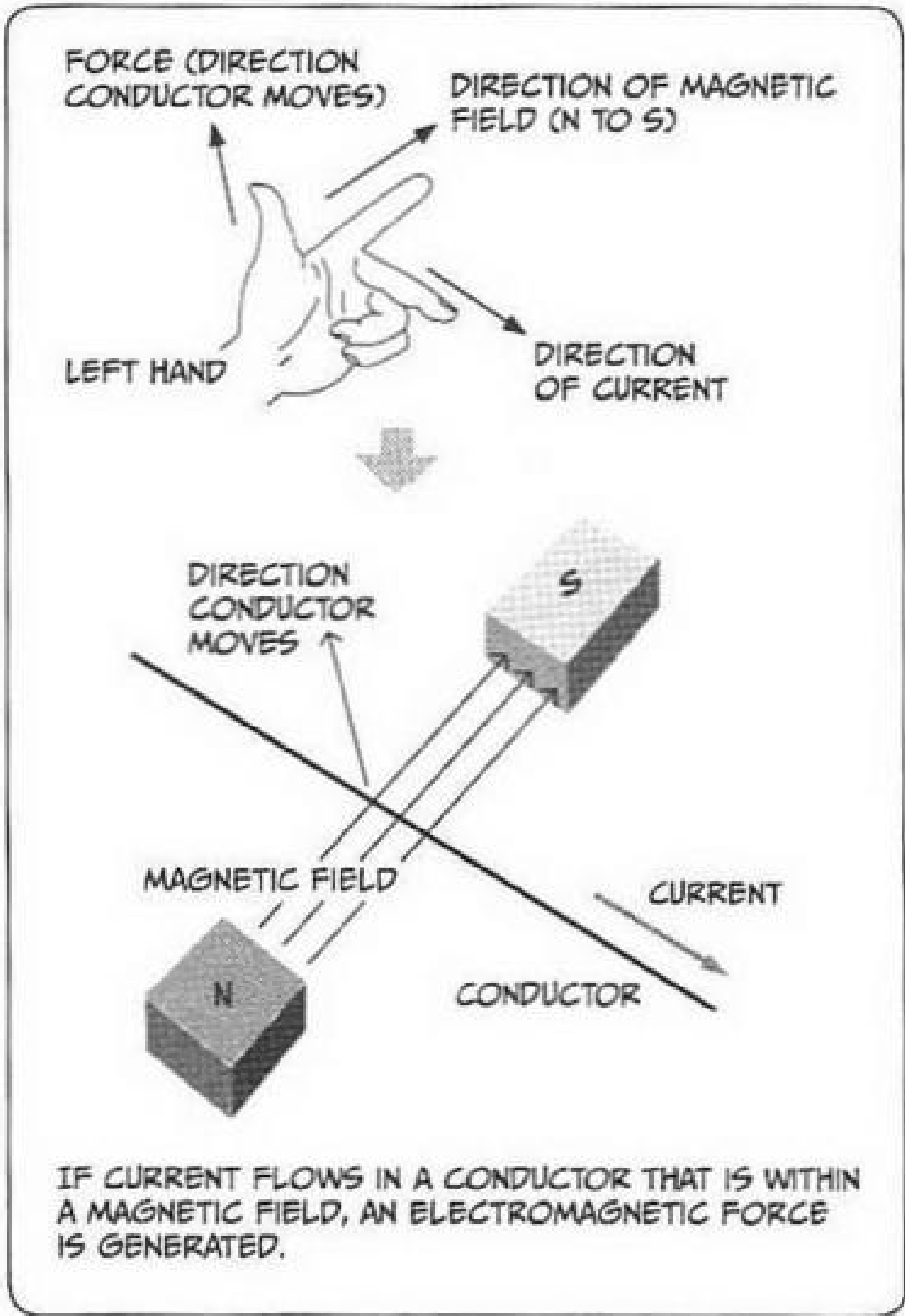


Forces generated when current flows in two conductors

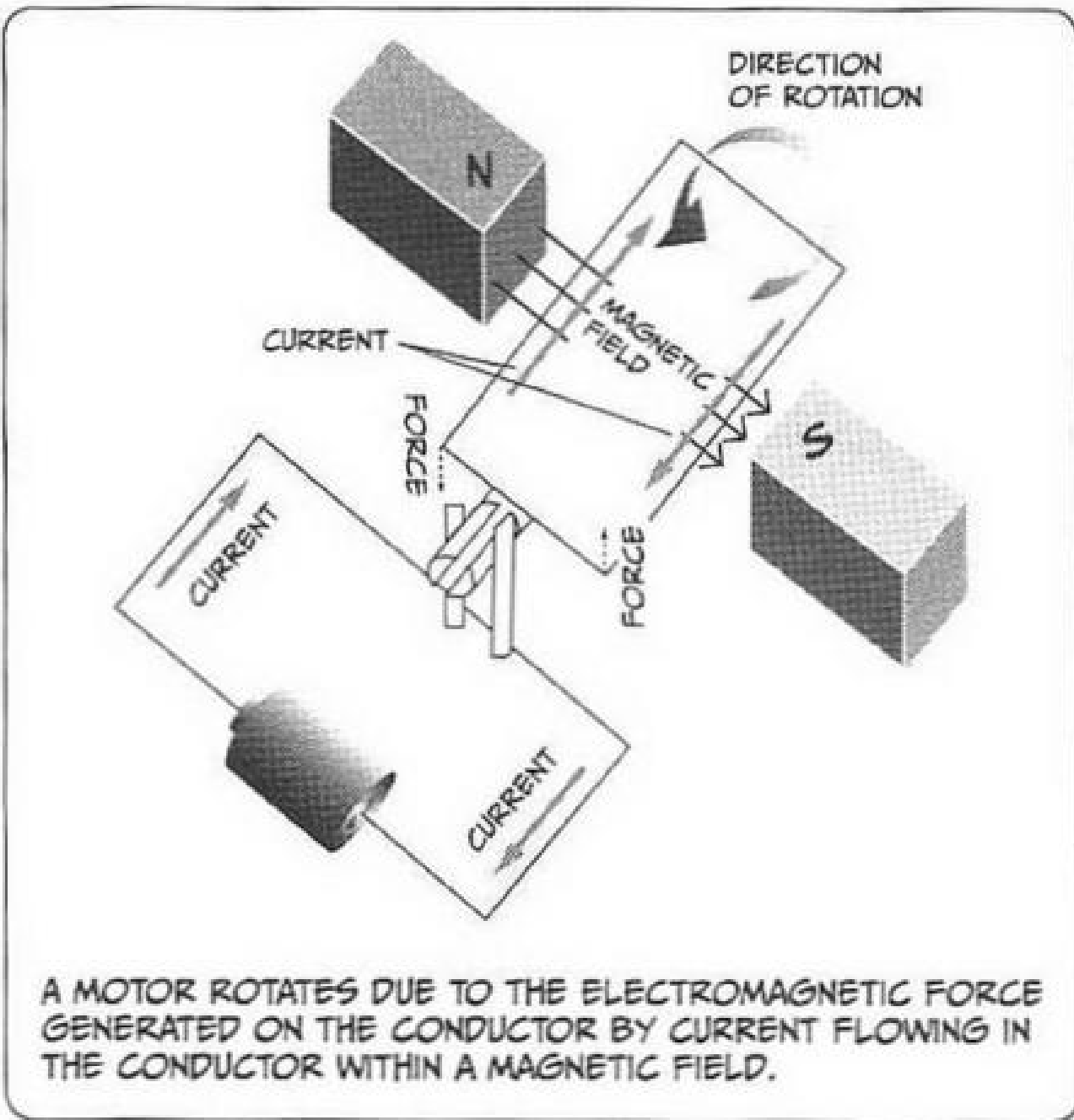
The additive property of magnetic fields also holds true for more than two wires (for example, a coil). In this way, a large magnetic field can be generated.

# FLEMING'S LEFT-HAND RULE AND MOTORS

If current flows in a conductor that is within a magnetic field, an *electromagnetic force* is generated on the conductor. *Fleming's left-hand rule* indicates an easy-to-remember relationship among the directions of the magnetic field, the current, and the movement of the conductor. This rule says that when you extend the thumb, index finger, and middle finger of your left hand so they are mutually perpendicular, the index finger points in the direction of the magnetic field, the middle finger points in the direction of the current, and the thumb points in the direction that the conductor moves (the direction of the electromagnetic force). The name of this rule comes from the name of the English electrical engineer John Ambrose Fleming who defined it. You can determine the direction of rotation of a motor by using Fleming's left-hand rule.



Fleming's left-hand rule

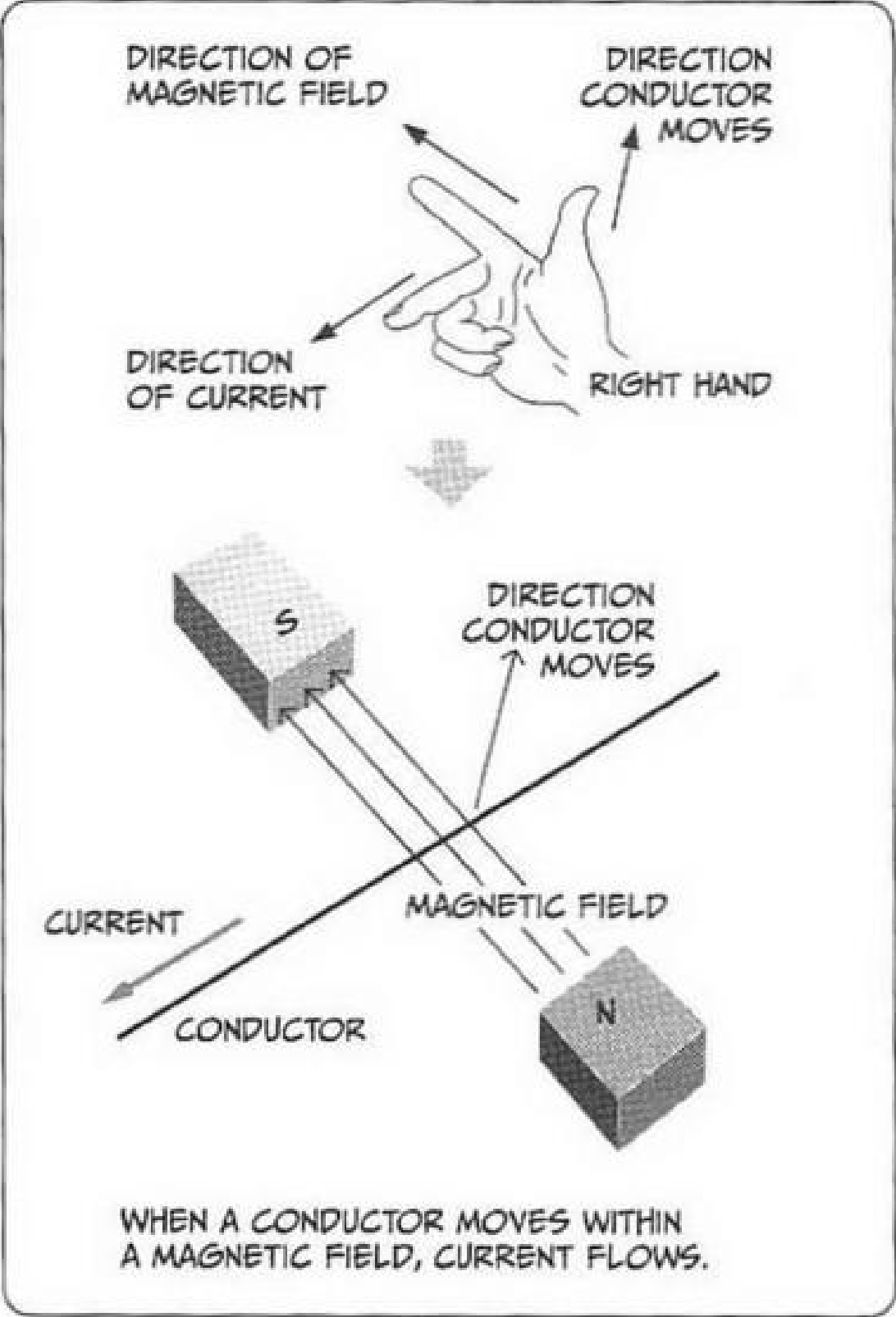


Motor rotation

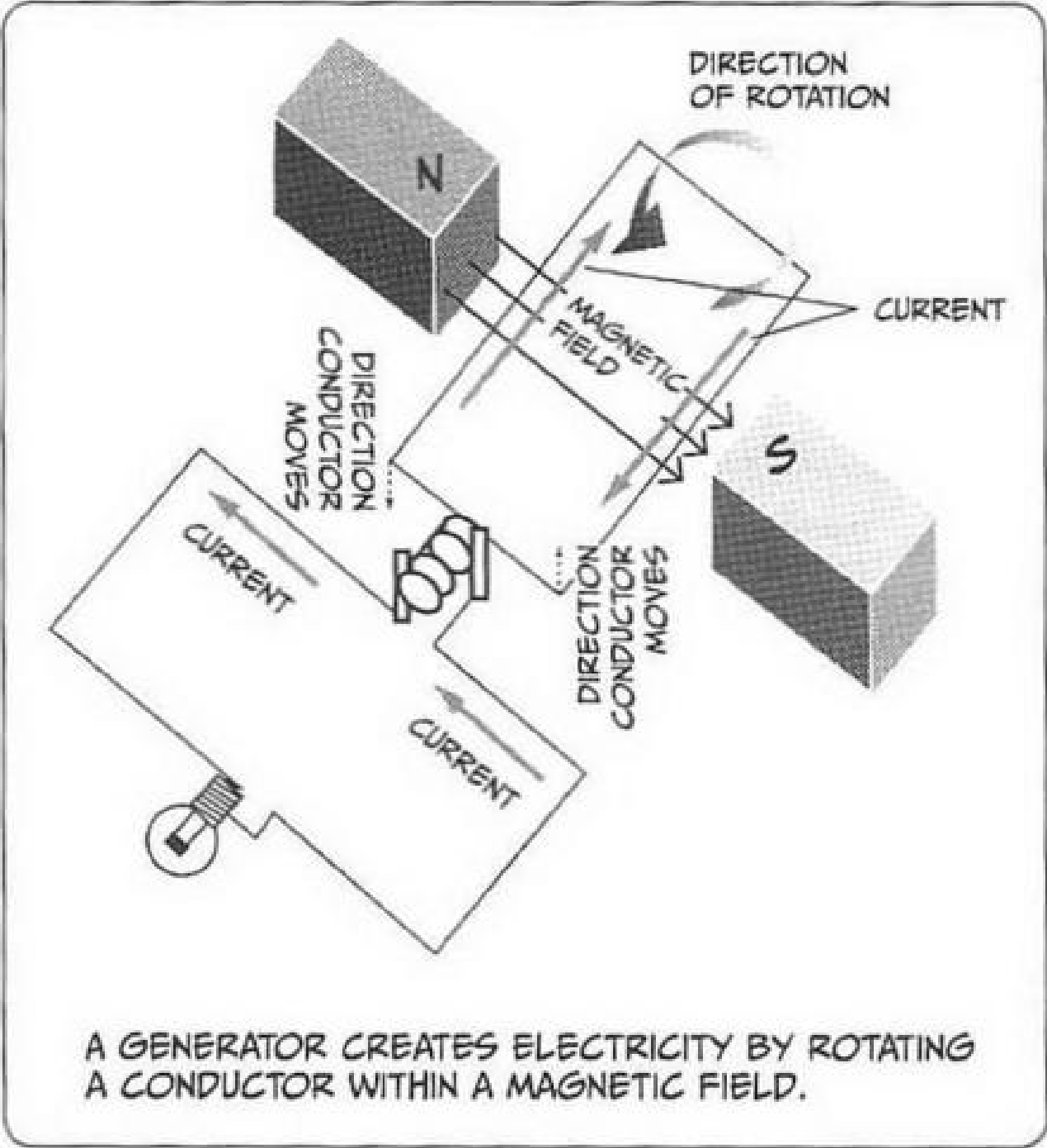


# FLEMING'S RIGHT-HAND RULE AND ELECTRIC GENERATORS

You can determine the direction of the electromotive force created by an electric generator by using *Fleming's right-hand rule*. When a conductor moves between the poles of a magnet, the conductor crosses a magnetic field facing from the north (N) pole to the south (S) pole of the magnet; electromotive force is thus generated in the conductor, and current flows. *Fleming's right-hand rule* indicates an easy-to-remember relationship among the directions of the magnetic field, the movement of the conductor, and the current. When you extend the thumb, index finger, and middle finger of your right hand so they are mutually perpendicular, the index finger points in the direction of the magnetic field, the thumb points in the direction that the conductor moves, and the middle finger points in the direction of the current.



Fleming's right-hand rule



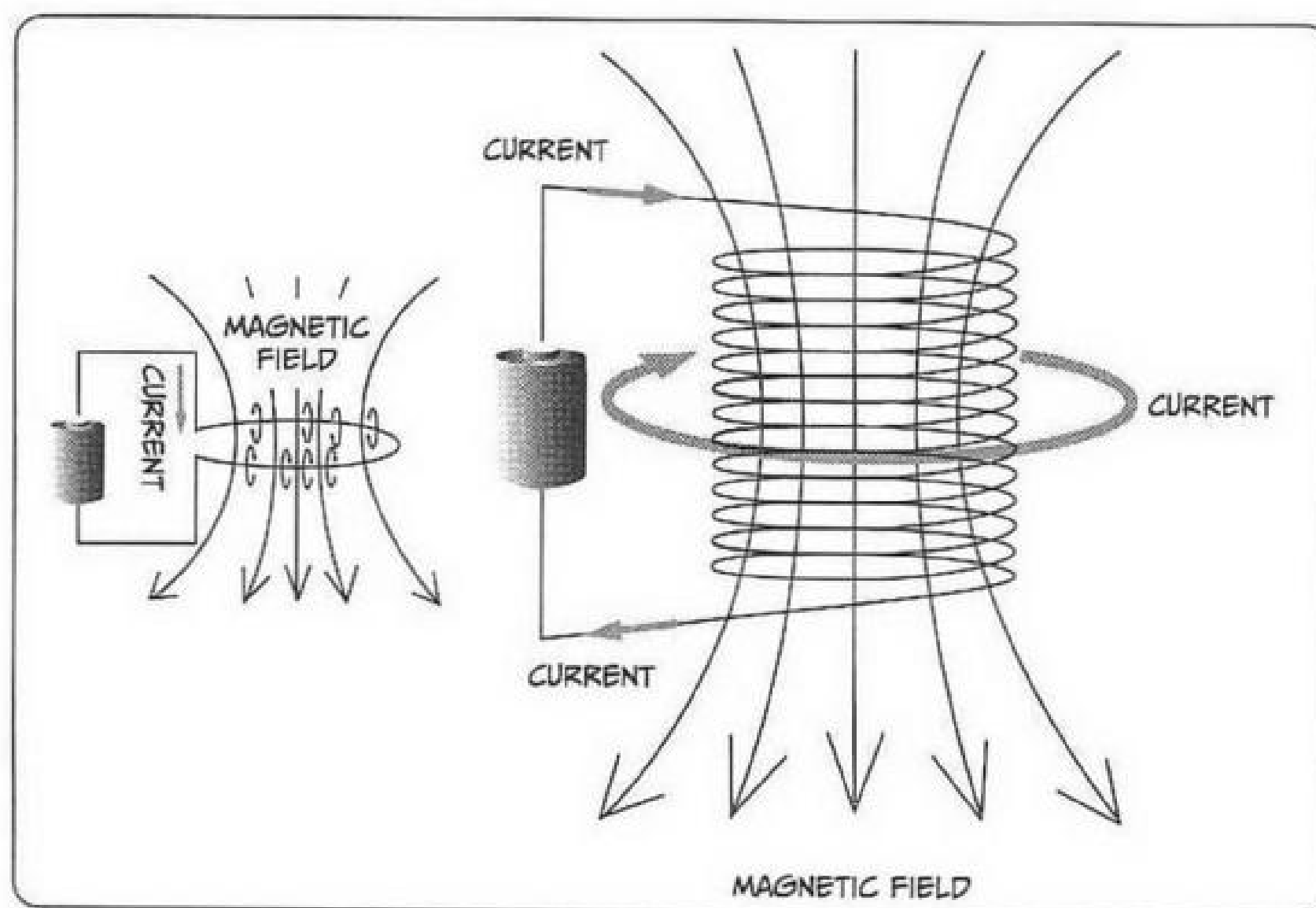
Electricity generated by a generator

You must apply a force to keep the loop spinning within the magnetic field. This could be the force from falling water, like in a hydroelectric generator, or the force of pressurized steam, like in a coal power plant.

But why do Fleming's hand laws work? We can better understand why generators and motors work by understanding how magnetism and electricity are related.

## ELECTRICITY AND COILS

An electric wire wound in loops is called a *coil*. If current flows in a coil, a magnetic field is generated that goes through the inside of the coil. If an iron core is inserted in the coil, the magnetic field is concentrated in the iron, and it becomes a strong *electromagnet*. The strength of an electromagnet is proportional to the product of the current and the number of loops in the coil; if the direction of the current is reversed, the polarity of the electromagnet is also reversed. If the current is stopped, the magnetic force of the electromagnet disappears.



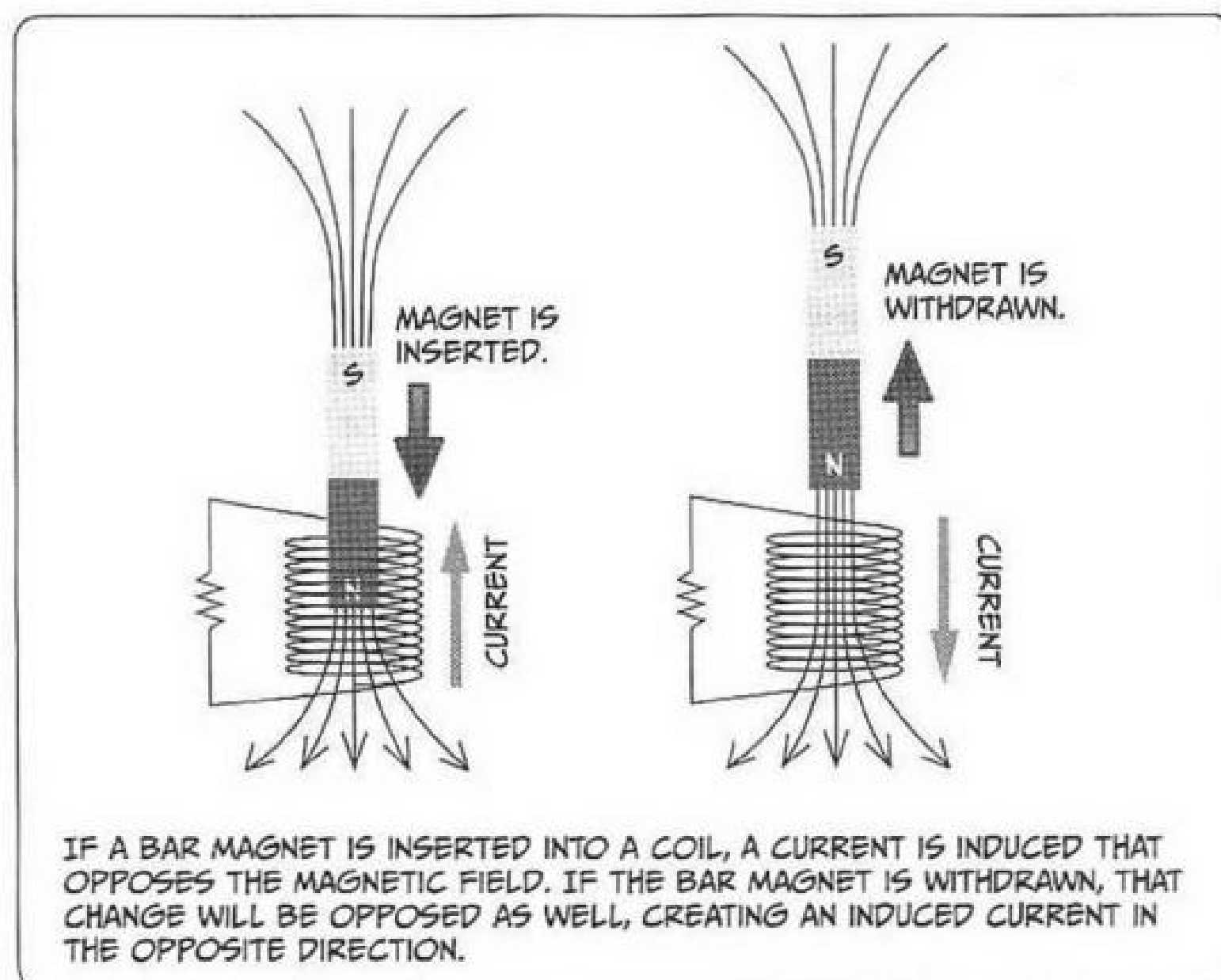
*Magnetic field created by a coil of electric wire*

You can use your right hand to find the orientation of the magnetic field induced by a coil. Just curl your fingers in the direction the current flows in the coil, and your thumb will point towards the N pole of the induced magnetic field.

### COILS AND ELECTROMAGNETIC INDUCTION

When a bar magnet moves within a coil, current flows in that coil, which creates a magnetic field in order to oppose the change in magnetism. If the direction of the bar magnet's movement changes, the direction of the current in the wire also changes. This phenomenon is called *electromagnetic induction*, and the electricity that is generated during this process is called *induced electromotive force*. The current generated is called *induced current*.

Lenz's law, discovered by the Russian physicist Heinrich Friedrich Emil Lenz, states that the current due to electromagnetic induction flows in a direction such that the magnetic field produced by that current obstructs the motion of the magnet.

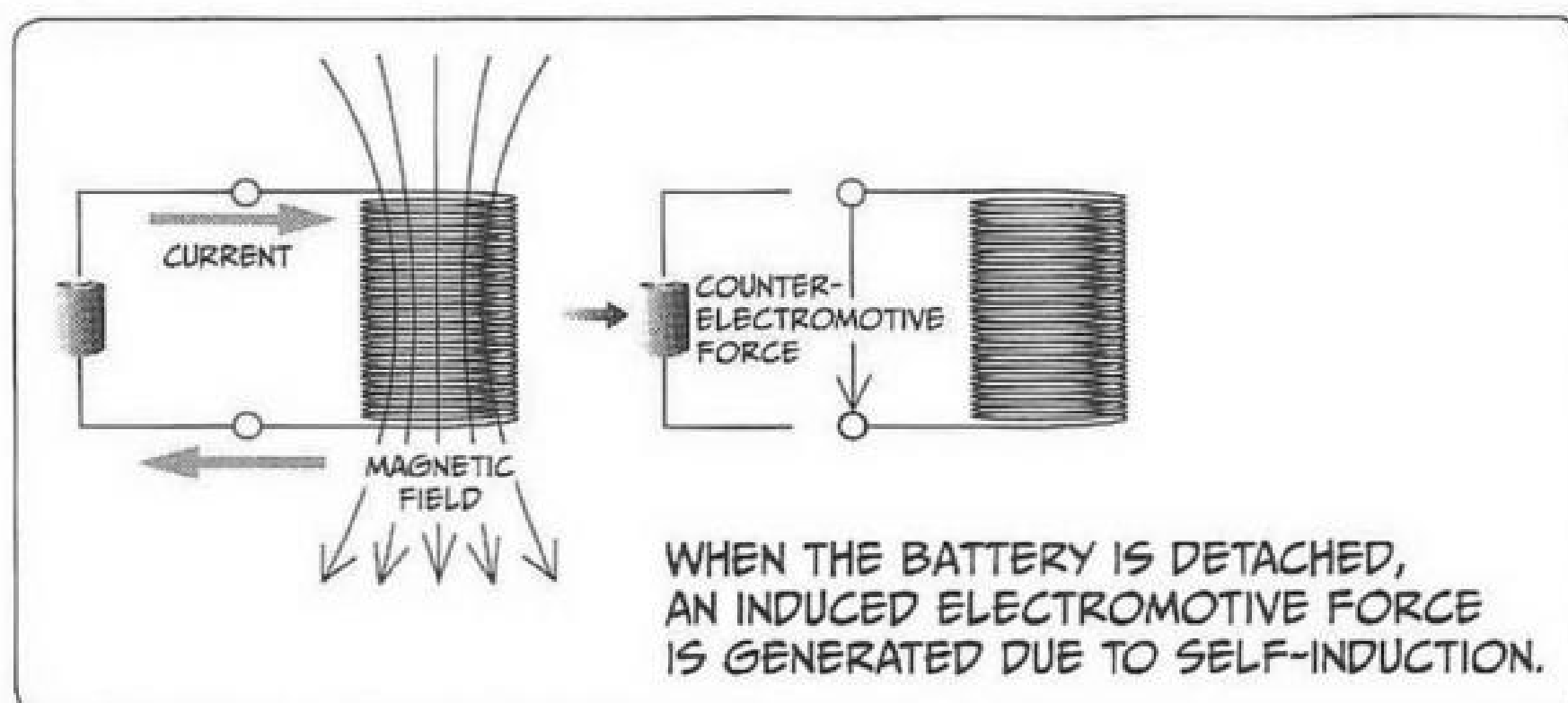


Electromagnetic induction

## COILS AND INDUCTANCE

If a coil is connected to a battery and current begins flowing, the magnetic field generated becomes larger, and the coil becomes an electromagnet. At this time, an induced electromotive force is generated on the coil itself due to the varying magnetic fields. This is called *self-induction* or simply *inductance*.

When the current to the coil is cut off, the magnetic field begins to disappear, and an induced electromotive force is generated in the direction that obstructs the flow of current in the coil. This is called a *counter-electromotive force*. The counter-electromotive force can be easily verified. When a battery is connected to a coil and current flows, a magnetic field is generated. When the current is constant, no counter-electromotive force is generated, but when the battery is detached and the current is cut off, the magnetic field that was being generated becomes smaller. At this time, voltage due to the counter-electromotive force appears at both ends of the coil.



Self-induction of a coil

## COILS AND ALTERNATING CURRENT

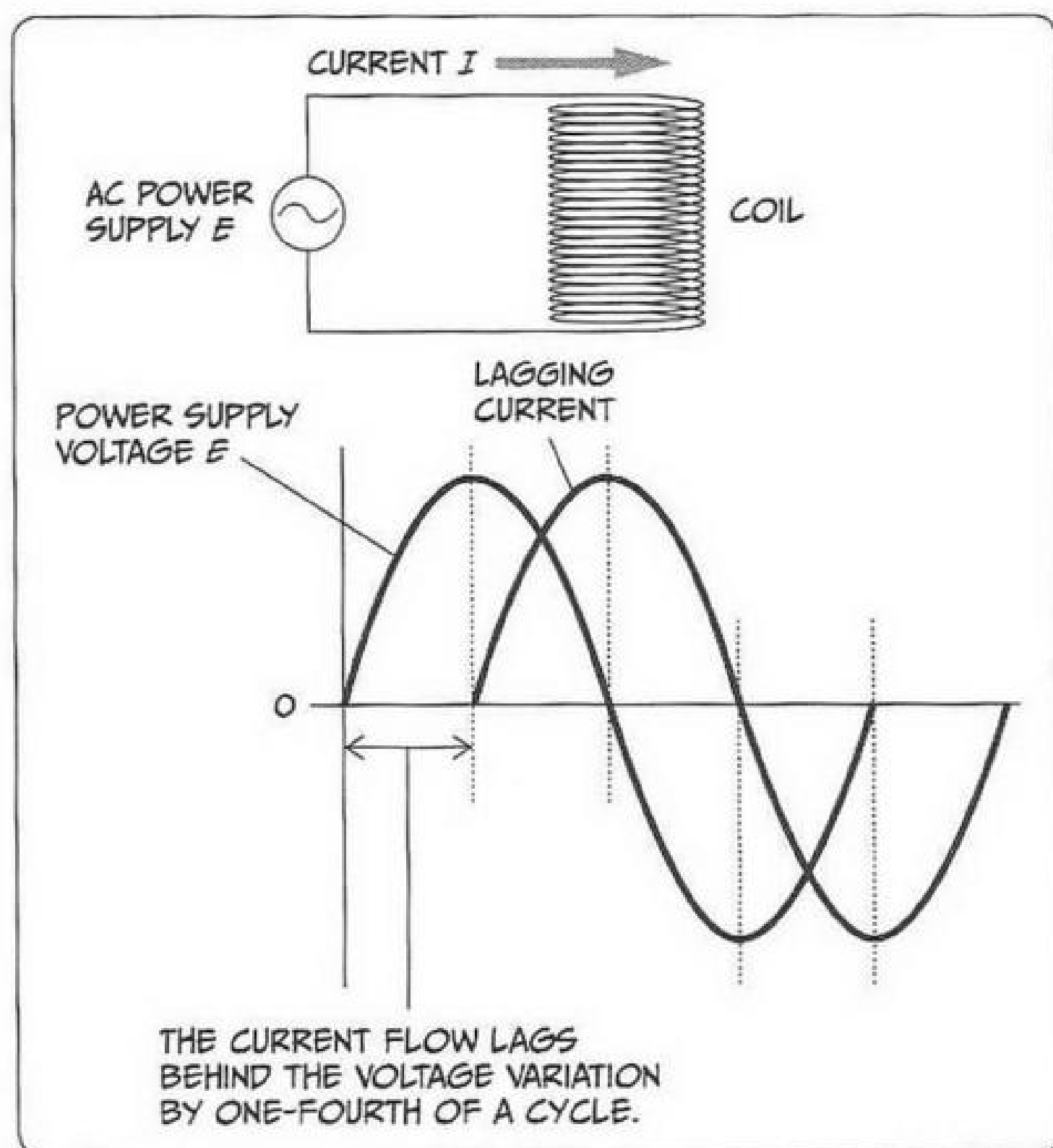
The magnitude of alternating current is always changing. If alternating current flows in a coil, an induced electromotive force is generated in the coil in the direction that obstructs the flow of the current, and current flows so that it lags behind the power supply voltage variation by one-fourth of a cycle. This is called the *lagging current*, and it flows in an electrical device such as a motor with a coil. This temporal lag is called a *phase difference*. The coil acts like a resistance to the current as described above. This is called *inductive reactance*, and its magnitude is proportional to the frequency of the alternating current.

Electric power consumption is represented by the product of voltage and current, and when the voltage and current waves match with respect to time, 100 percent work is done—in other words, “the power factor is 100 percent.” If the current lags, the power factor will be less than 100 percent, and the circuit is said to have a “low power factor.”

If the power factor is low, the electric power that is input from the power supply will not do 100 percent work, so a power supply having a correspondingly larger capacity is required. The ratio of the consumed power to the input power is the *power factor*.

$$\text{Power factor} = \frac{\text{Consumed power}}{\text{Input power}}$$

A low power factor means that some current returns to the power supply without doing work.



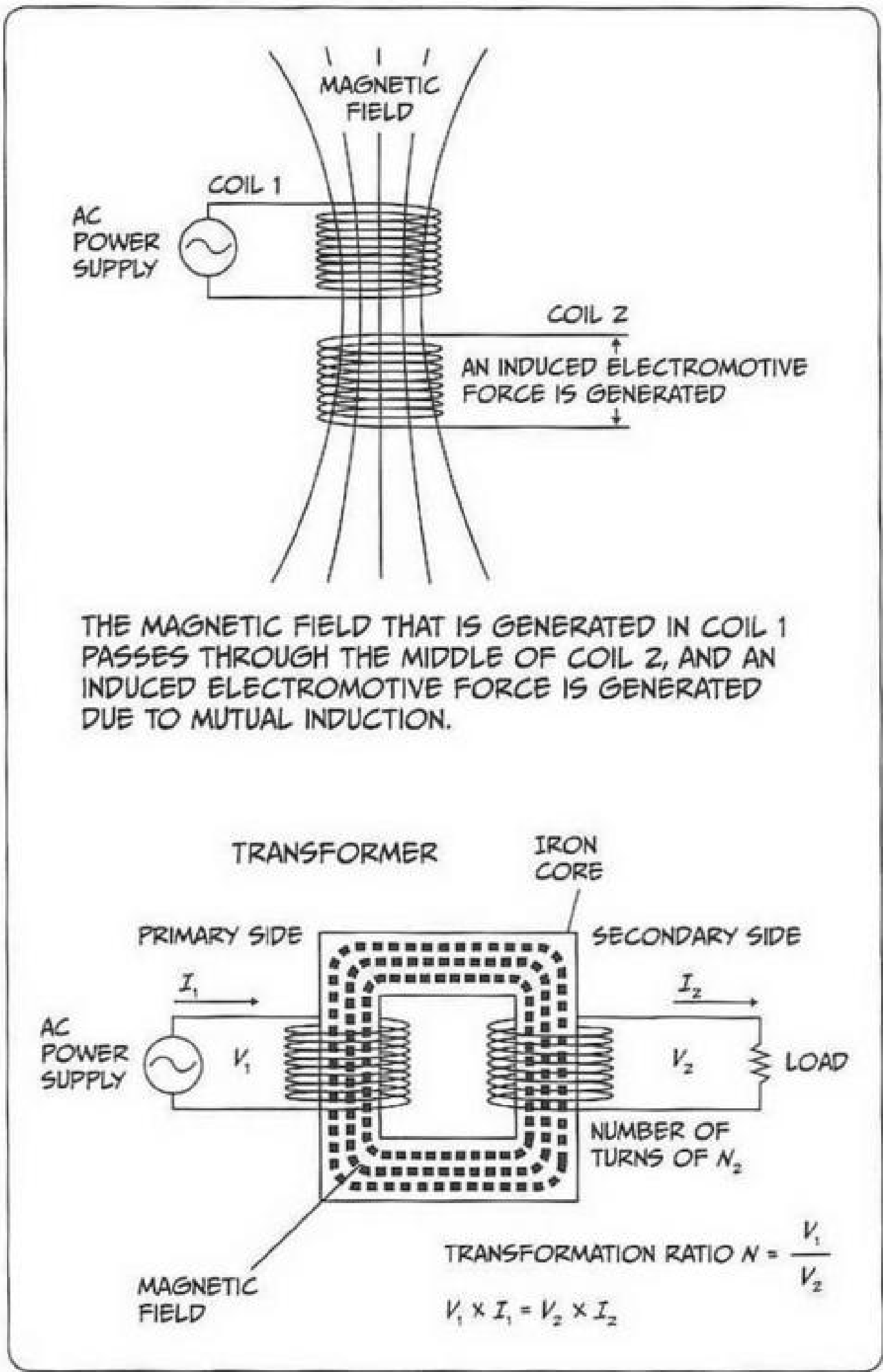
Lagging current flowing in a coil

# COILS AND TRANSFORMERS

If an AC power supply is connected to coil 1, a magnetic field is generated. When this magnetic field varies within coil 2, an induced electromotive force is generated in coil 2. This phenomenon is called *mutual induction*. A *transformer* is an electrical device that uses this phenomenon to change voltage.

If two coils are wrapped around an iron core, and an AC power supply is connected to coil 1, a magnetic field is generated and passes through the inside of the iron core. Since coil 2 has been wrapped around the same iron core, the magnetic field varies inside coil 2, and an induced electromotive force is generated in coil 2.

The power supply side of a transformer is called the *primary side*, and the load side is called the *secondary side*. The voltage generated on the secondary side is determined by the ratio of the number of turns ( $n_1$ ) of the primary coil and the number of turns ( $n_2$ ) of the secondary coil. For example, if the number of turns of the secondary coil is twice that of the primary coil, twice the voltage is generated on the secondary side. The current that flows



Mutual induction in a transformer

in the secondary coil at this time will be half the current that flows in the primary coil. The equation that describes this relationship is:

$$V_1 I_1 = V_2 I_2$$

The ratio of the primary voltage ( $V_1$ ) and secondary voltage ( $V_2$ ) is called the *transformation ratio*, and the product of the primary voltage and the current will be equal to the product of the secondary voltage and the current. In other words, a transformer only changes voltage—it does not change the magnitude of the electric power.

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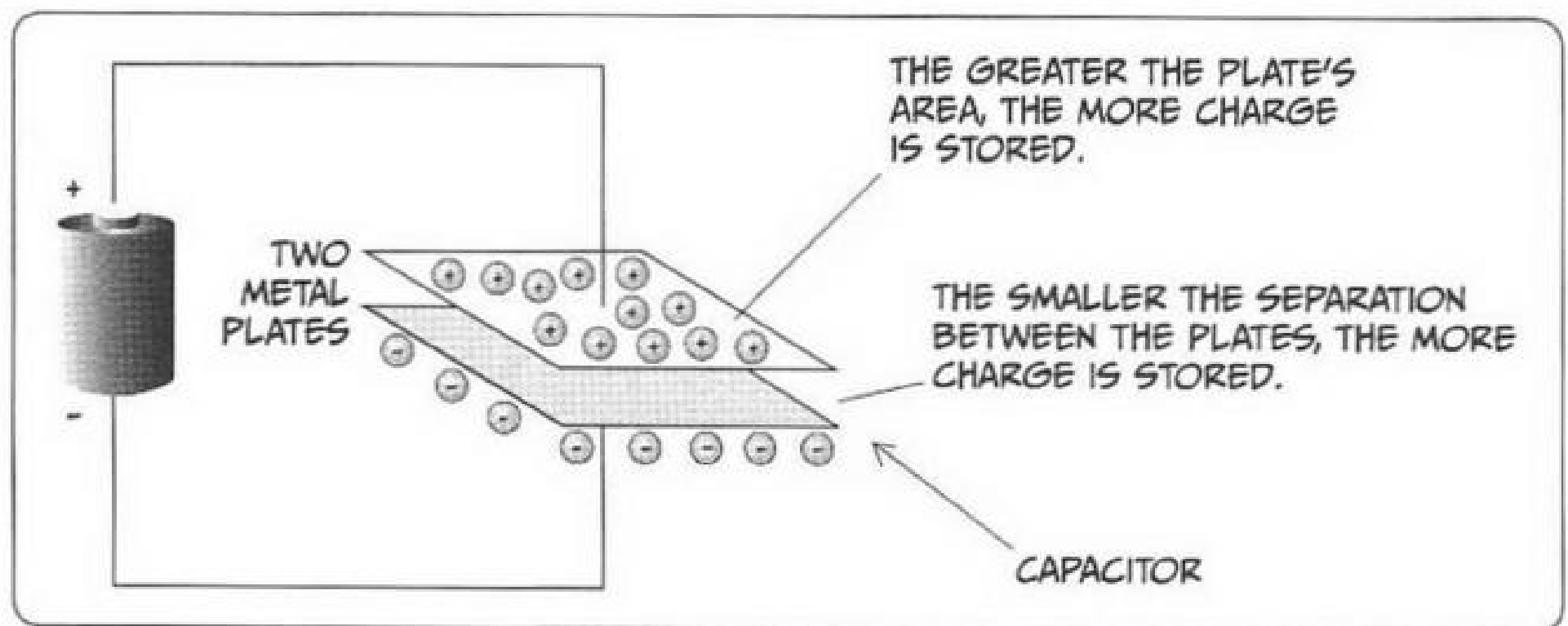
## CAPACITORS

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When an insulator is sandwiched between two metal plates and a battery is connected, electrons move from the negative pole of the battery to the bottom metal plate to charge it. Since the electrons in the top metal plate move to the positive pole of the battery, the top metal plate is positively charged. At this time, charge is stored on the metal plates. An object that stores charge in this way is called a *capacitor*.

Current flows from the instant the battery is connected, but eventually the electrons will stop moving, as charge builds on the capacitor. In other words, if a DC power supply is connected to a capacitor, current flows only at first and then stops because of the gap in the circuit. If the battery is detached in this state, the charge remains stored on the capacitor. If the battery is then connected in the reverse direction, the charge that had been stored discharges, and the capacitor is charged in the opposite direction.

The ability of the capacitor to store charge in this way is called *capacitance*; its magnitude is directly proportional to the area of the metal plate and inversely proportional to the distance between the metal plates. Capacitance is measured in *farads* ( $F$ ).



*Charge stored on a capacitor*

### CAPACITORS AND ALTERNATING CURRENT

If AC voltage is applied to a capacitor, a charged current flows until the power supply voltage reaches its maximum (starting from 0V). The current is zero at the power supply's peak voltage. When the power supply voltage decreases from its peak voltage, discharging begins, and the discharge current reaches its maximum when the power supply voltage is 0V.



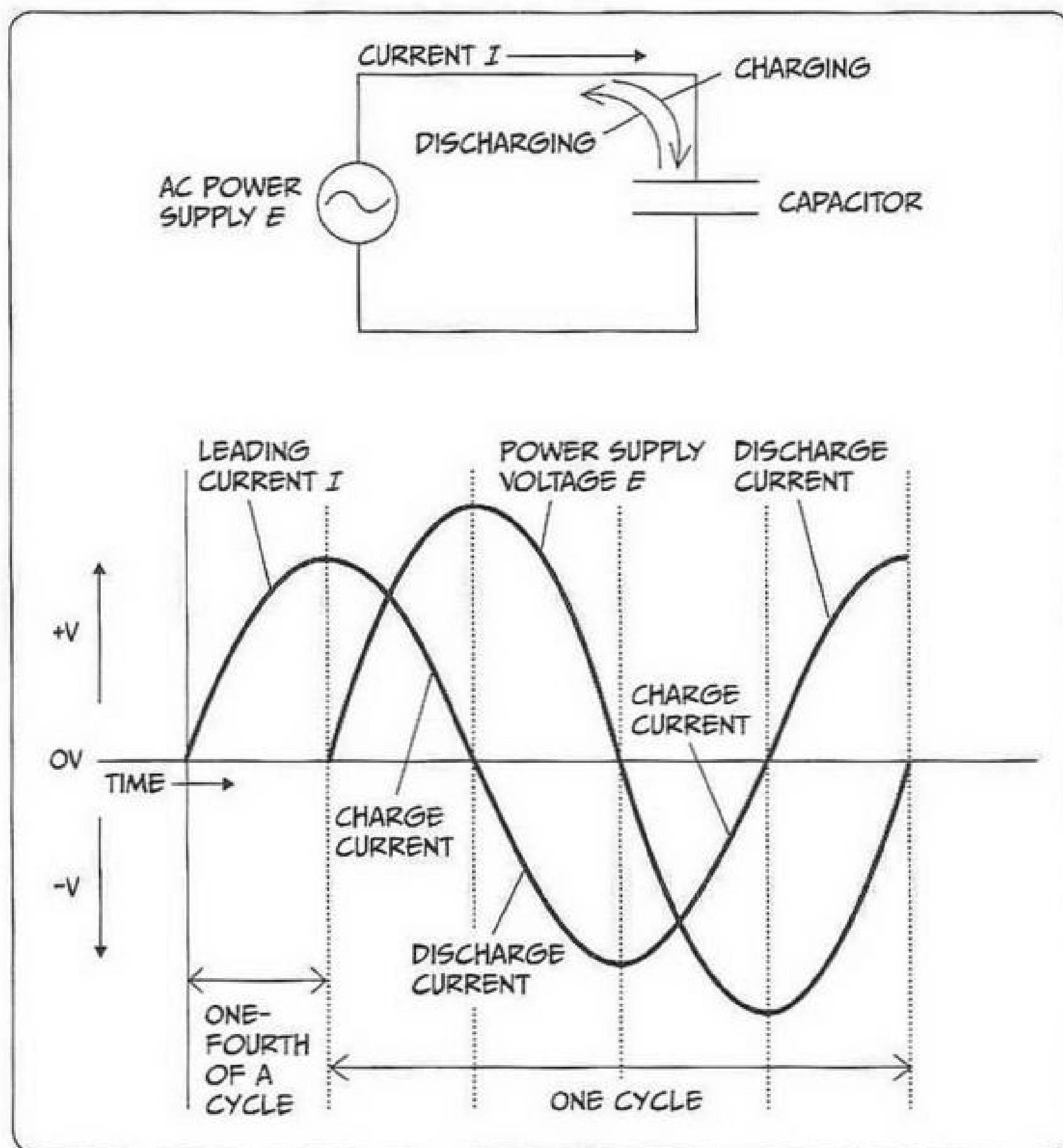
At this time, the polarity of the power supply voltage changes, and a current flows again. Charging stops when the power supply voltage reaches its peak voltage for the opposite polarity, and then discharging occurs again.

If a capacitor is connected to an AC power supply, the variation of the current is one-fourth of a cycle ahead of the variation of the power supply voltage; this current is called *leading current*.

A capacitor works like resistance to alternating current. This is called *capacitive reactance*, and its magnitude is inversely proportional to the frequency.

If an AC circuit has a coil, the current lags, and the power factor decreases. If a capacitor is connected to that circuit, the current leads, and the power factor increases.

In an AC circuit, capacitors and coils act like resistance, and are called *impedance*.



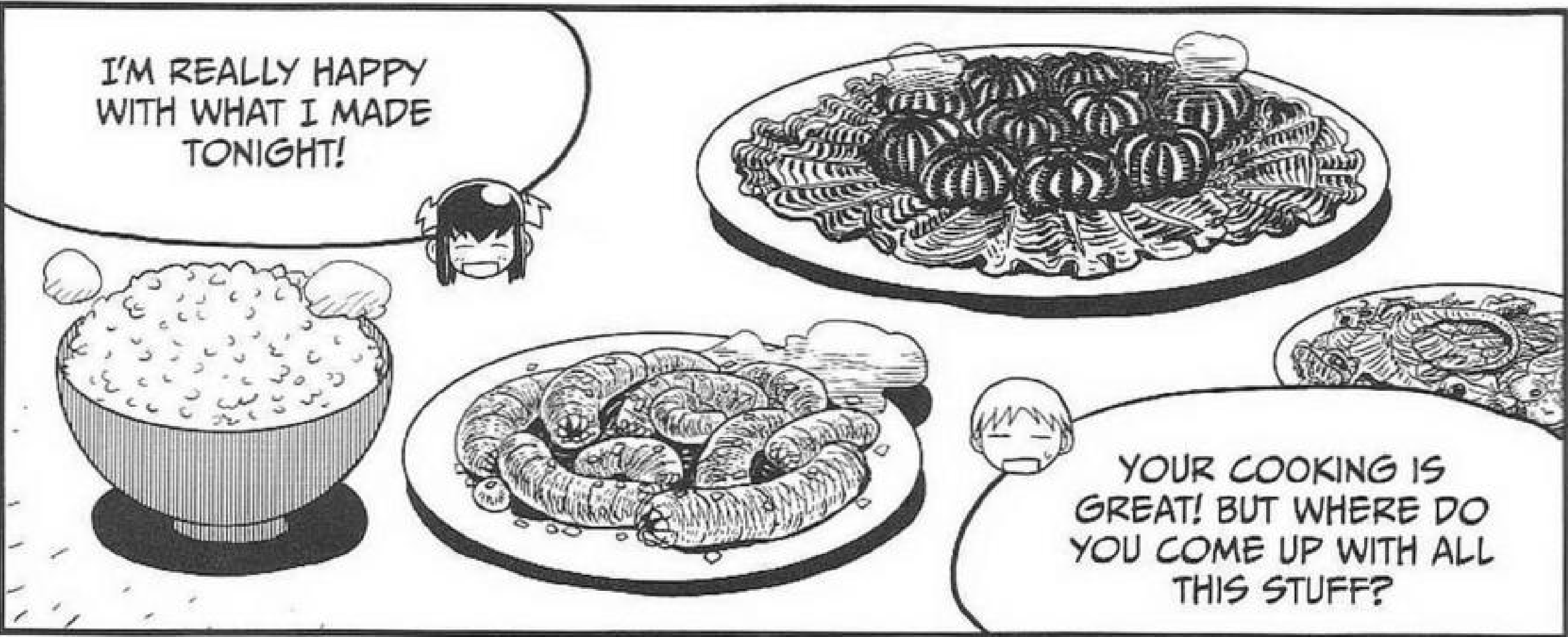
Leading current flowing in a capacitor

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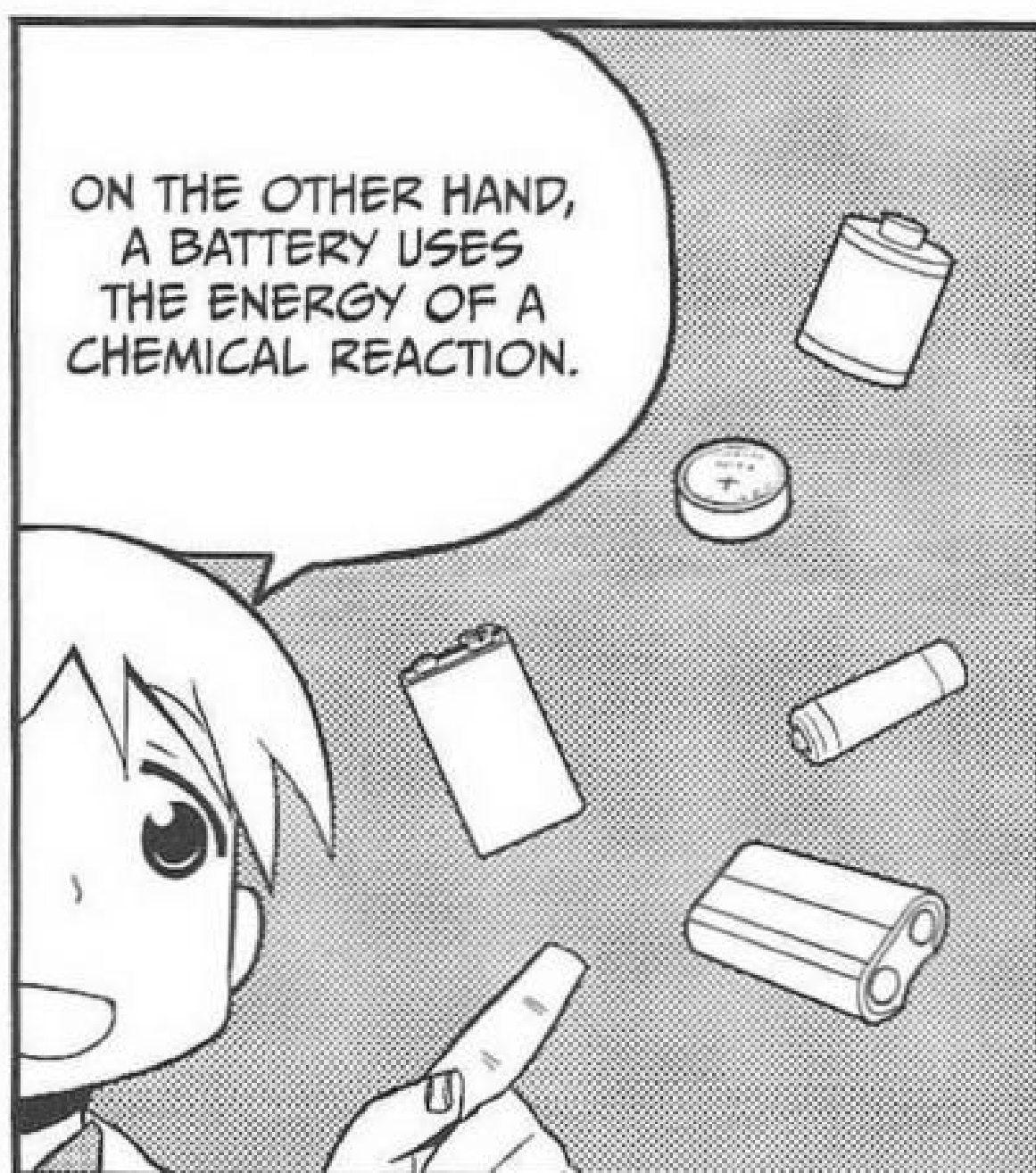
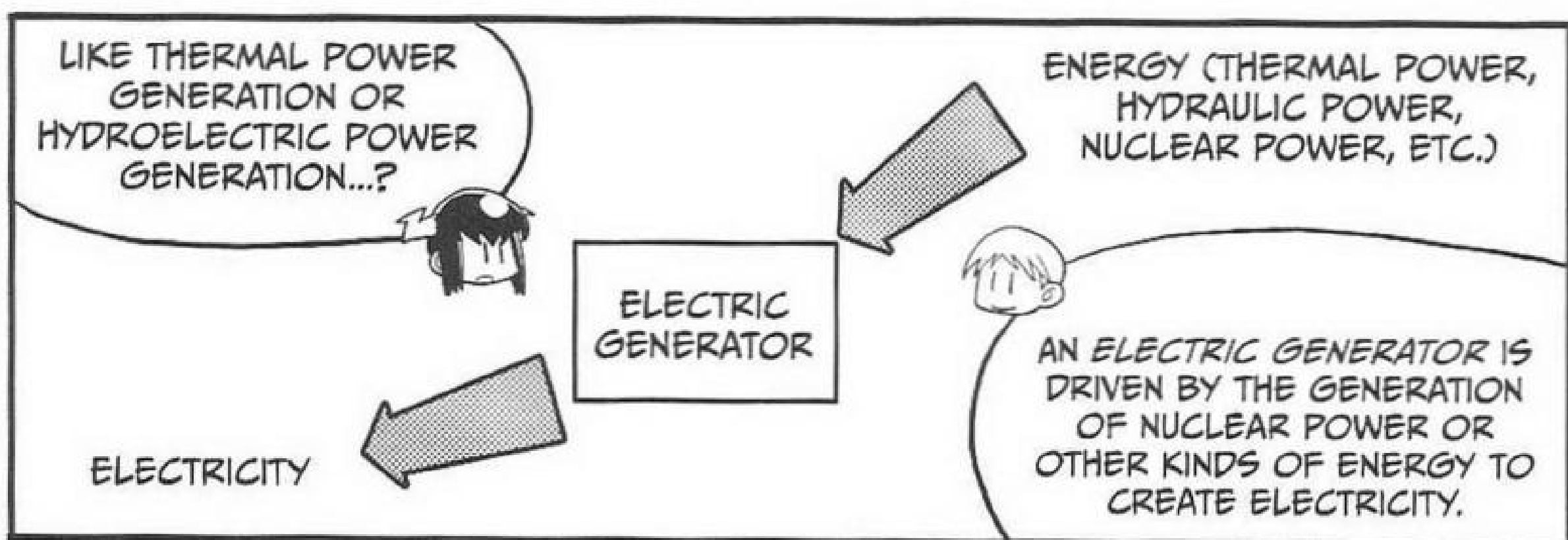
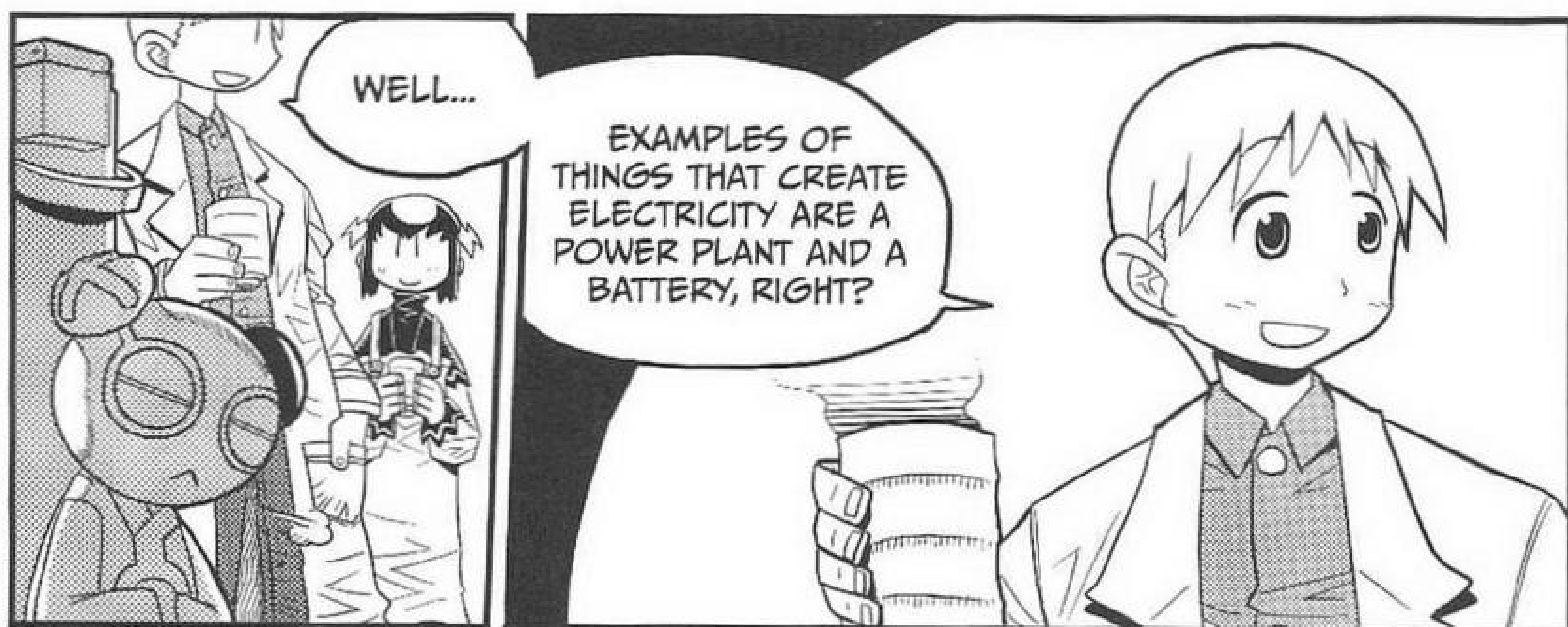
HOW DO YOU CREATE ELECTRICITY?



GENERATORS



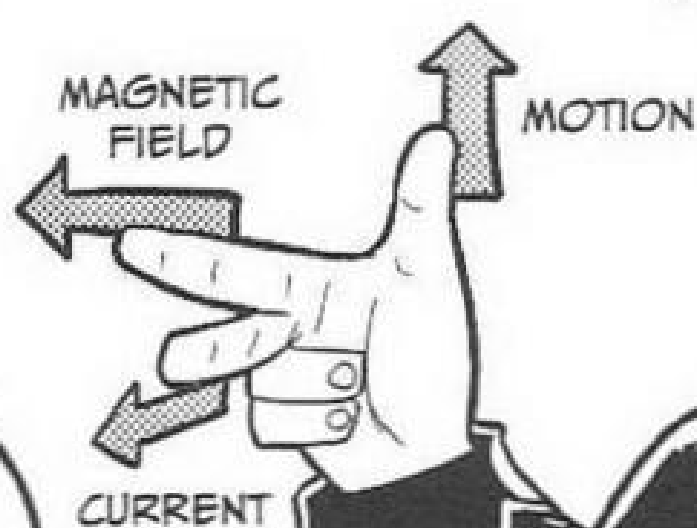




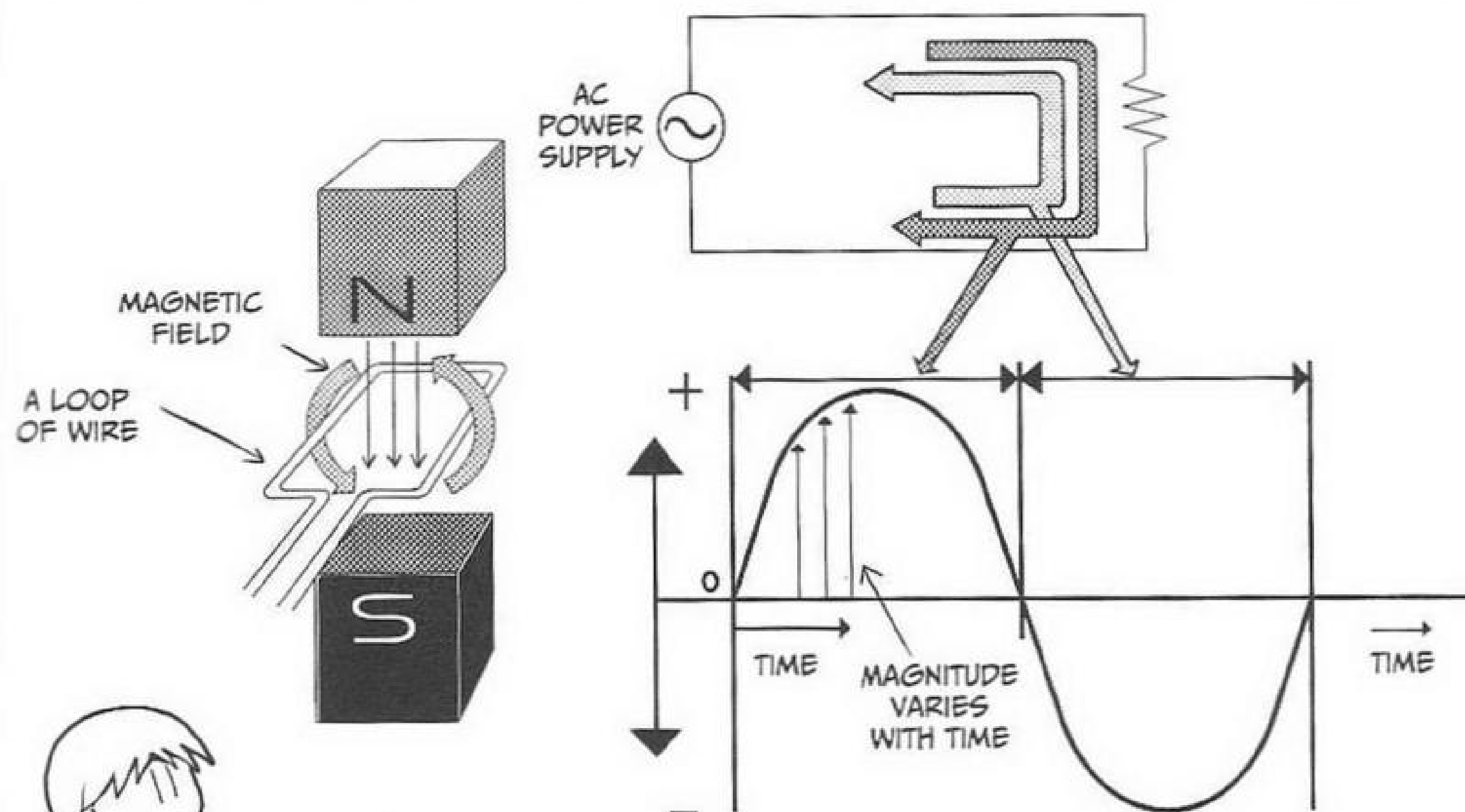


# HOW DOES A POWER GENERATOR CREATE ELECTRICITY?

FIRST, LET'S TALK ABOUT ELECTRICITY CREATED BY AN ELECTRIC GENERATOR. THE OTHER DAY, WE TALKED ABOUT ELECTRICITY BEING CREATED ACCORDING TO FLEMING'S RIGHT-HAND RULE.



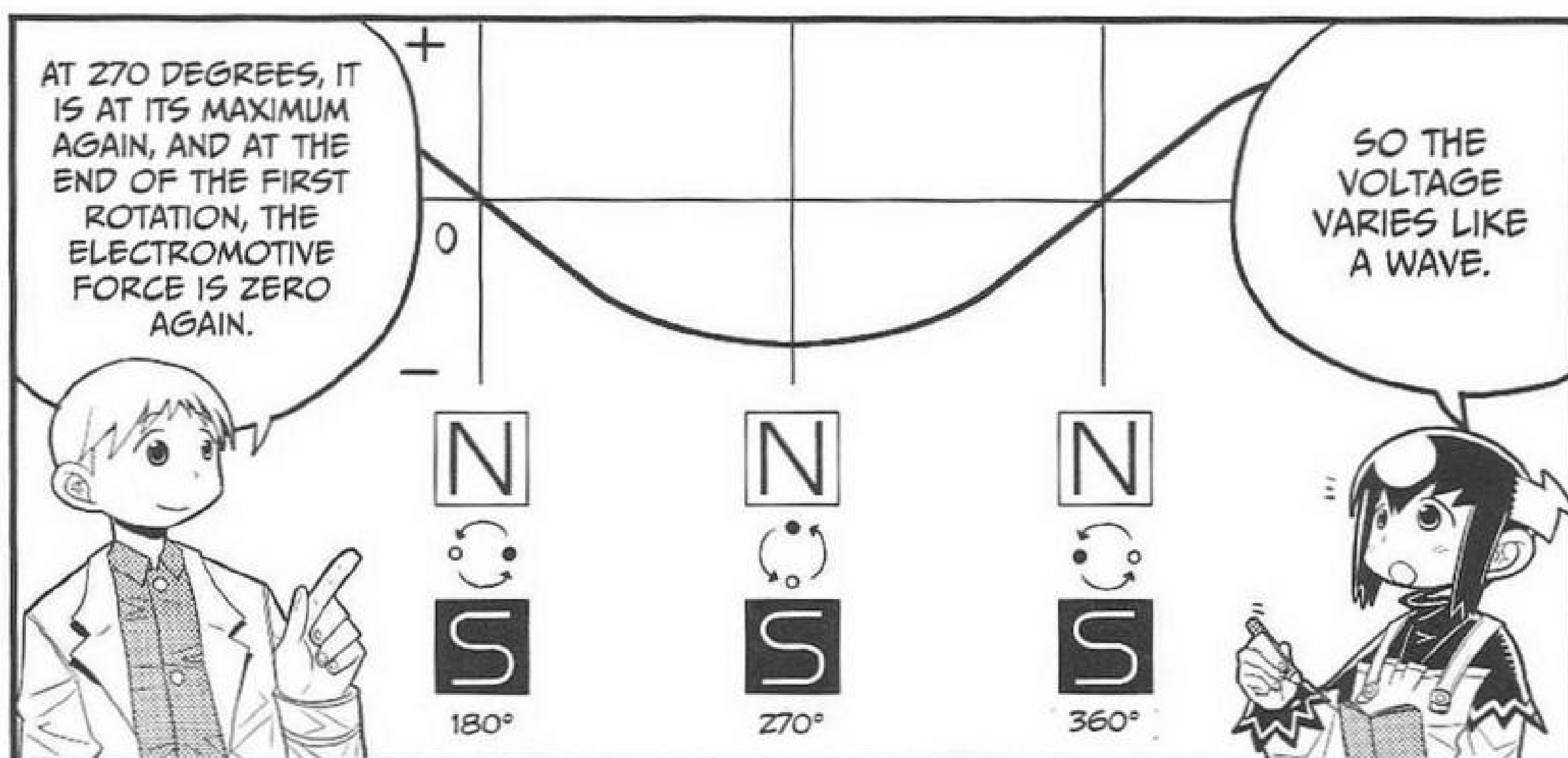
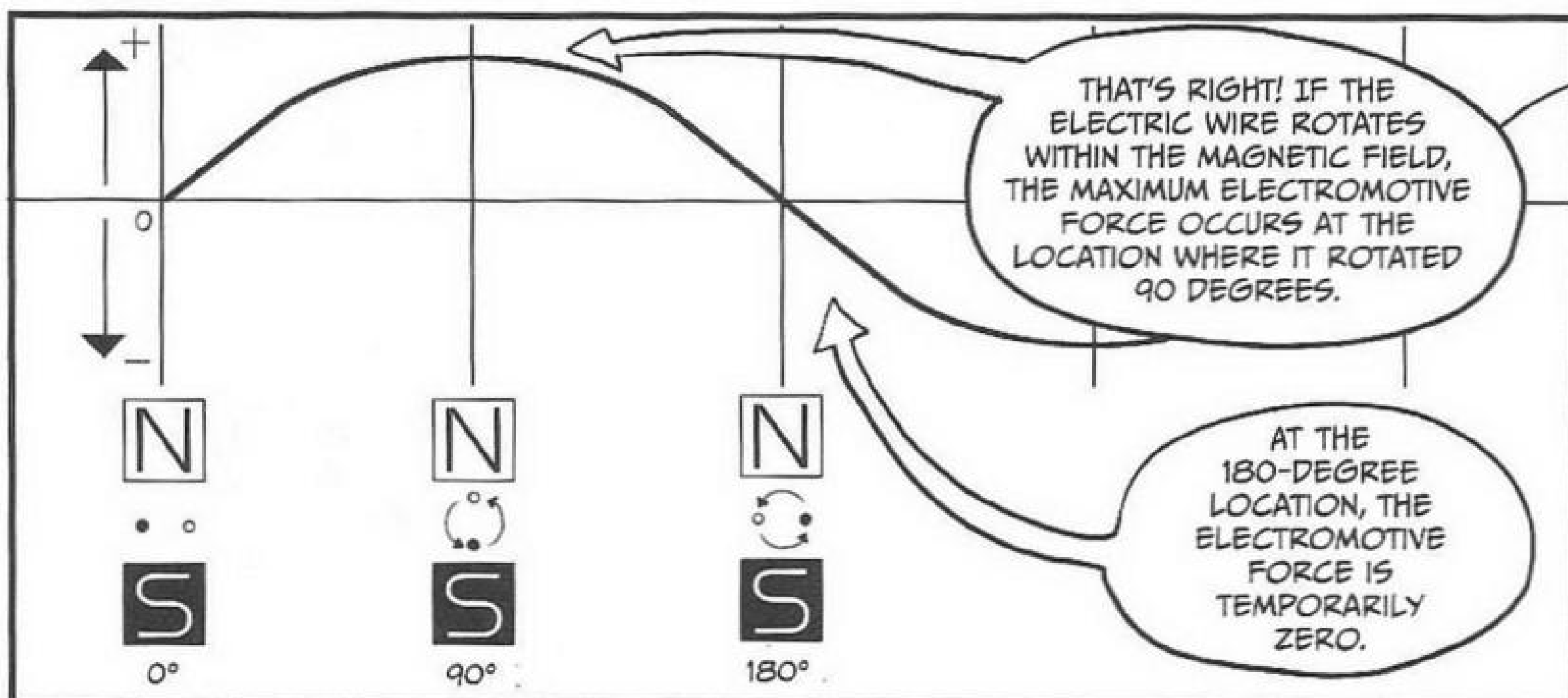
YEAH! IT'S THIS, RIGHT?



YES, BUT ACTUALLY, SINCE THE LOOP OF WIRE IS ROTATING WITHIN THE MAGNETIC FIELD, ELECTRICITY IS CREATED FOR WHICH BOTH THE MAGNITUDE AND DIRECTION OF FLOW VARY REPEATEDLY LIKE A WAVE.

THIS IS AC ELECTRICITY, RIGHT?





THE VOLTAGE OF AN ORDINARY HOUSEHOLD ELECTRIC OUTLET IS 120V AC.

THIS VALUE IS CALLED THE **EFFECTIVE VOLTAGE**. IT IS THE VOLTAGE VALUE FOR WHICH THE AMOUNT OF HEAT THAT OCCURS WHEN AN AC POWER SUPPLY IS APPLIED TO A RESISTANCE IS THE SAME AS THE AMOUNT OF HEAT THAT OCCURS WHEN A DC POWER SUPPLY IS APPLIED TO THE SAME RESISTANCE.

DIRECT CURRENT (DC)  
120V

ALTERNATING CURRENT (AC)  
120V

AMOUNT OF HEAT GENERATED IS THE SAME

HUH?

SO YOU'RE SAYING THAT WHEN 120V DC AND 120V AC ARE EACH APPLIED TO THE SAME RESISTANCE, THE SAME HEAT IS PRODUCED.

YEAH, BUT ALTERNATING CURRENT HAS A WAVE...

PEAK VOLTAGE 170V  
EFFECTIVE VOLTAGE 120V

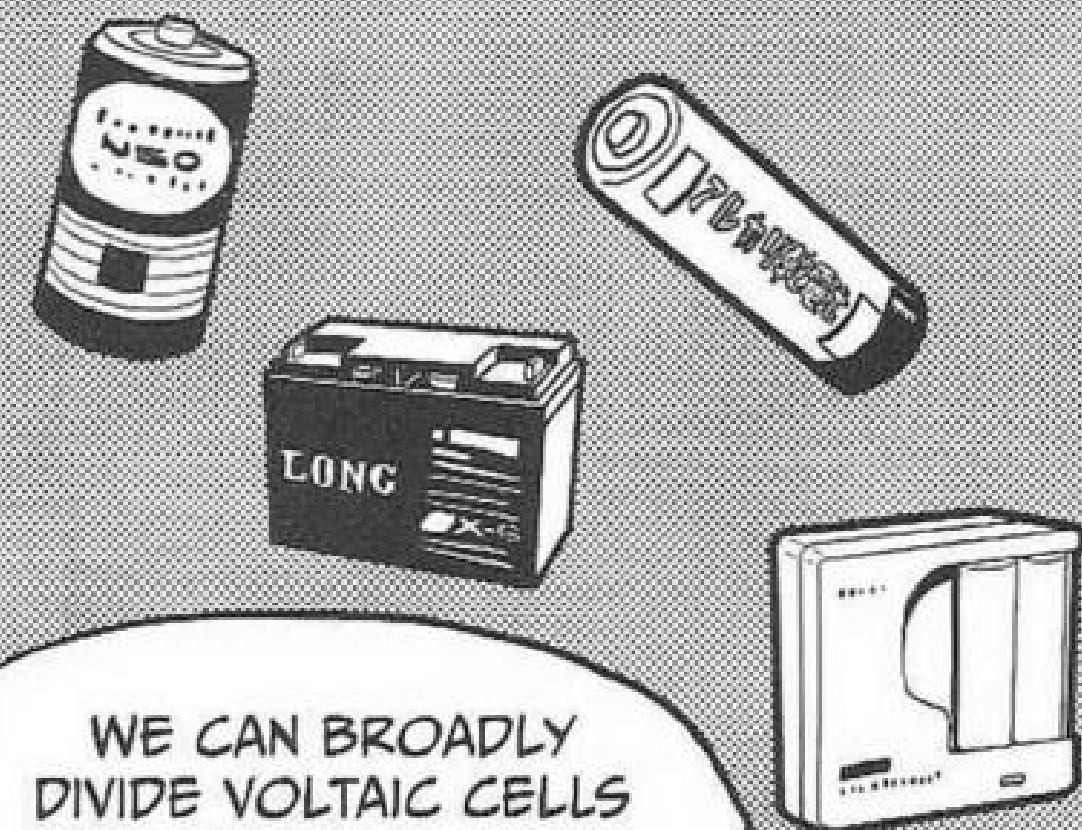
ALTHOUGH THE VOLTAGE (EFFECTIVE VOLTAGE) OF THE ELECTRIC OUTLET IS 120V AC, THE VOLTAGE AT THE POINT WHERE THE WAVE HAS THE GREATEST MAGNITUDE IS CALLED THE **PEAK VOLTAGE**, AND THIS IS APPROXIMATELY 170V.

## BATTERIES AND OTHER SOURCES OF ELECTRICITY

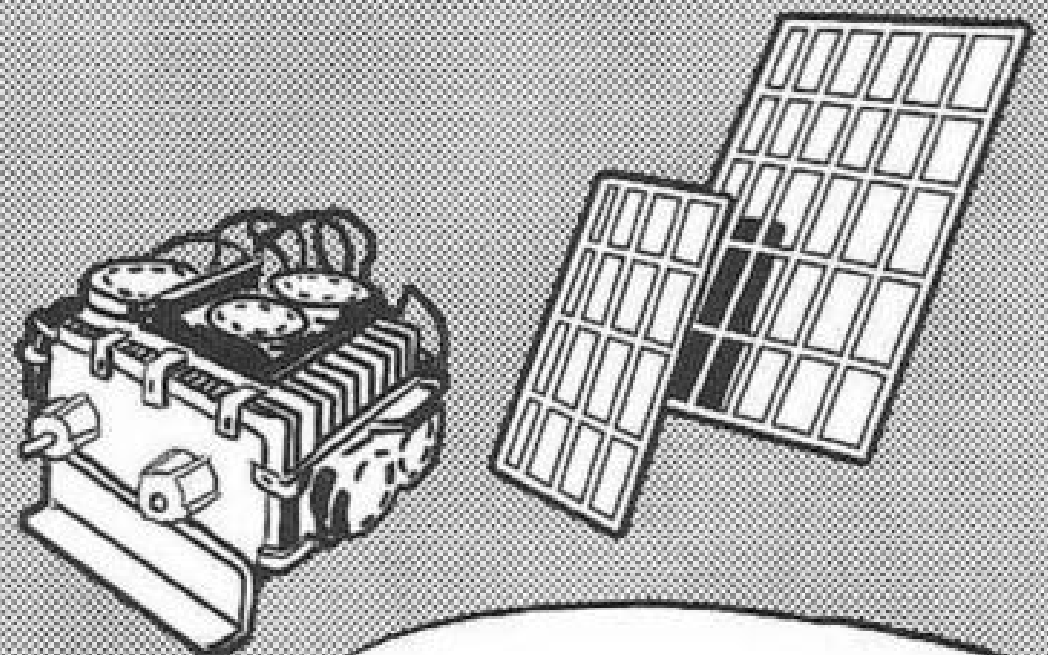
LET'S TALK ABOUT HOW TO CREATE ELECTRICITY.

BATTERIES ARE JUST ONE SOURCE OF ELECTRICITY. A MORE GENERAL TERM FOR THESE DEVICES IS VOLTAIC CELLS.

YEP, I KNOW THAT.



WE CAN BROADLY DIVIDE VOLTAIC CELLS INTO CHEMICAL CELLS, WHICH USE A CHEMICAL REACTION, AND...



PHYSICAL CELLS, WHICH USE SOLAR OR THERMAL ENERGY.

SO THERE ARE TWO MAIN TYPES.

PHYSICAL CELL

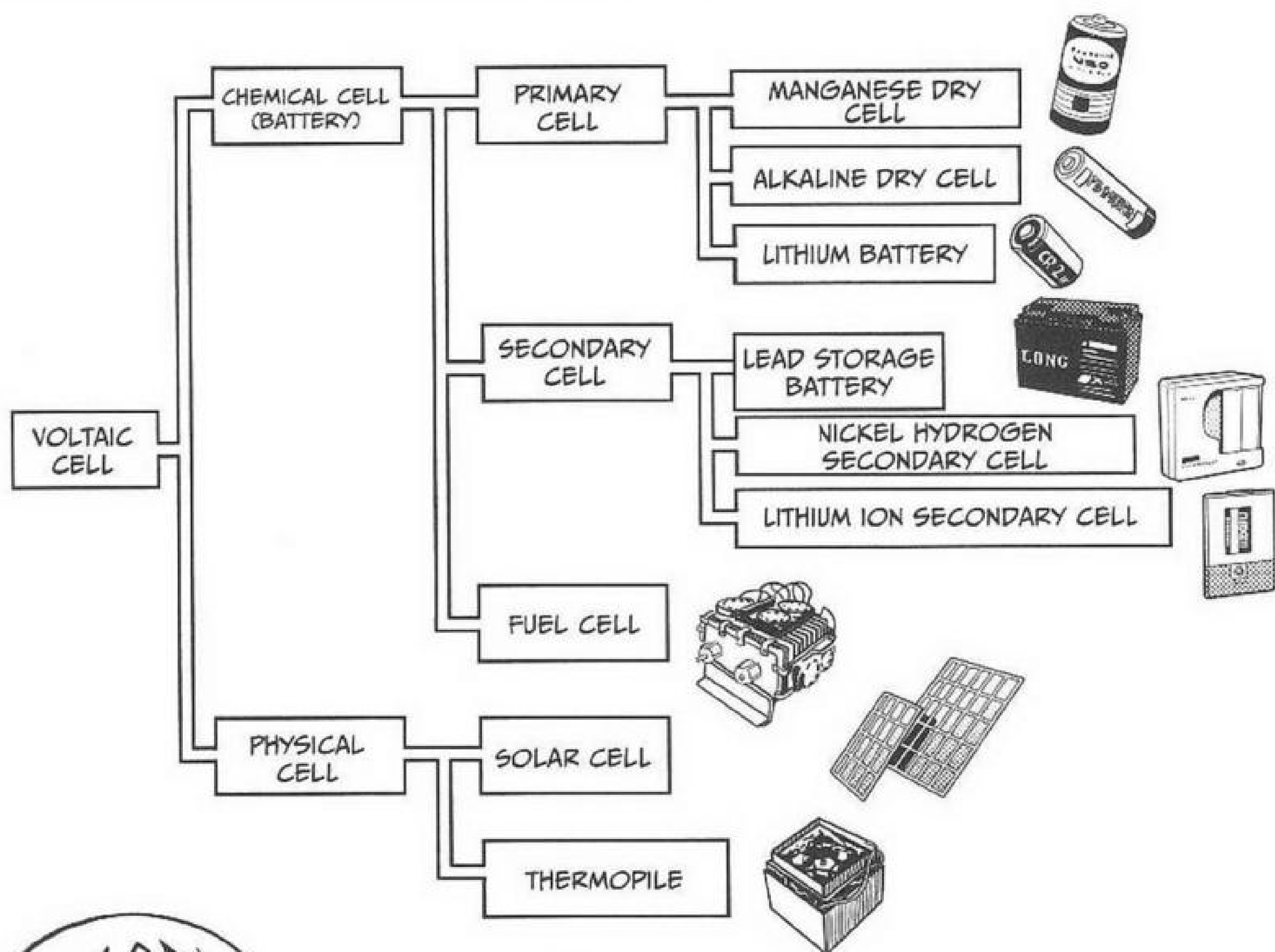
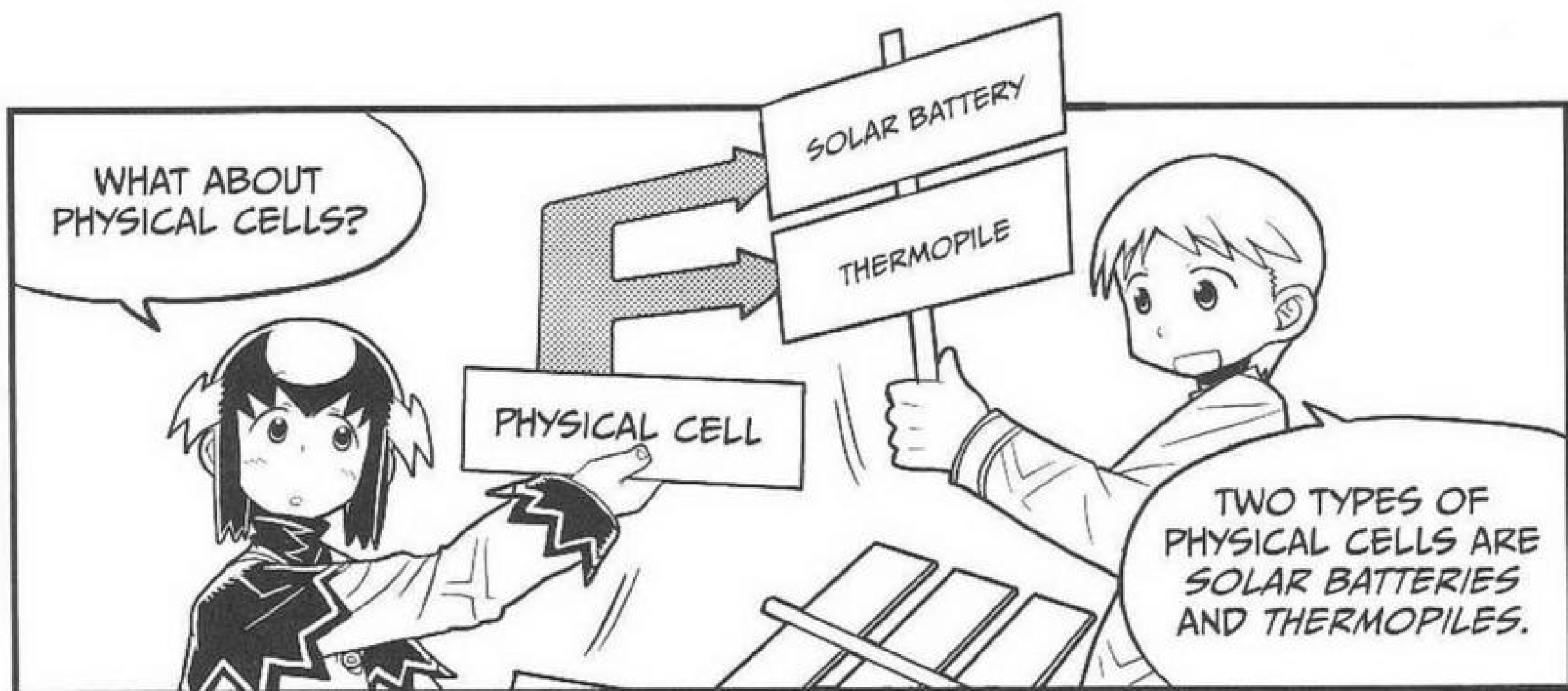
CHEMICAL CELL

PRIMARY CELL

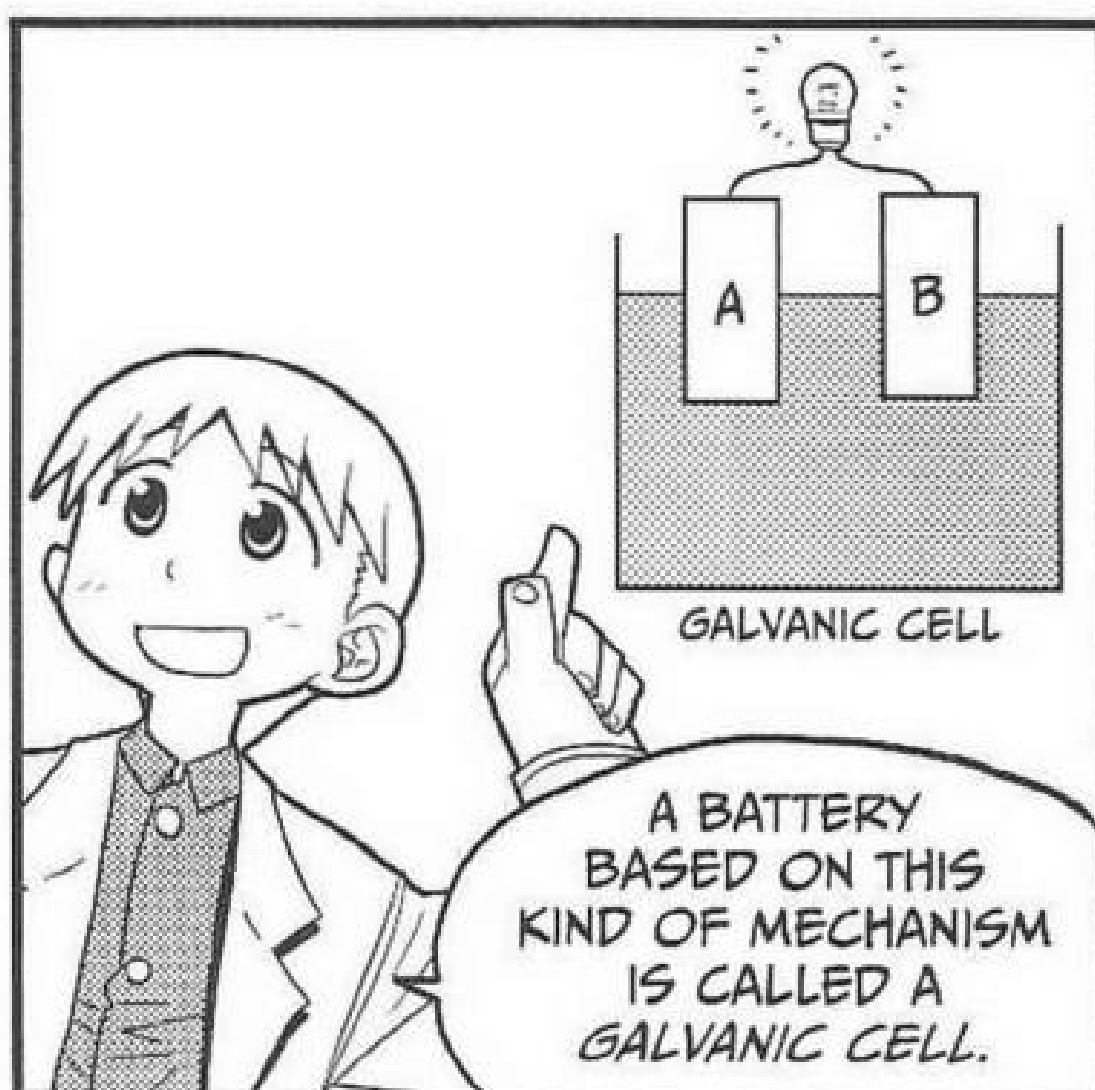
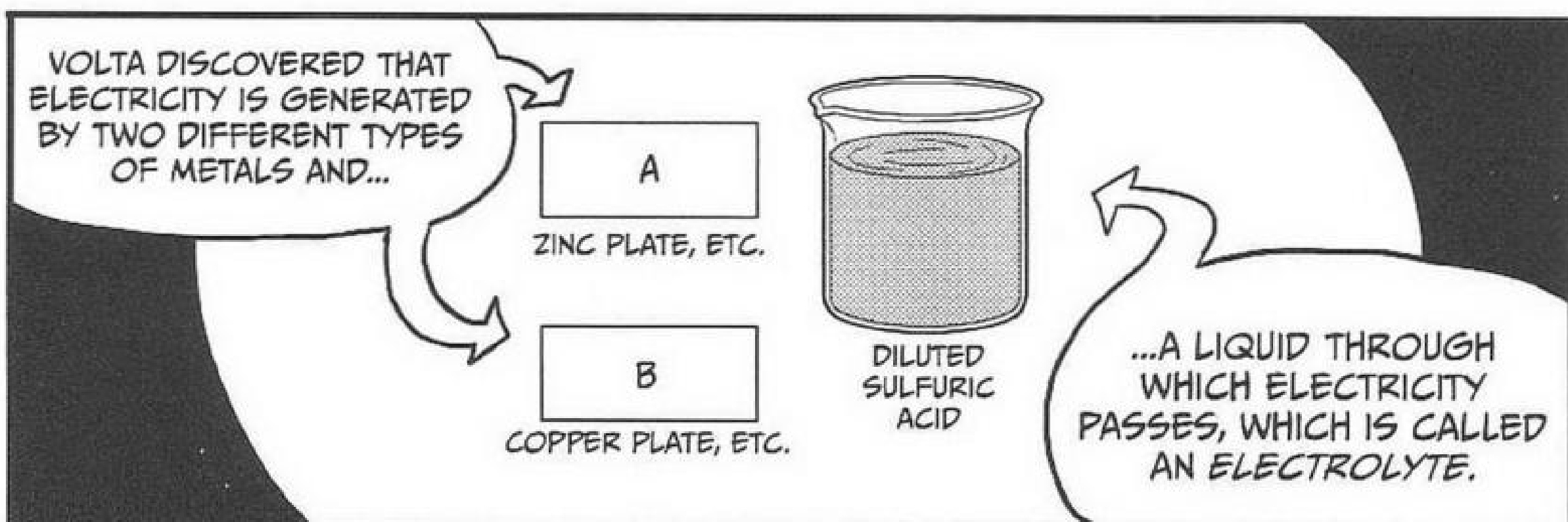
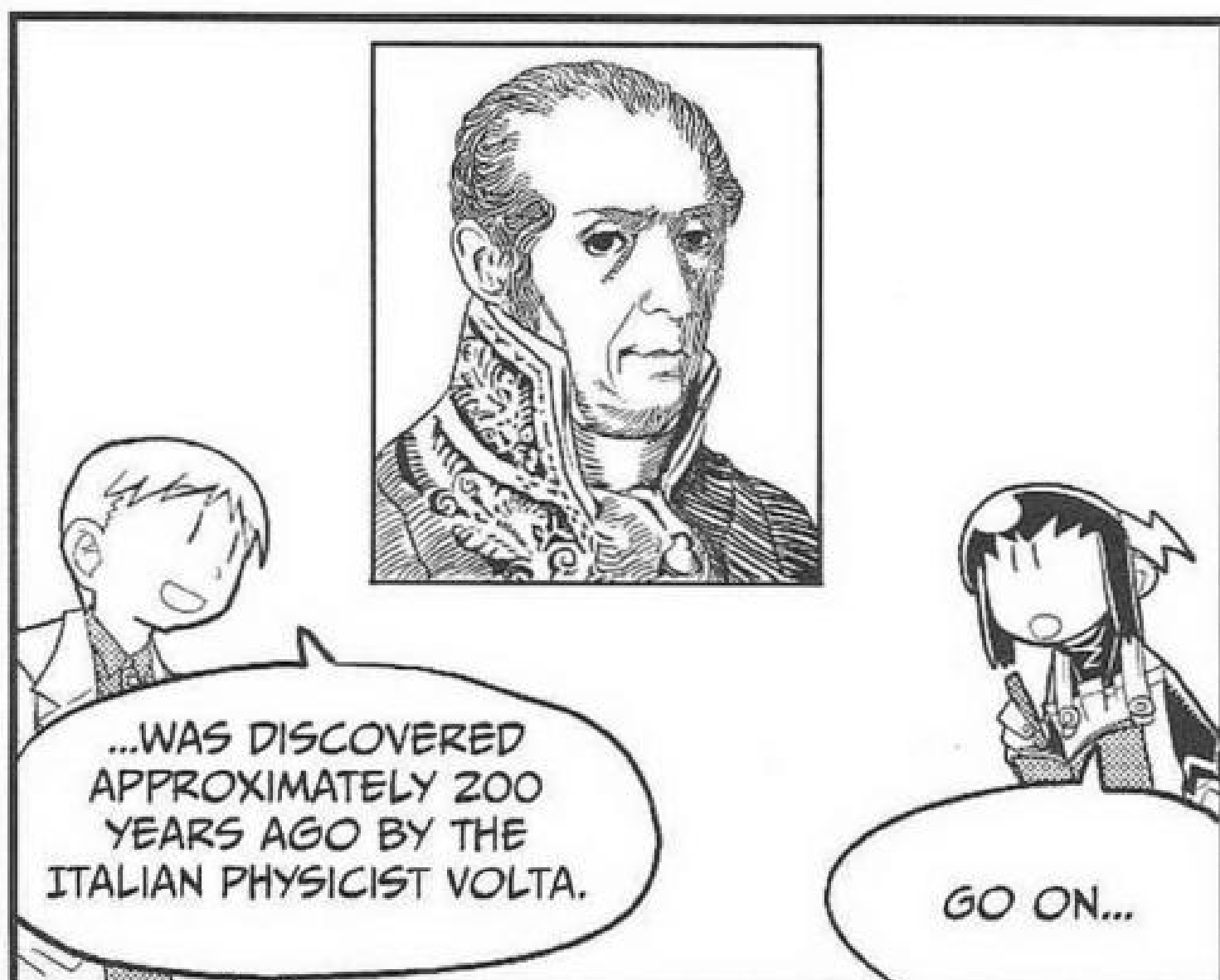
SECONDARY CELL

FUEL CELL

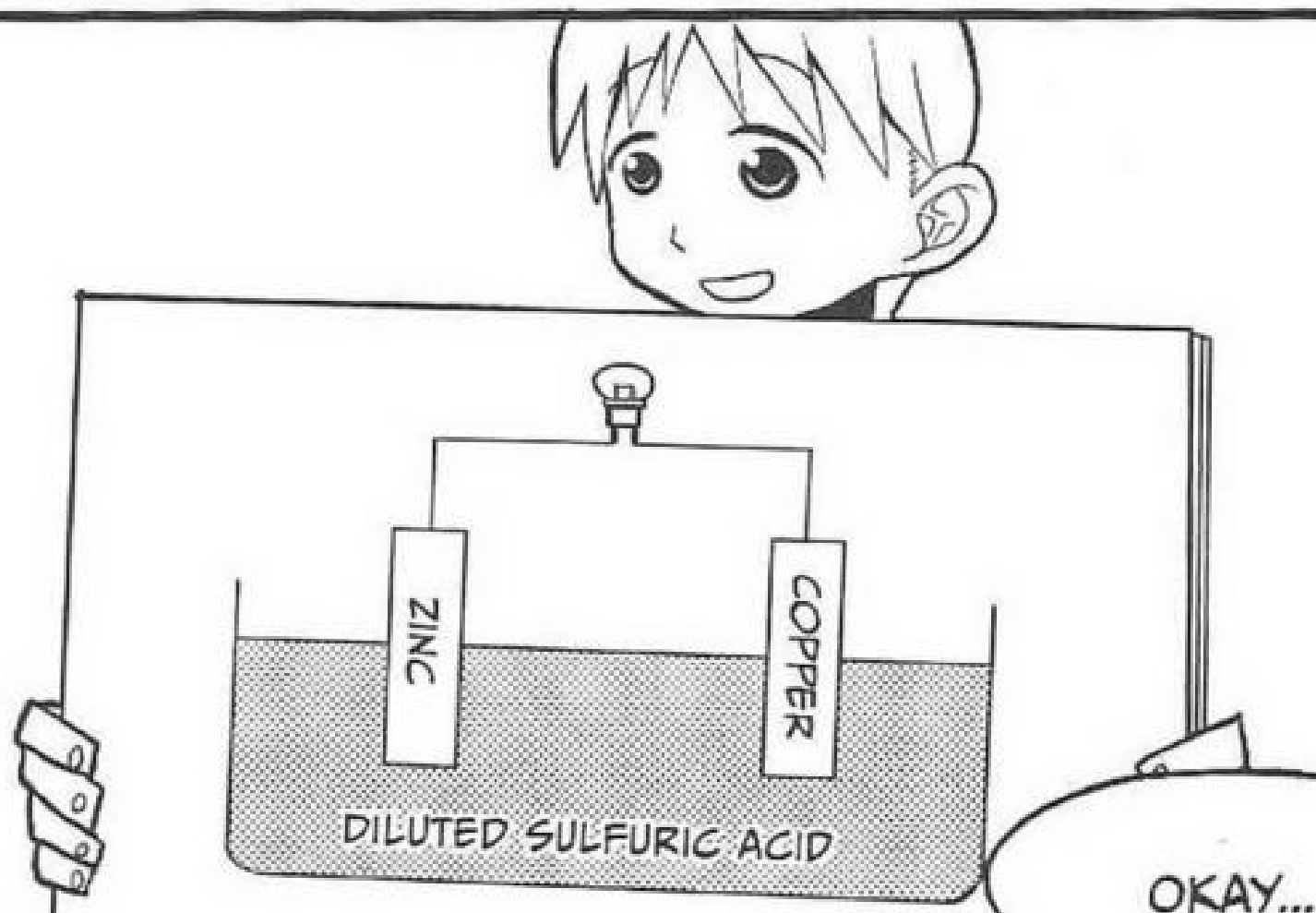
CHEMICAL CELLS CAN FURTHER BE DIVIDED INTO PRIMARY CELLS, WHICH CANNOT BE RECHARGED, SECONDARY CELLS, WHICH CAN BE RECHARGED AND REPEATEDLY USED, AND FUEL CELLS.



## CHEMICAL CELLS

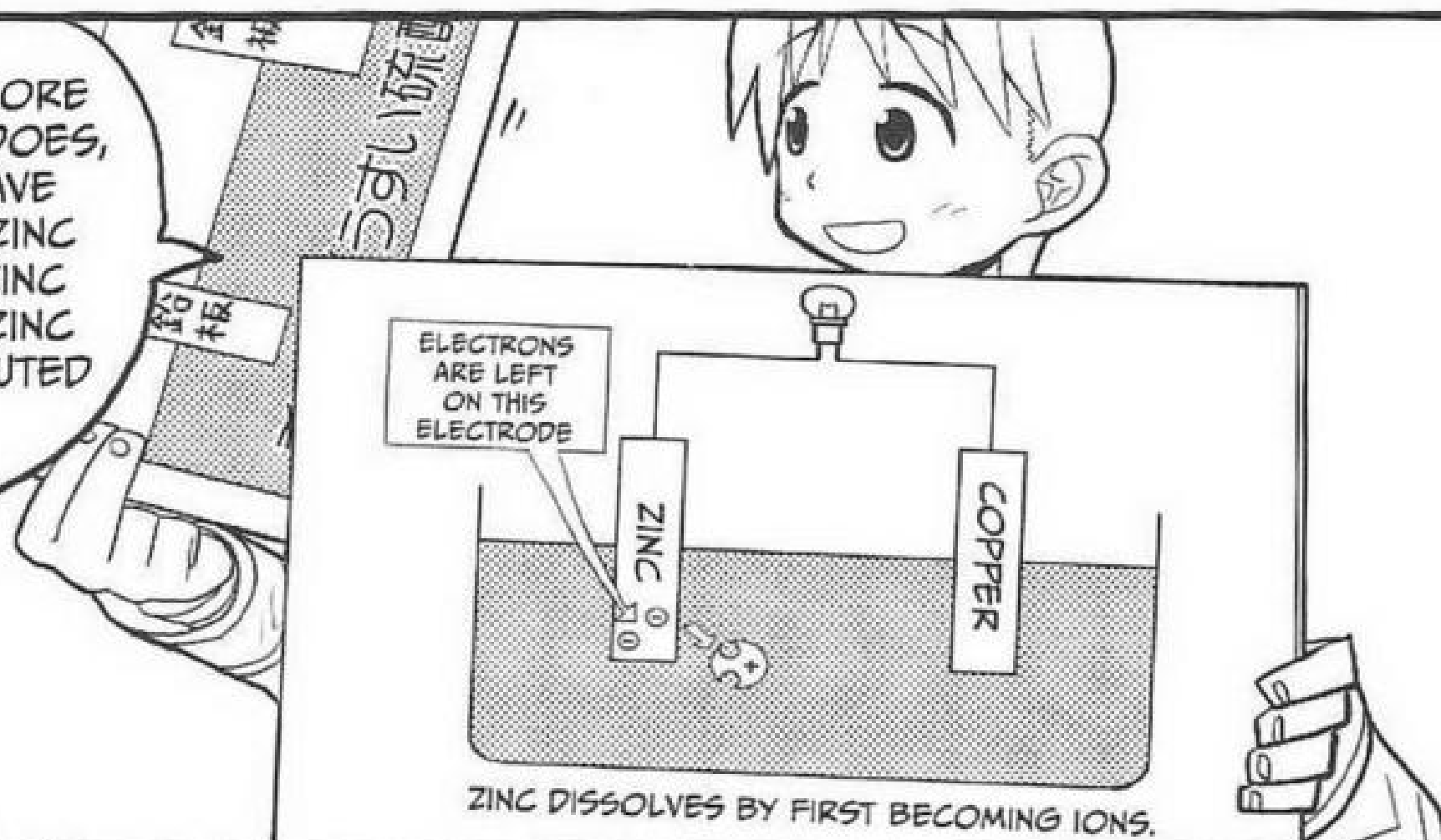


LET'S ASSUME THAT A ZINC PLATE AND A COPPER PLATE, WHICH ARE IMMERSSED IN DILUTED SULFURIC ACID, ARE CONNECTED BY A CONDUCTOR. THESE TWO PLATES ARE CALLED **ELECTRODES**.



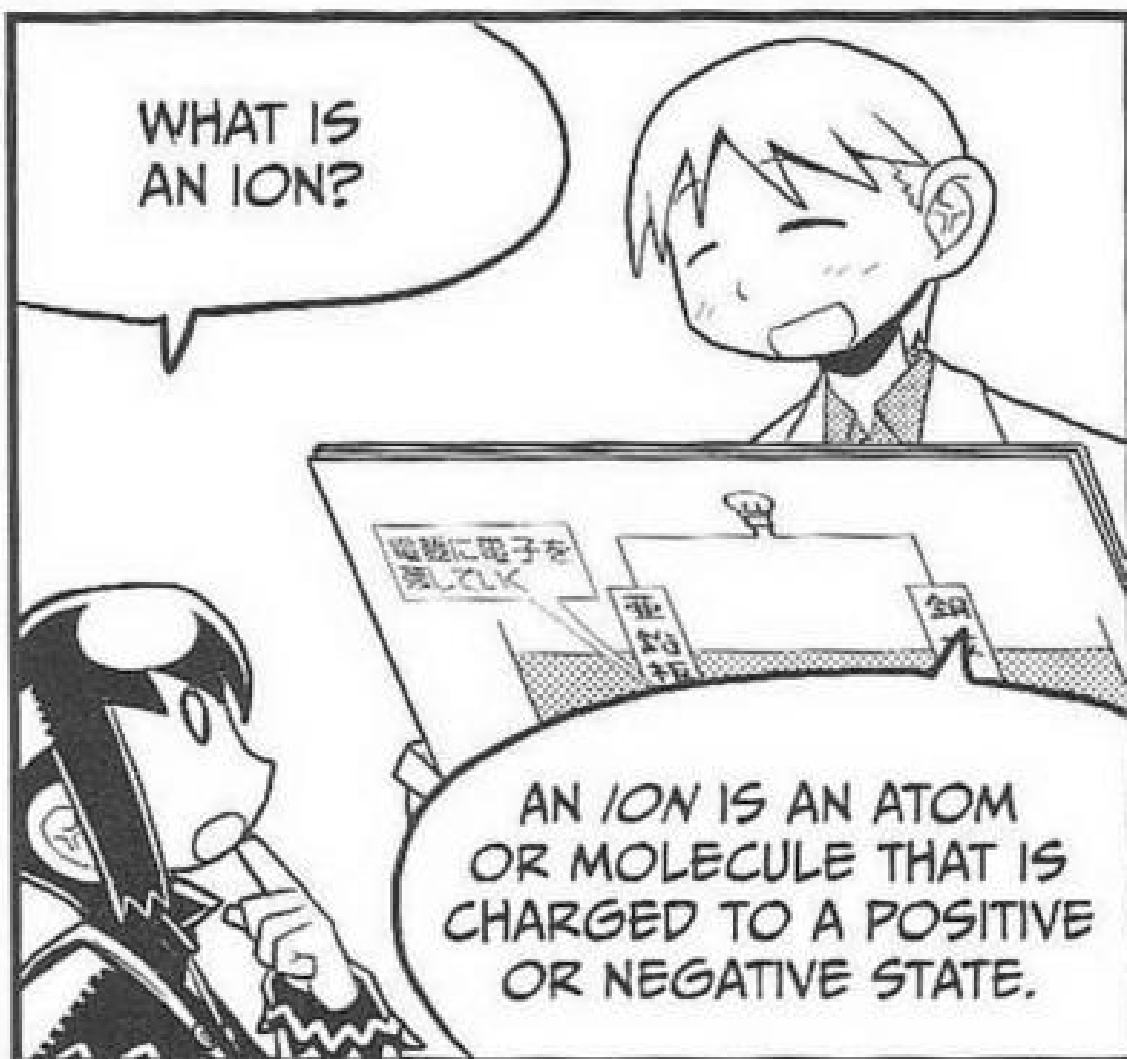
OKAY...

SINCE ZINC IONIZES MORE EASILY THAN COPPER DOES, THE ZINC ATOMS LEAVE ELECTRONS ON THE ZINC PLATE TO BECOME ZINC IONS ( $\text{Zn}^{2+}$ ) AND THE ZINC DISSOLVES IN THE DILUTED SULFURIC ACID.

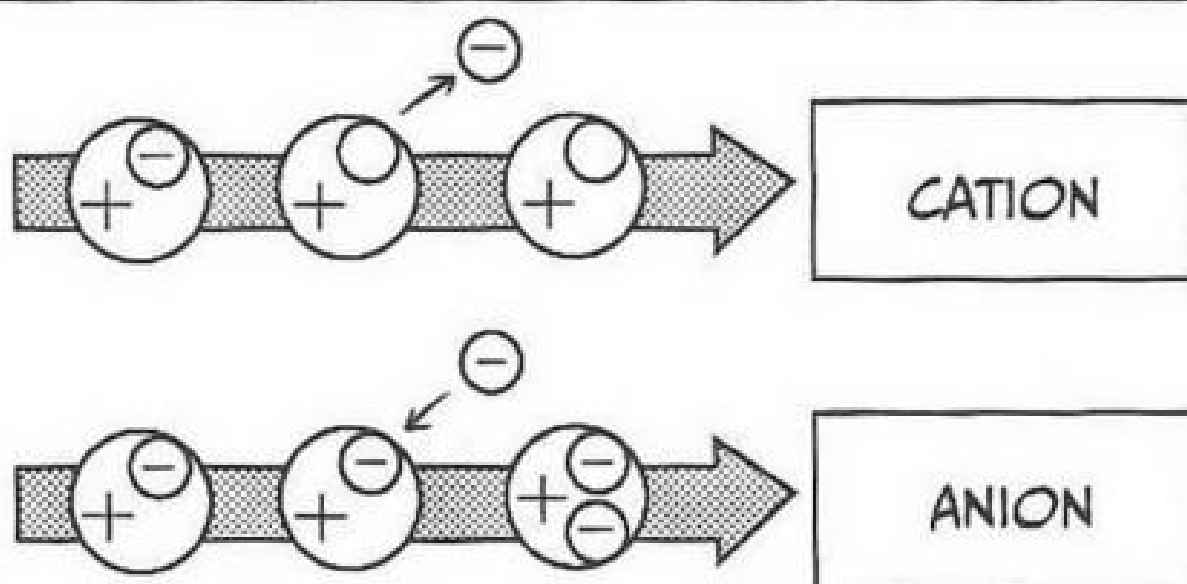


ZINC DISSOLVES BY FIRST BECOMING IONS.

WHAT IS AN ION?

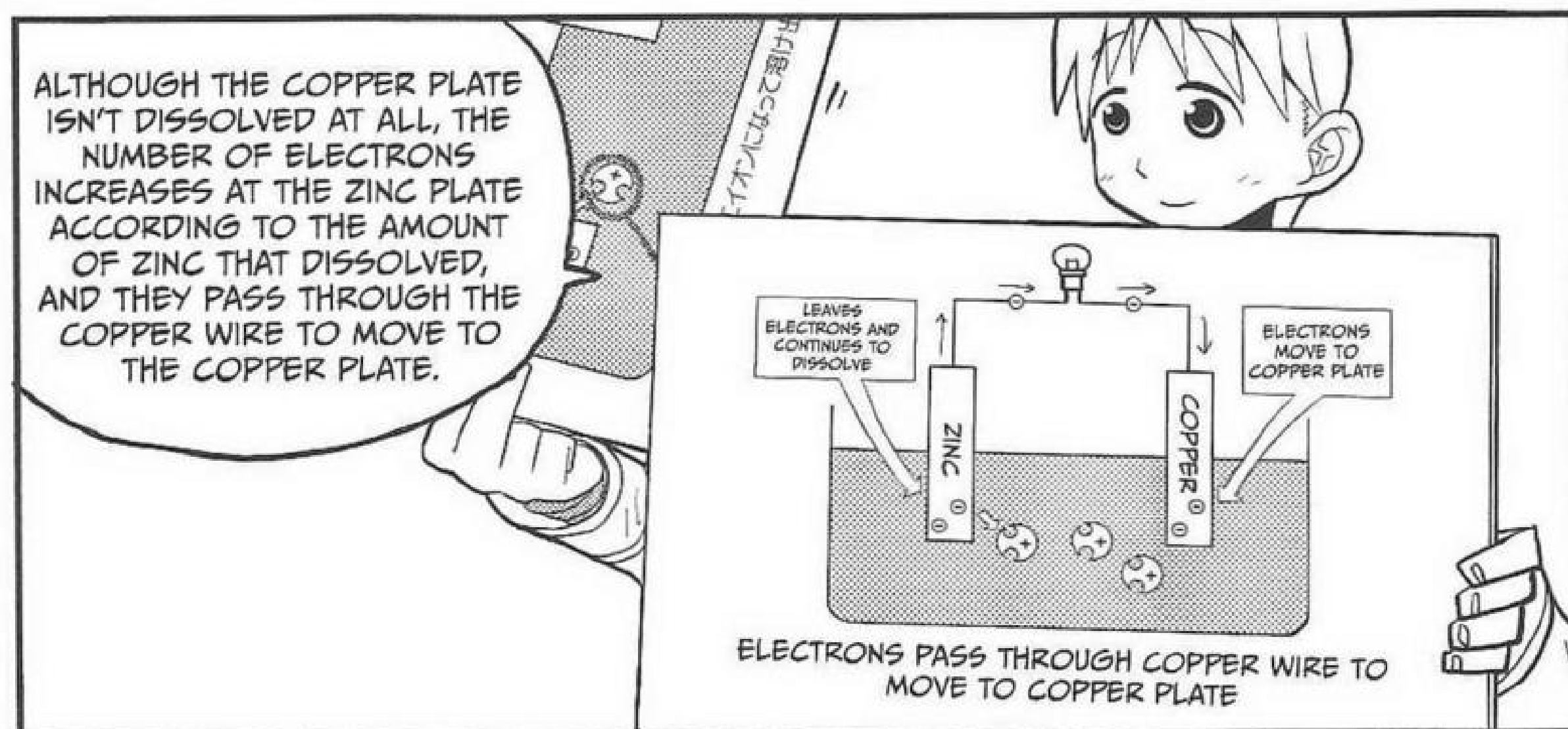
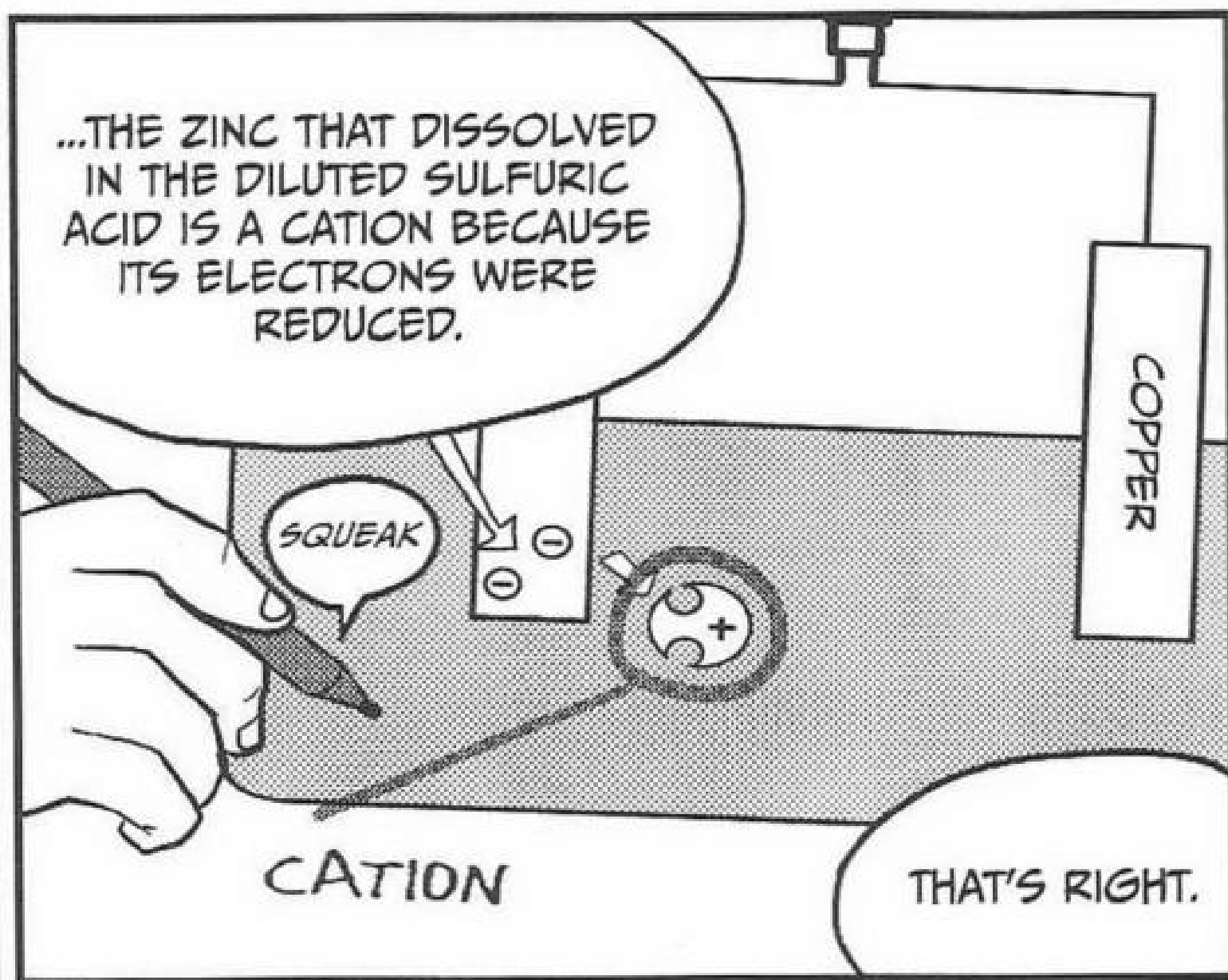


AN ION IS AN ATOM OR MOLECULE THAT IS CHARGED TO A POSITIVE OR NEGATIVE STATE.

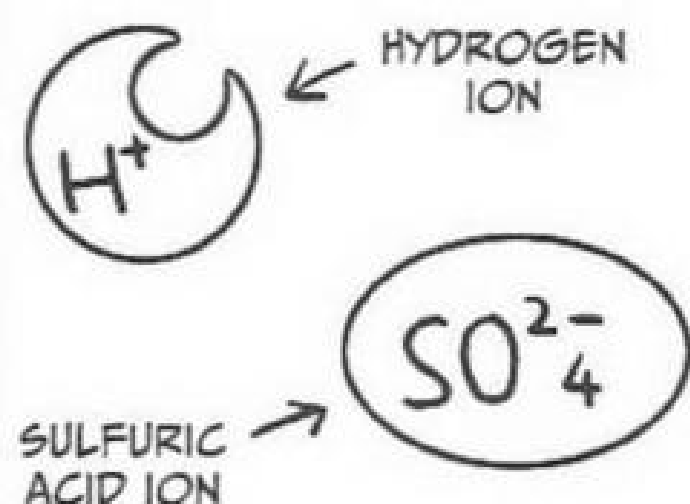


IF IT'S POSITIVE, IT'S CALLED A **CATION**, AND IF IT'S NEGATIVE, IT'S CALLED AN **ANION**.



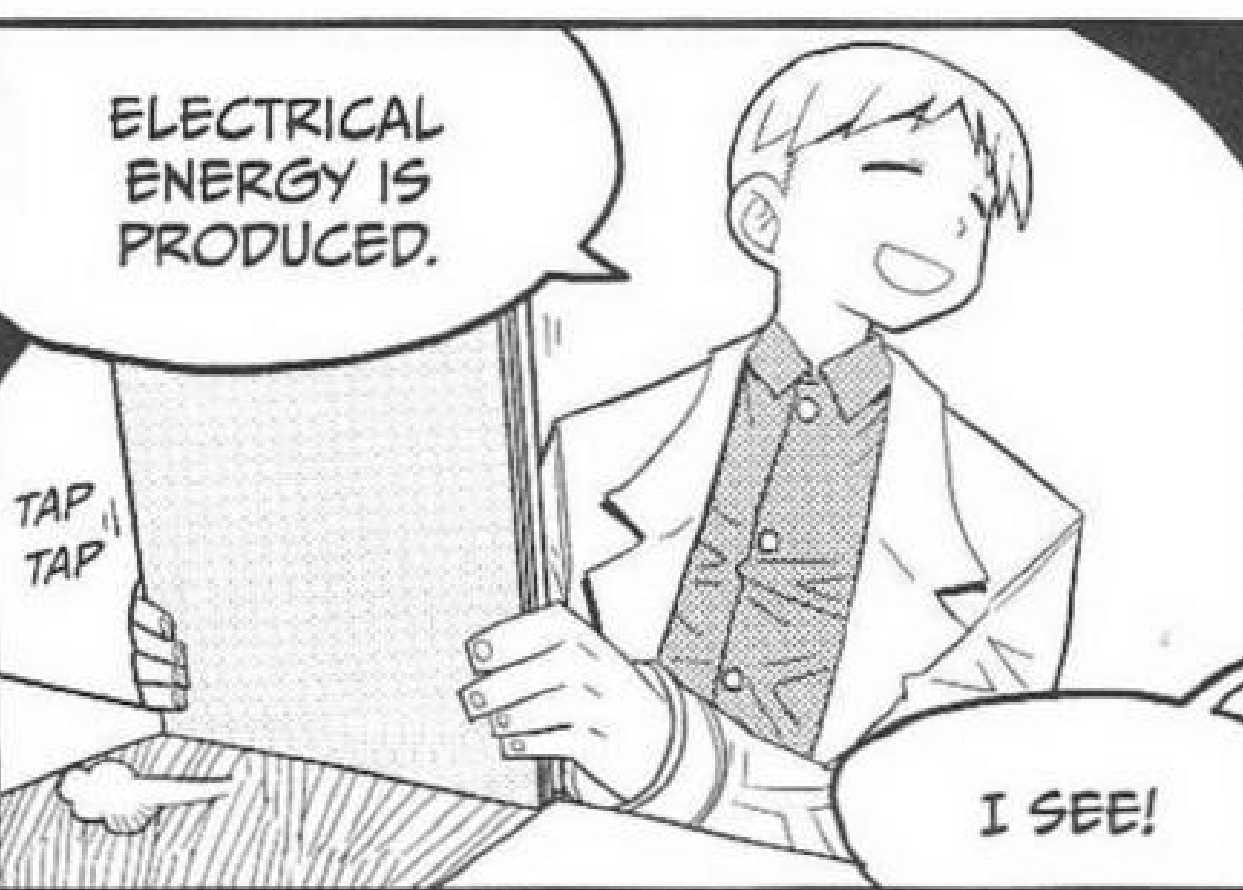
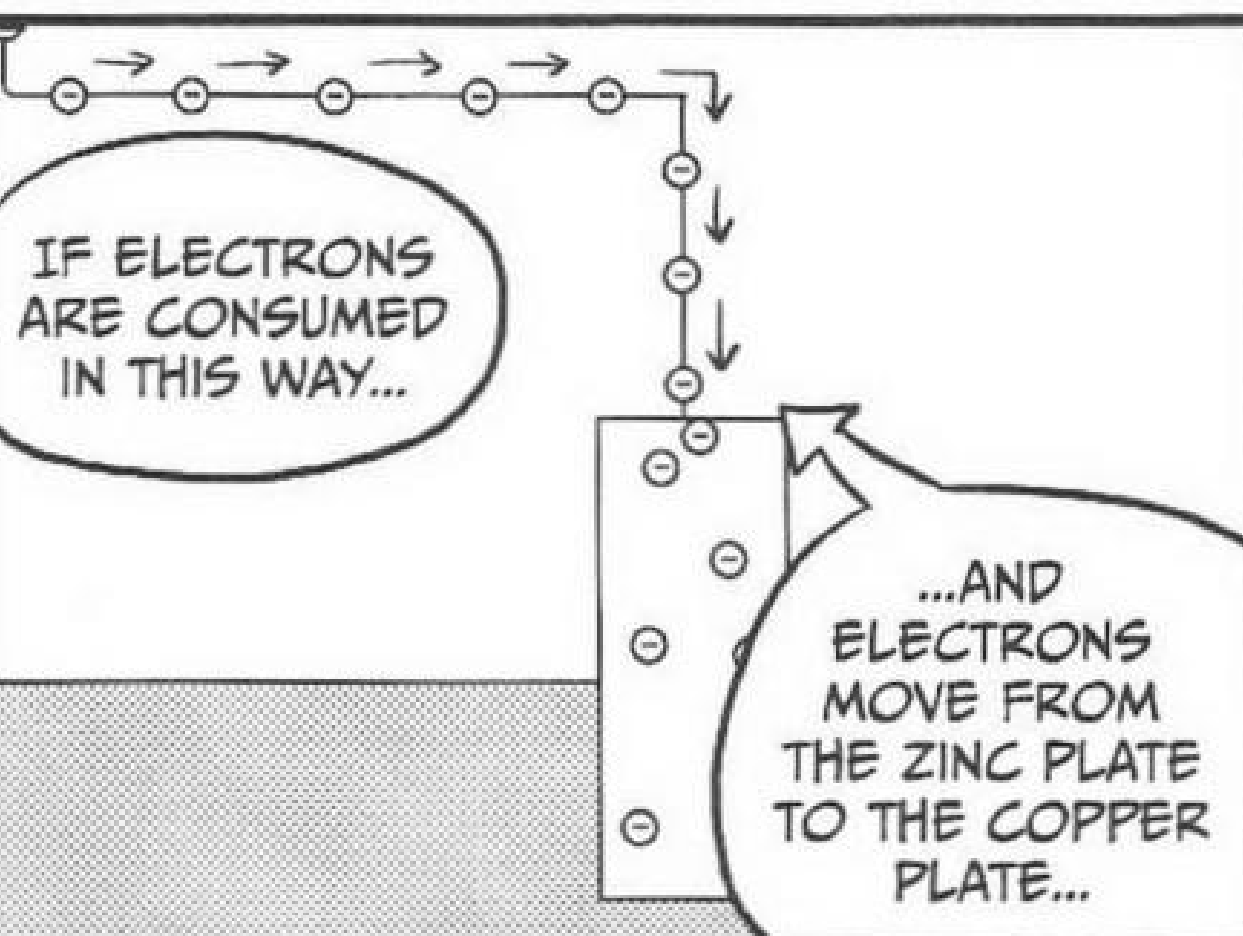
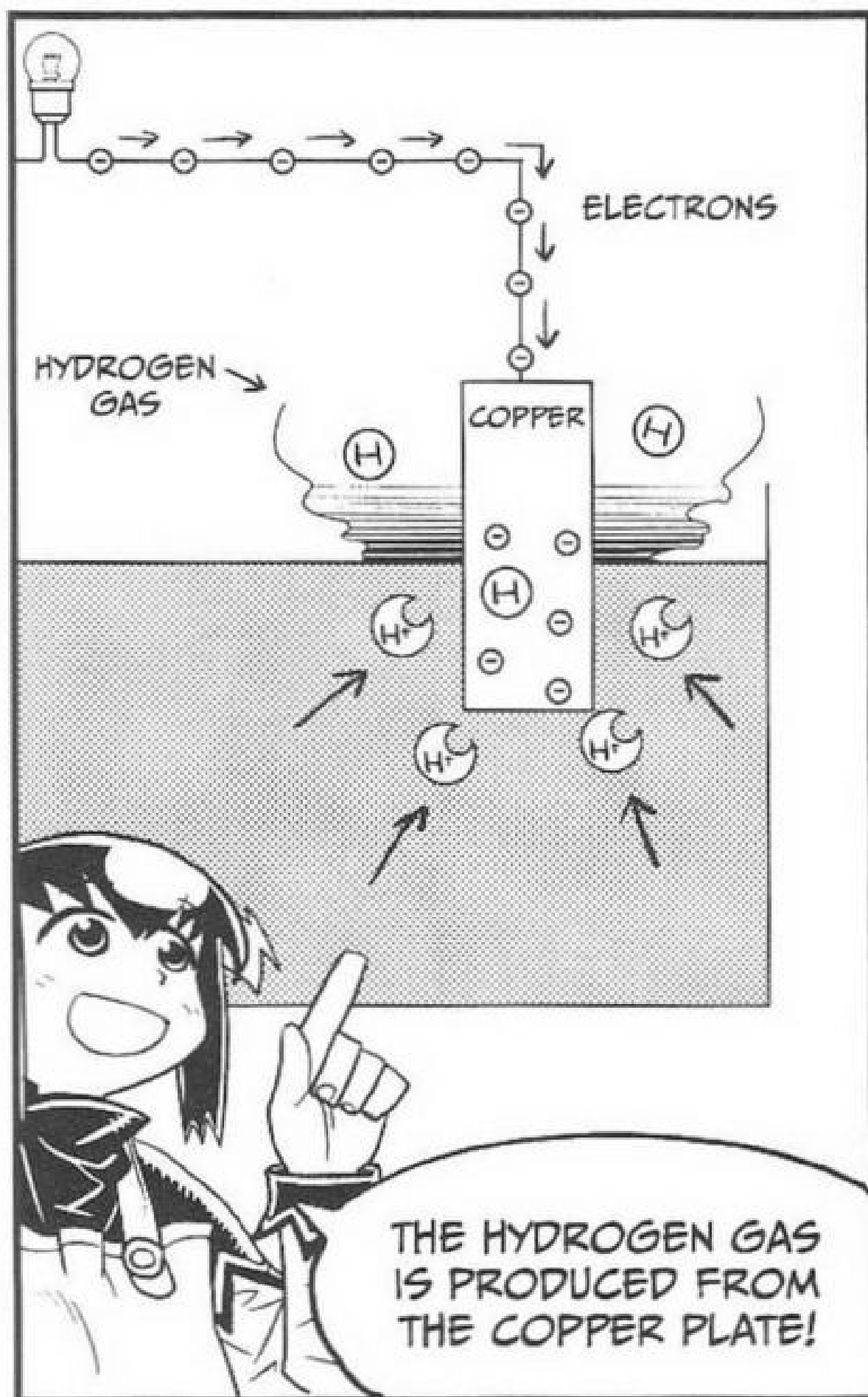
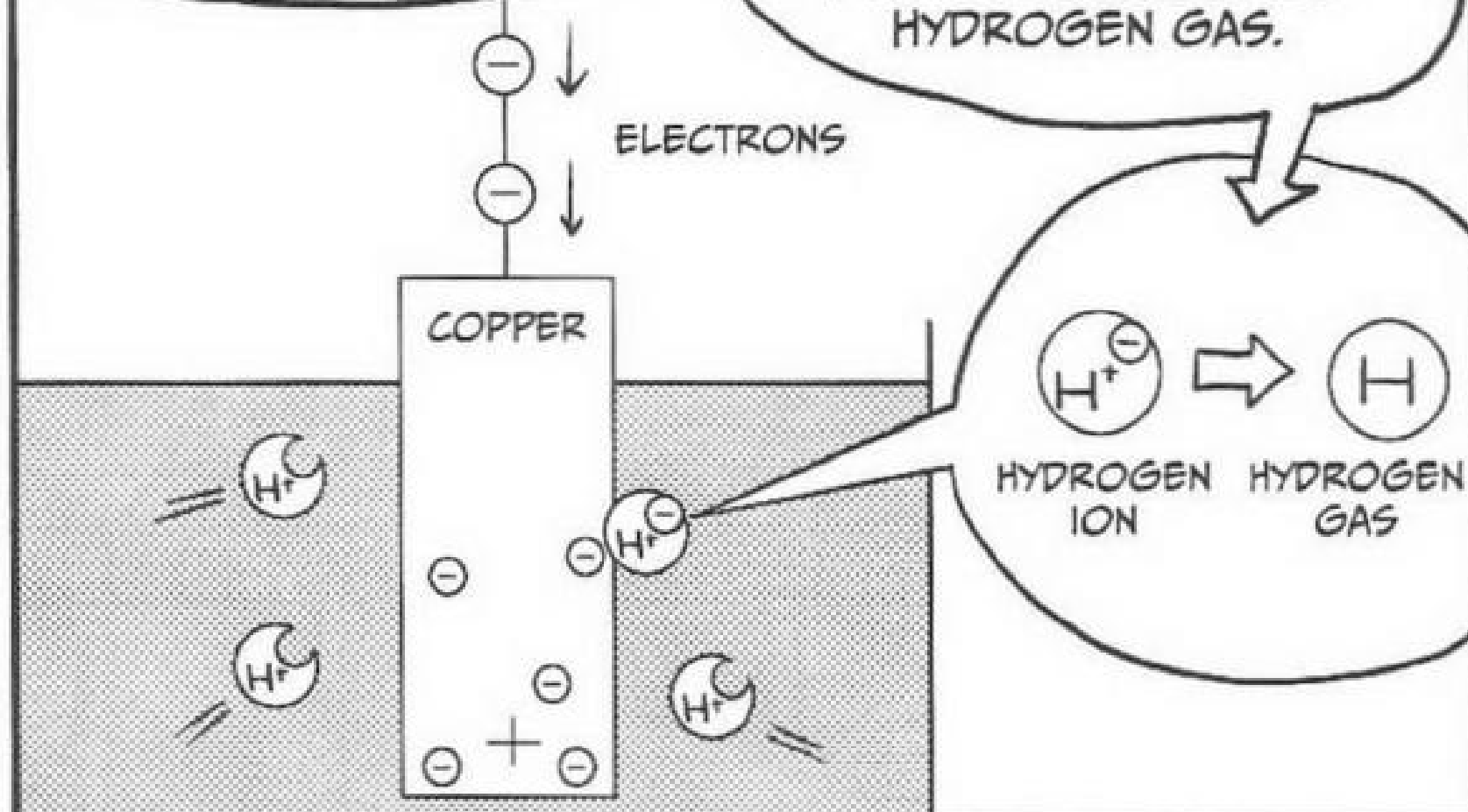


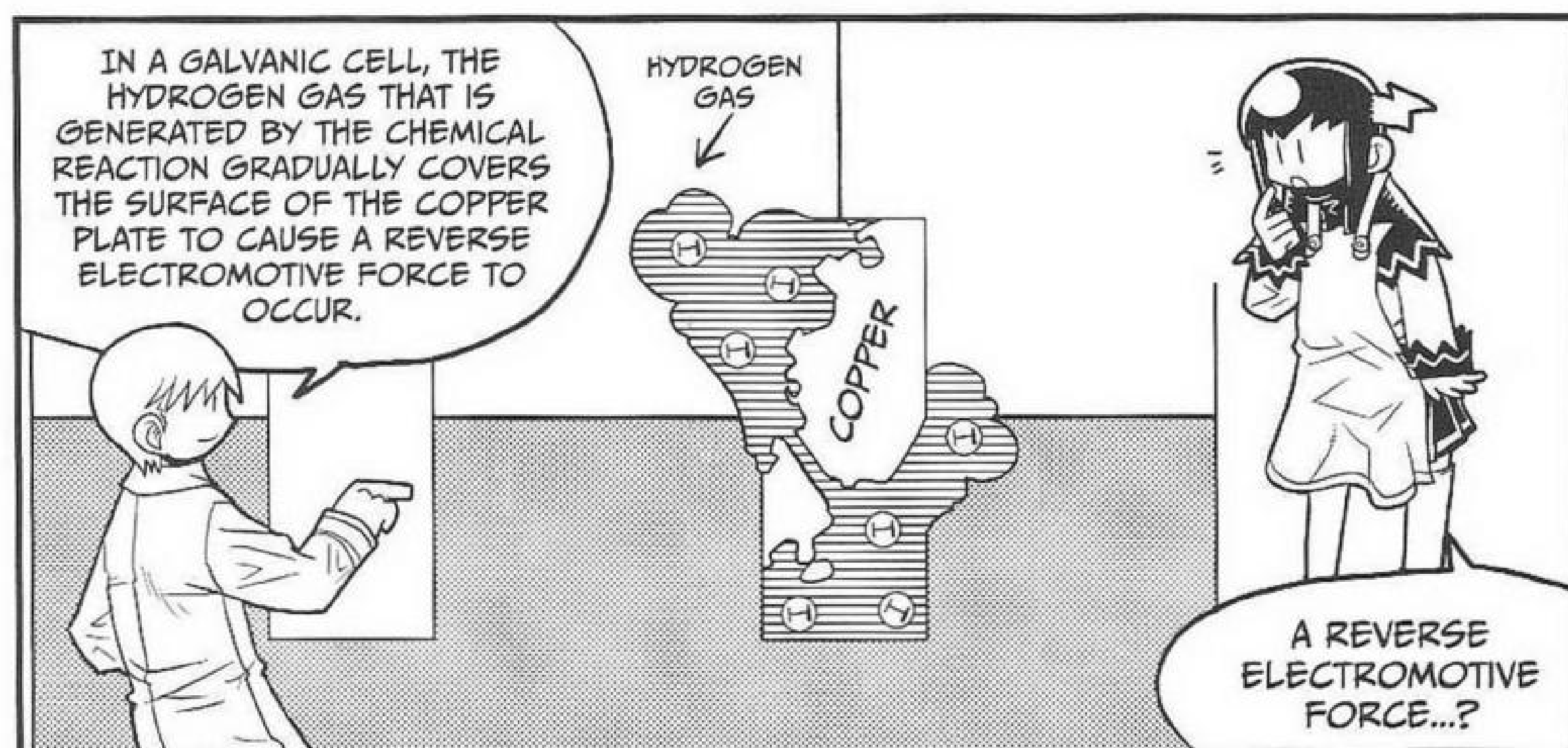
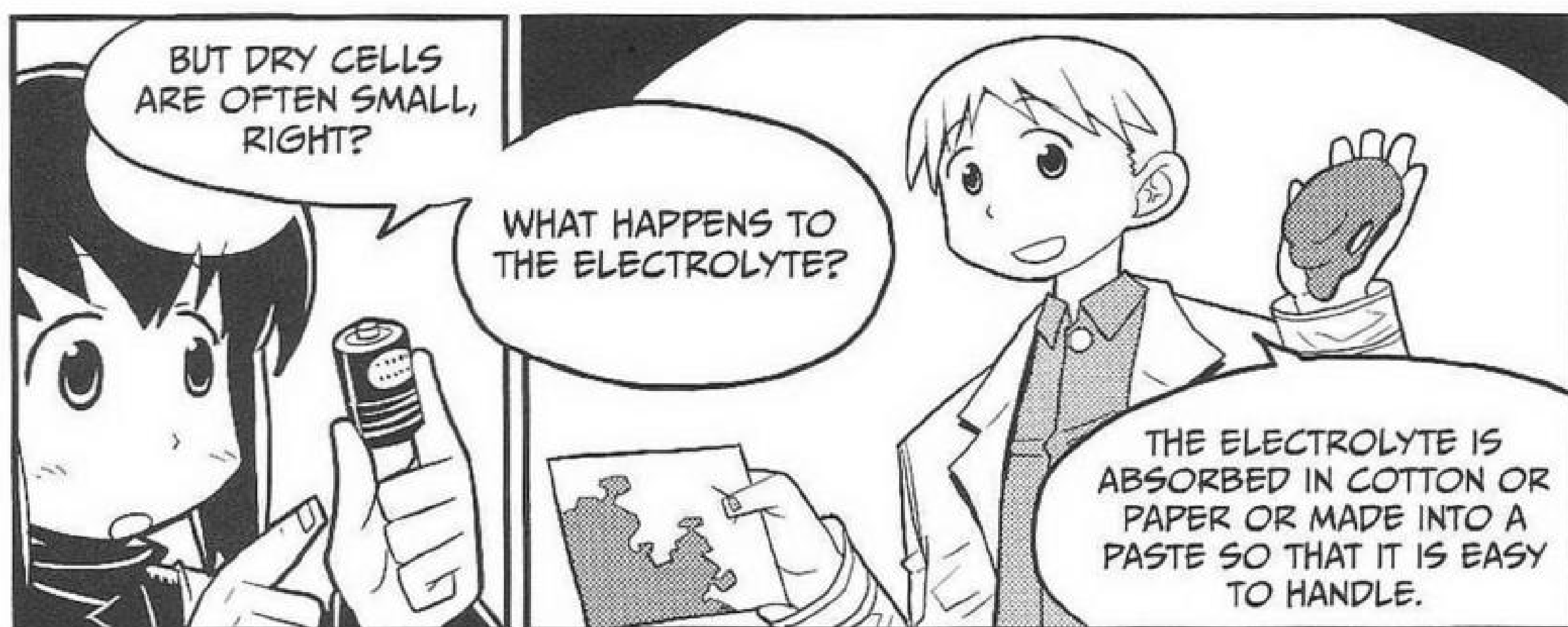
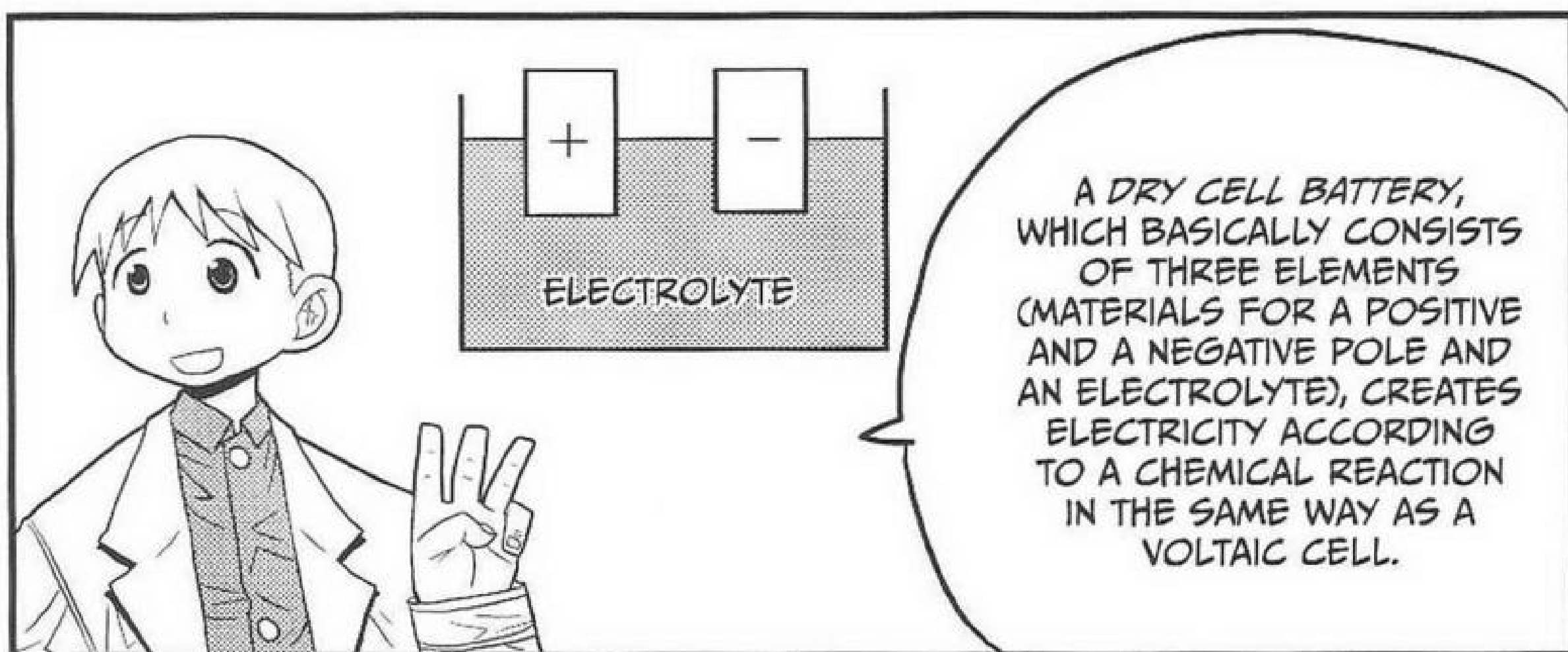
ALTHOUGH HYDROGEN IONS  $H^+$  AND SULFURIC ACID IONS  $SO_4^{2-}$  EXIST IN THE DILUTED SULFURIC ACID...

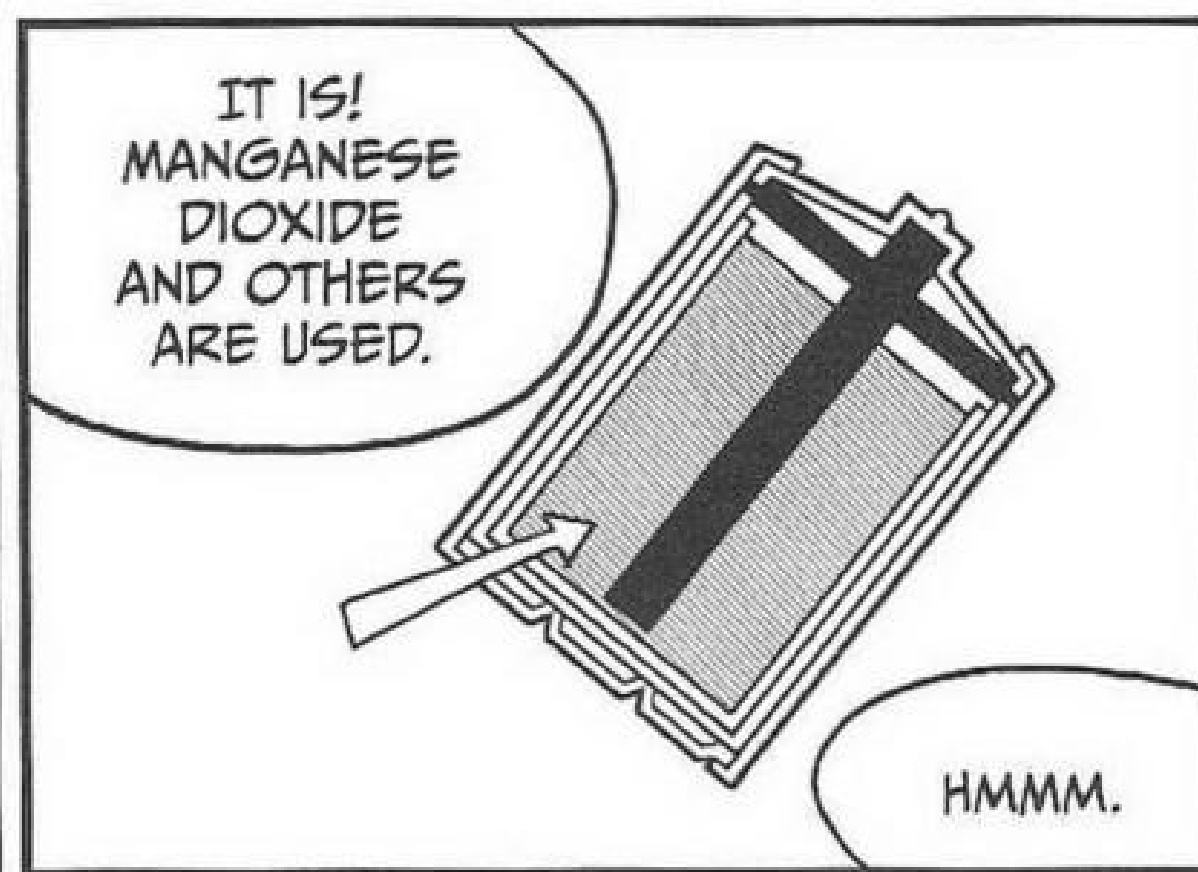
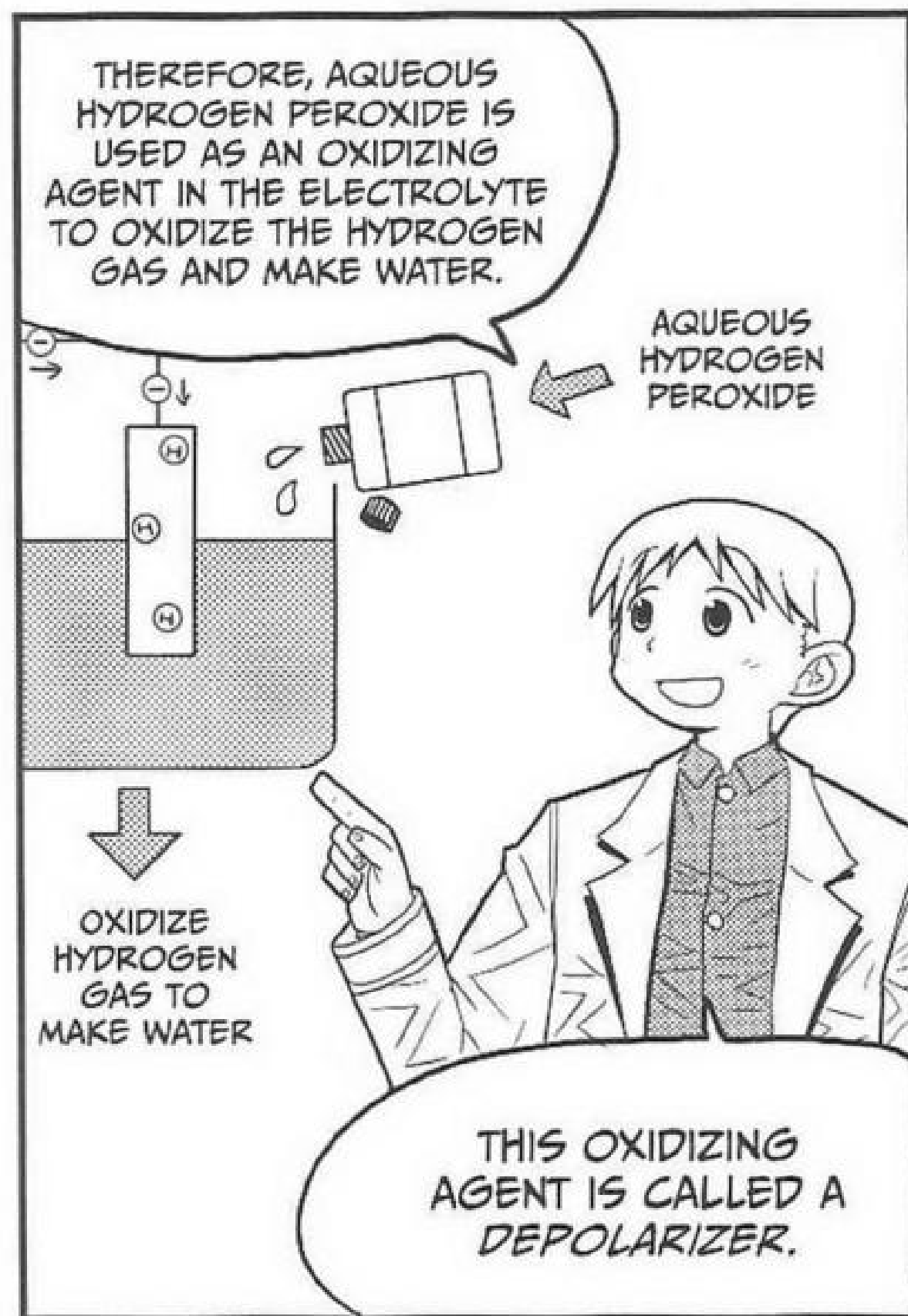
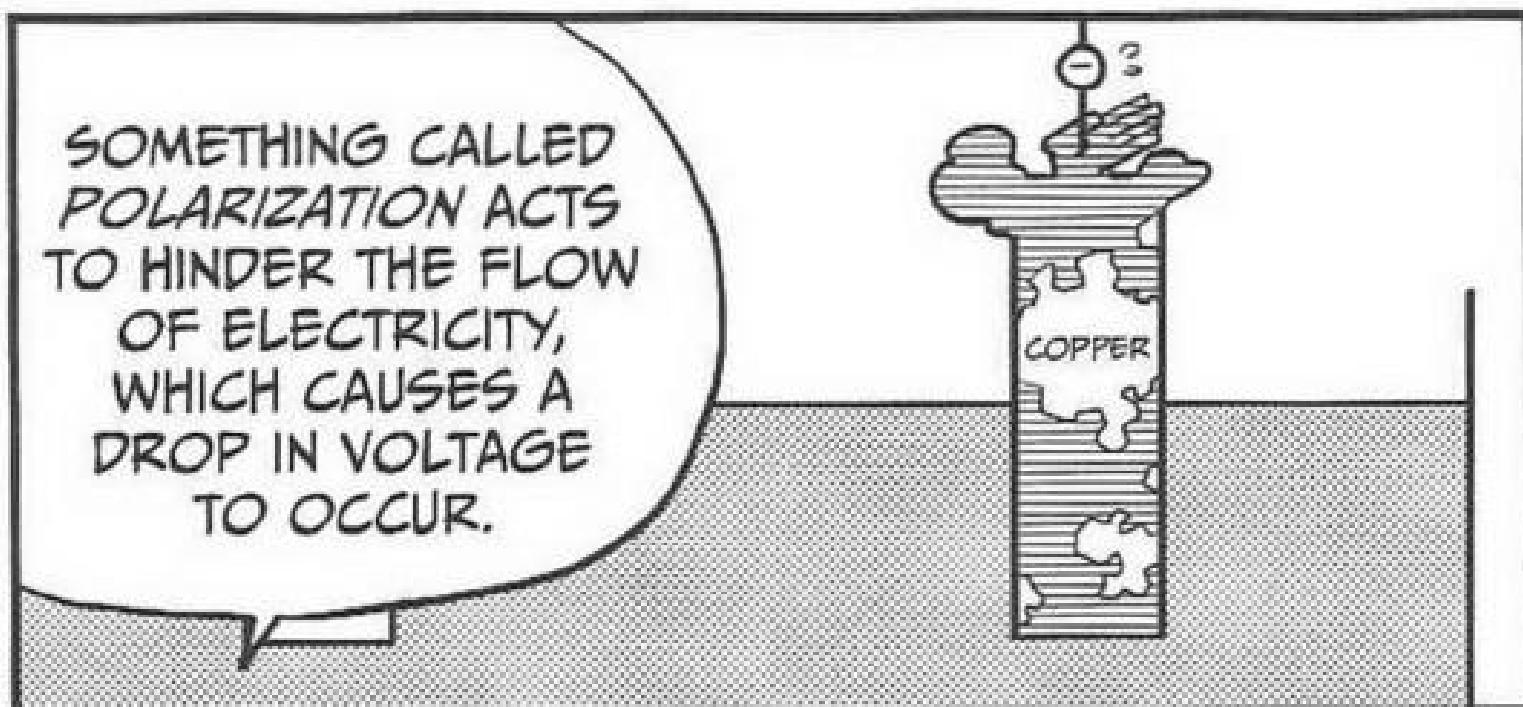


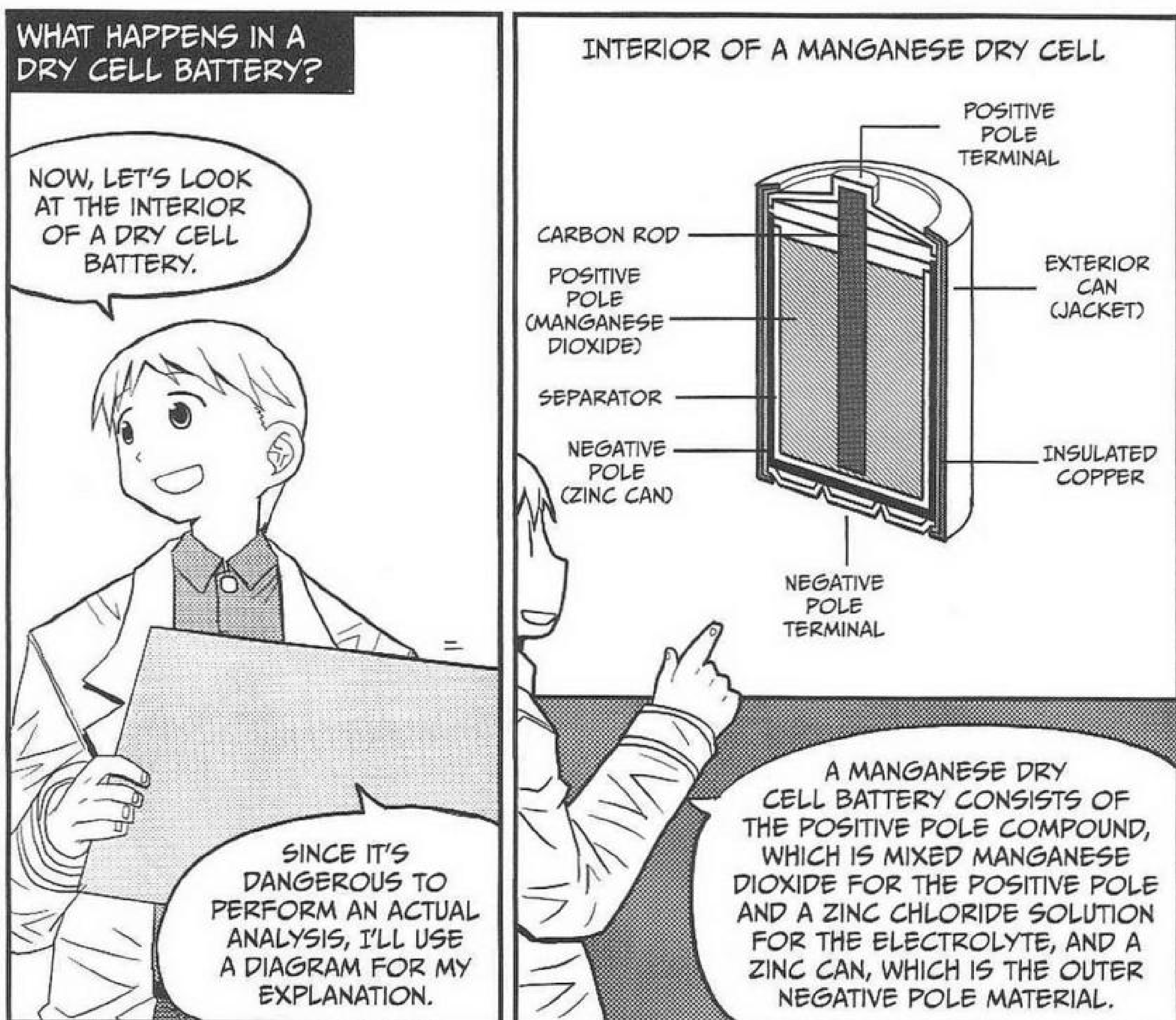
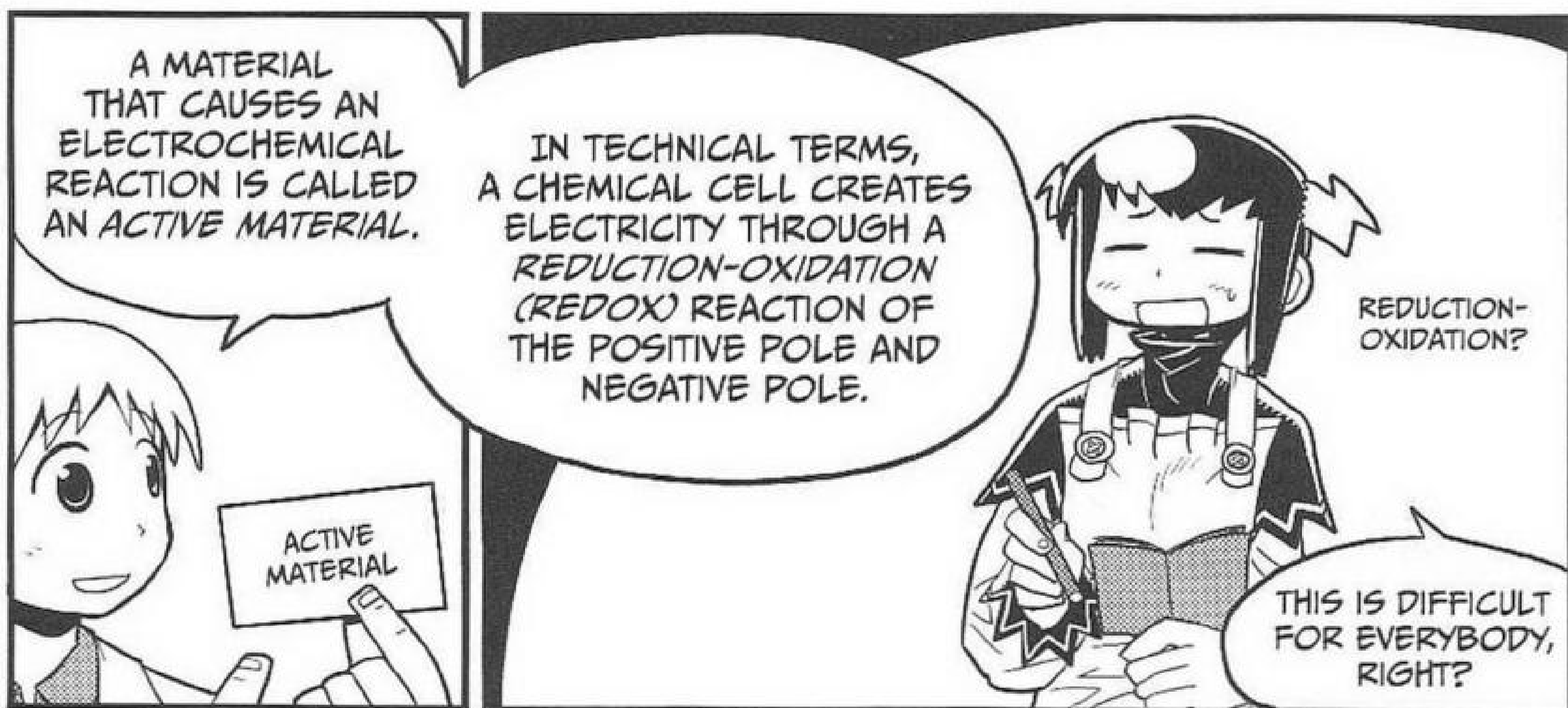
IF ZINC IONS ARE PRODUCED THERE, THE HYDROGEN, WHICH HAS A WEAKER IONIZATION TENDENCY THAN ZINC...

...UNITES WITH THE ELECTRONS THAT MOVED TO THE COPPER PLATE AND BECOMES HYDROGEN GAS.

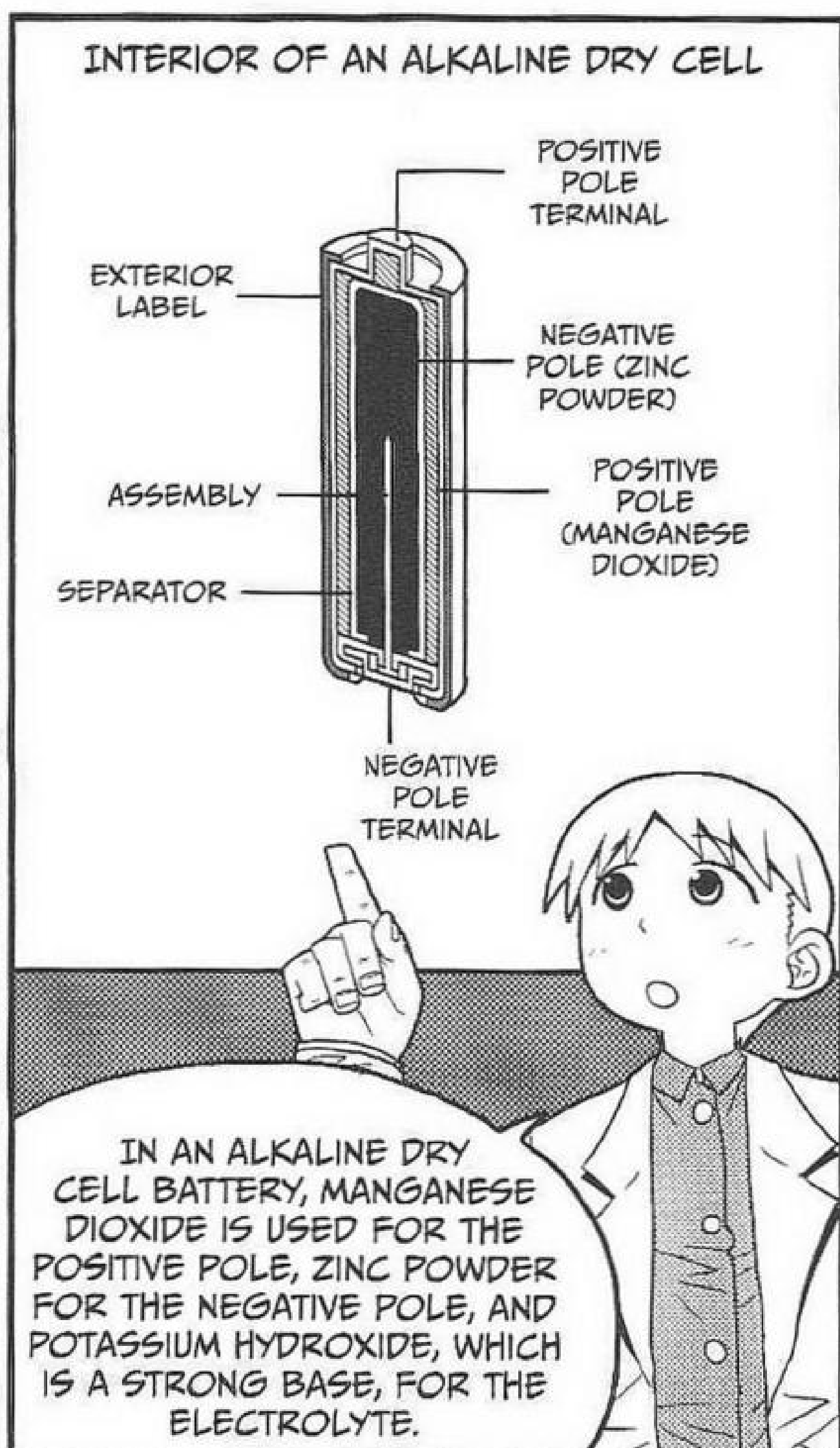
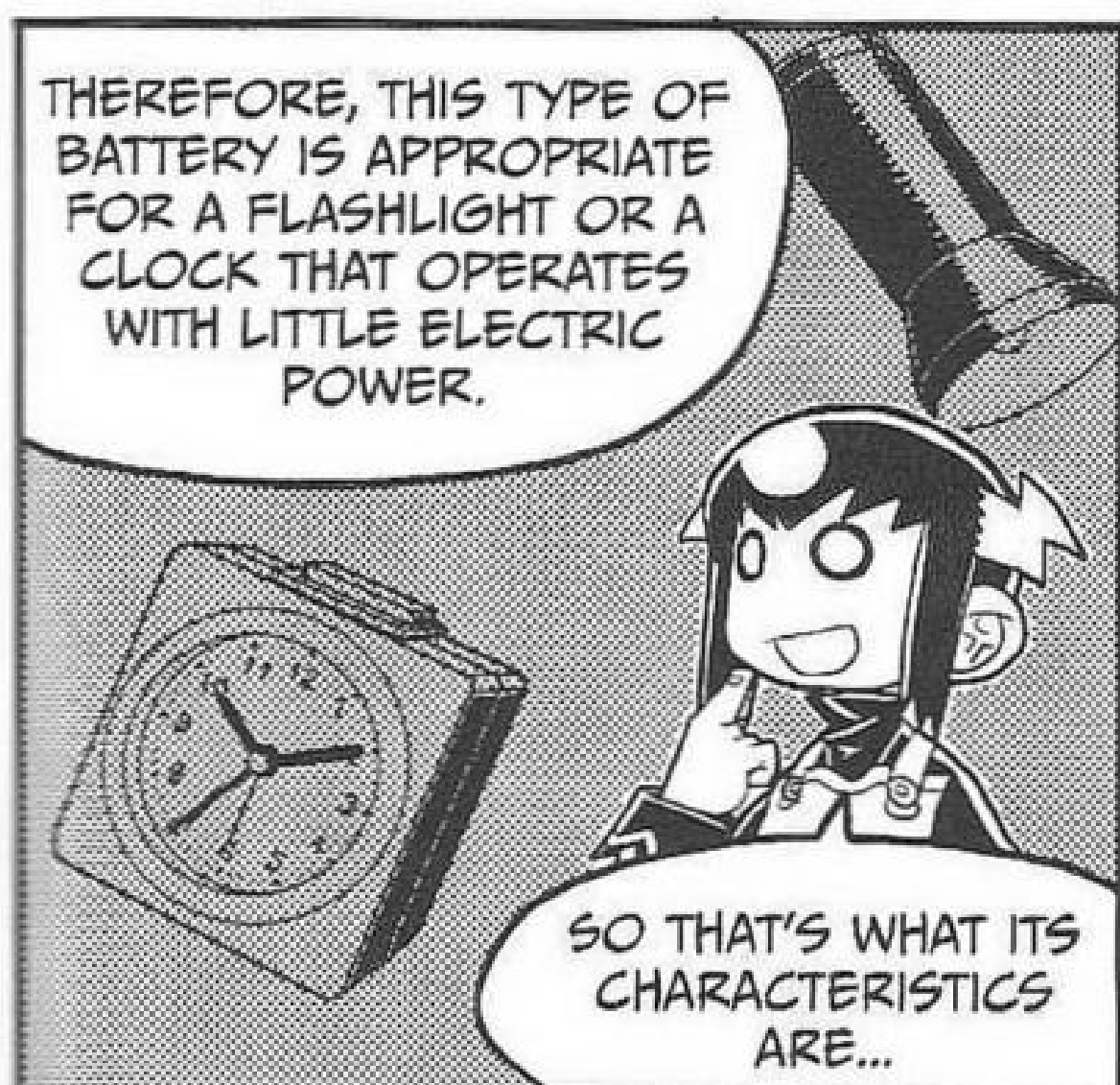
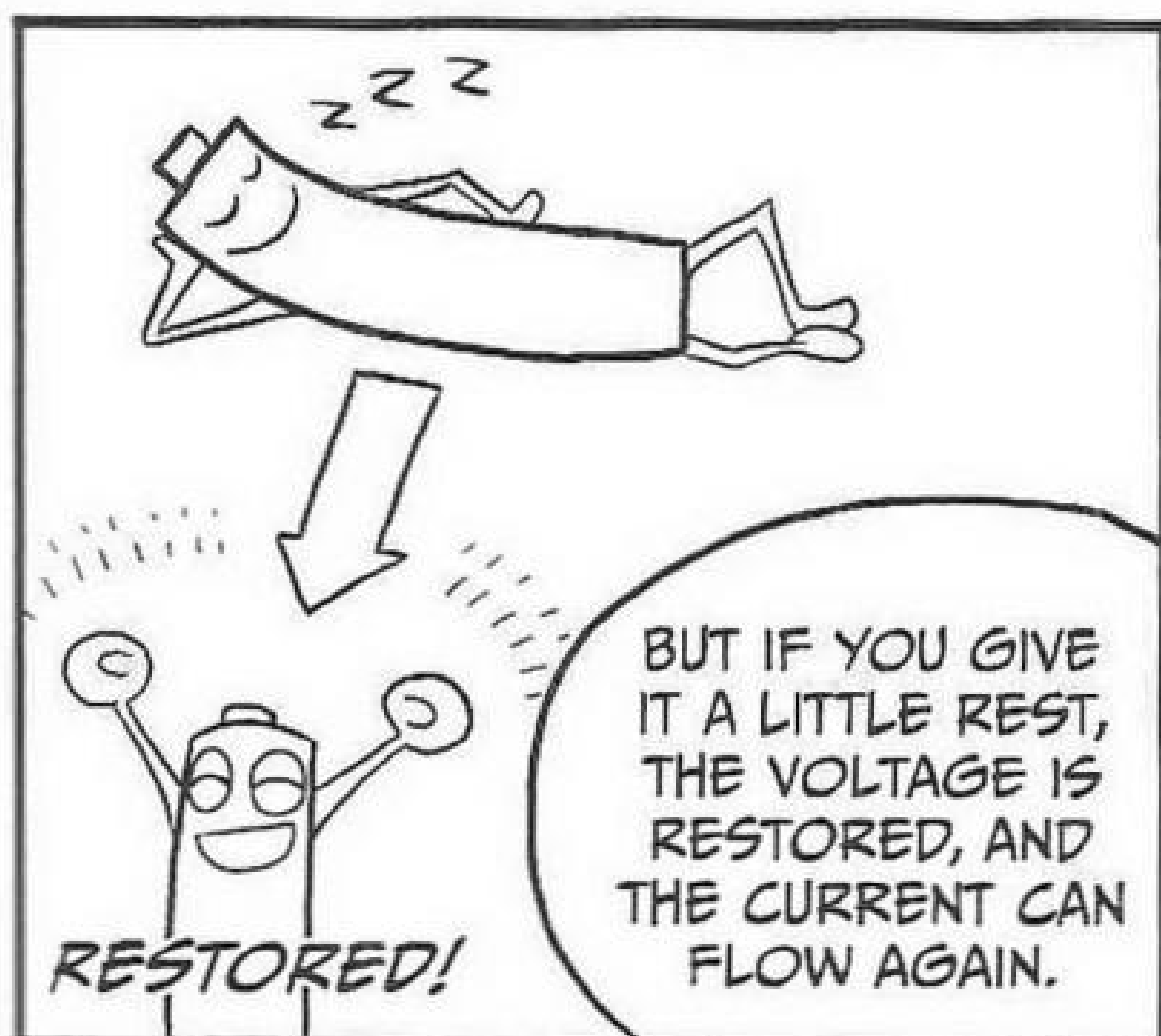




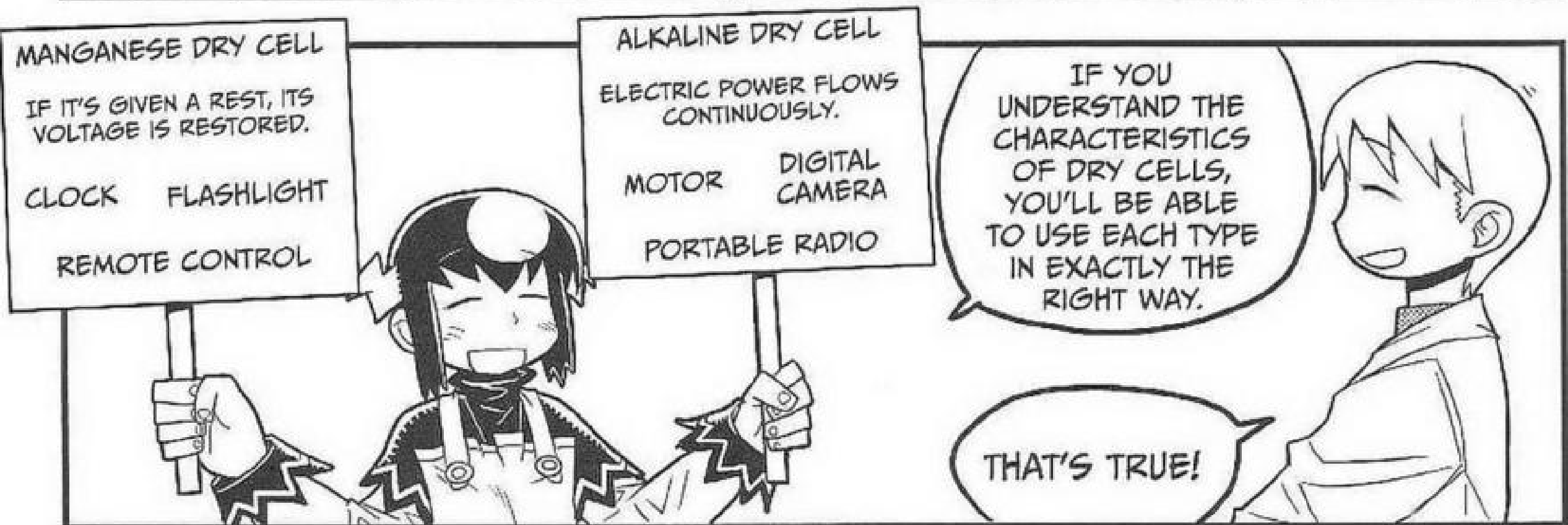
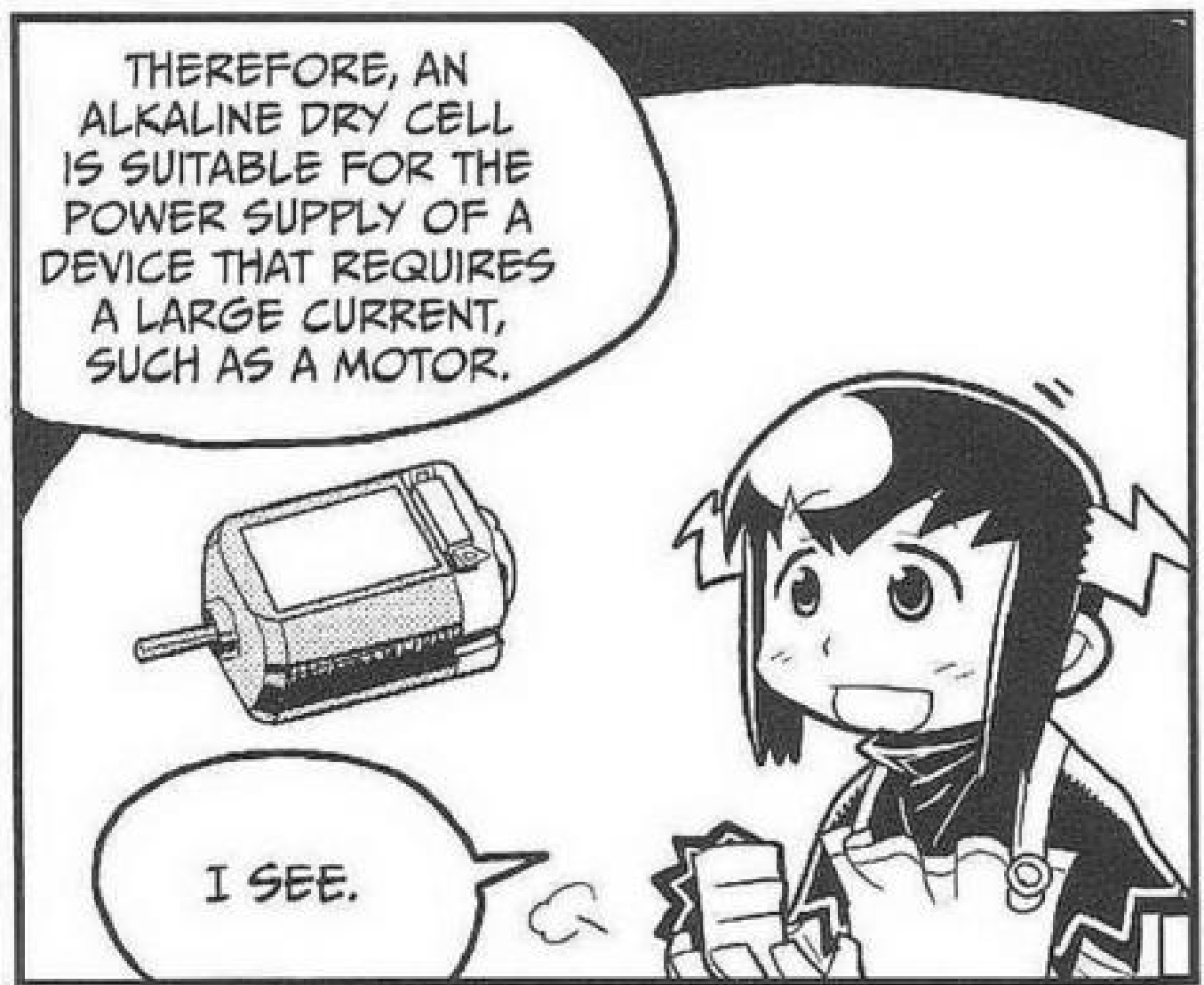
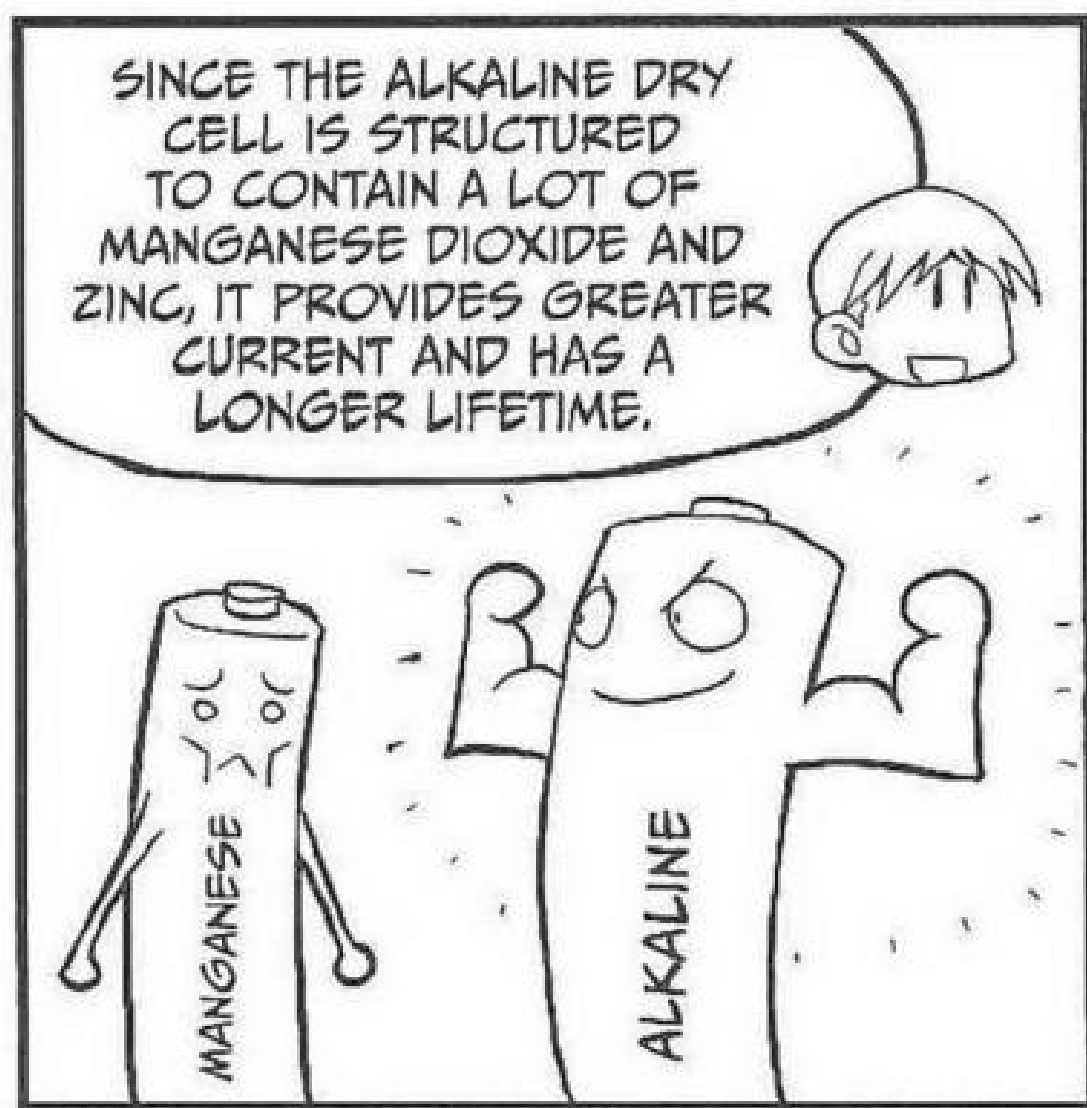
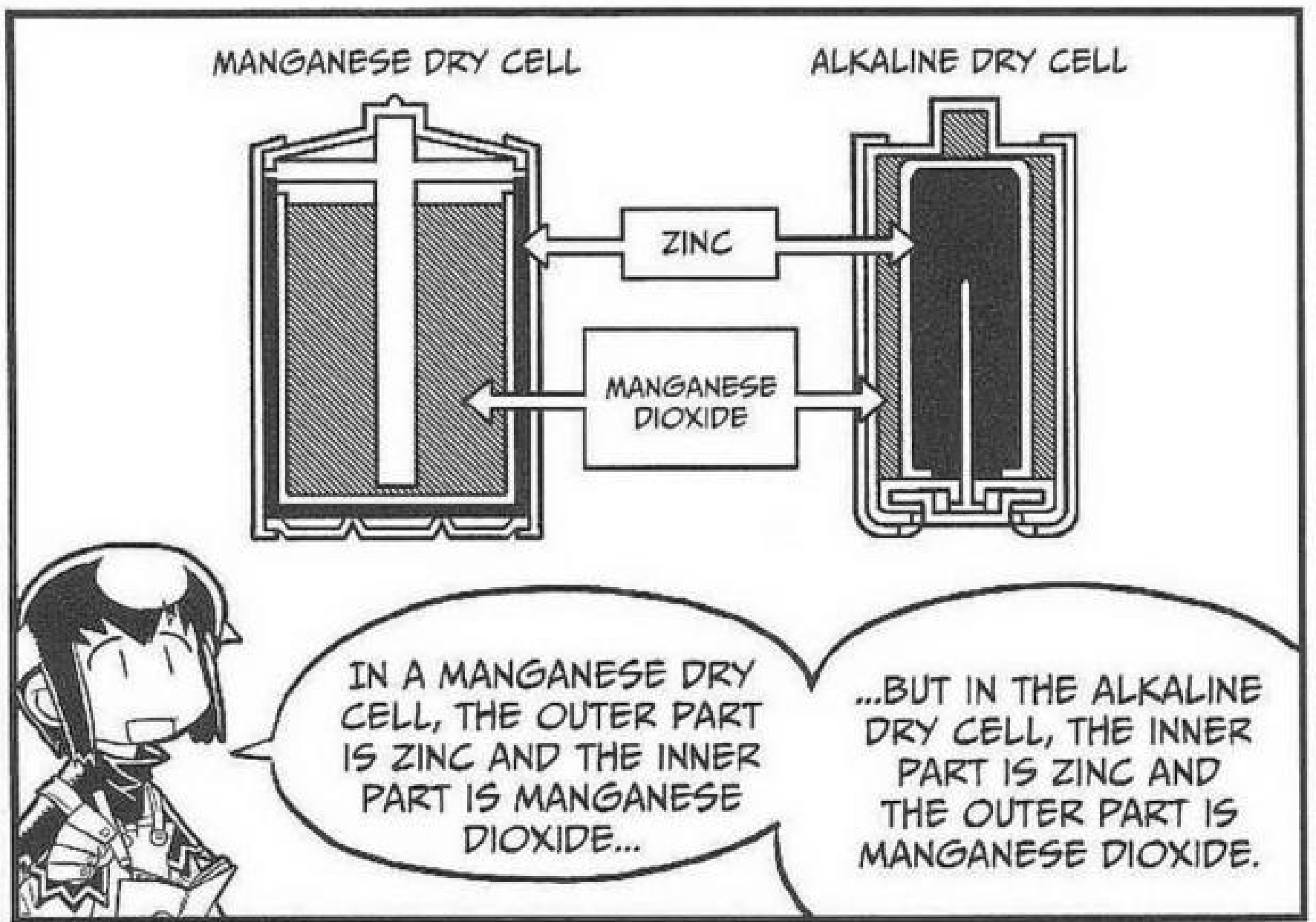


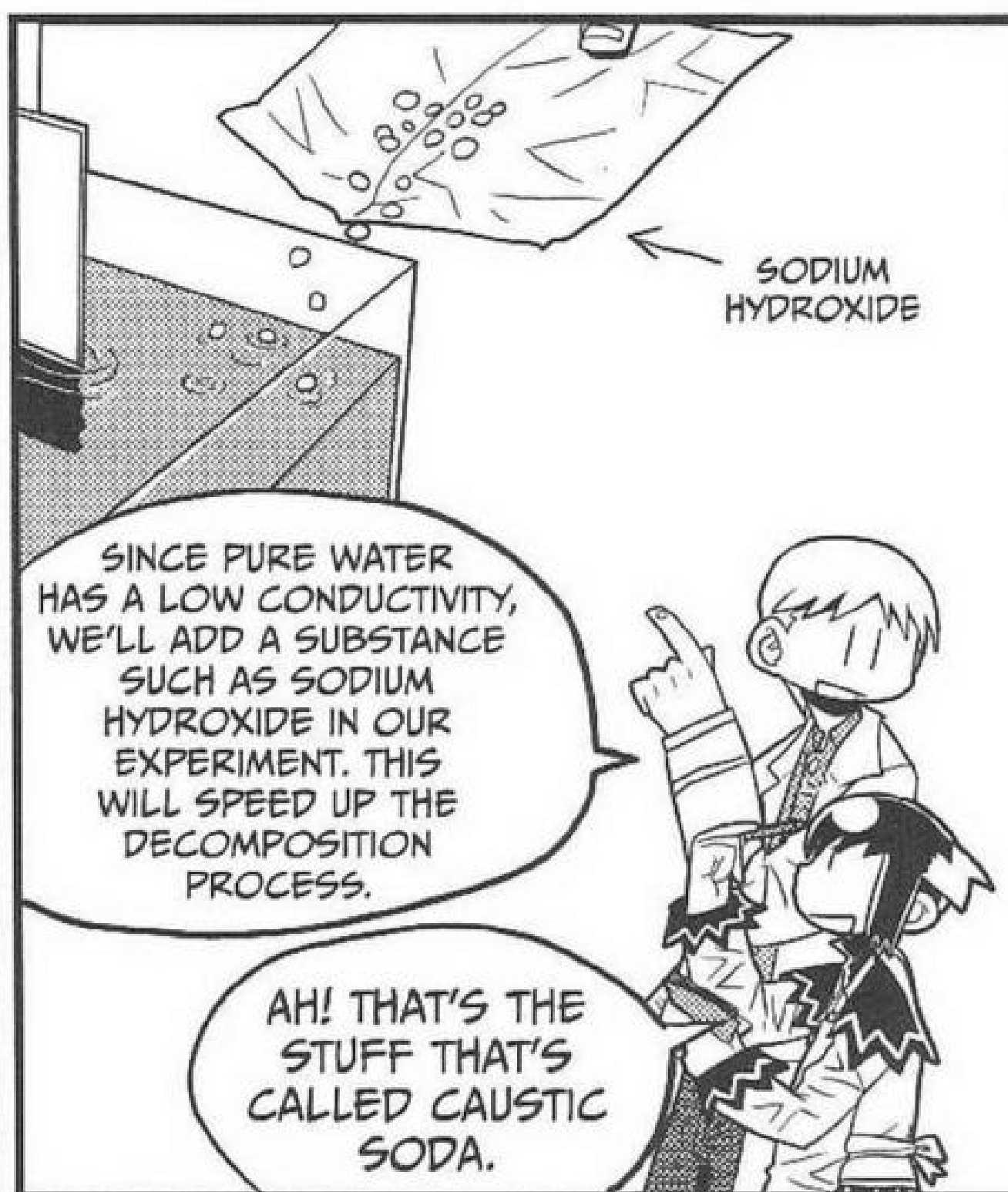
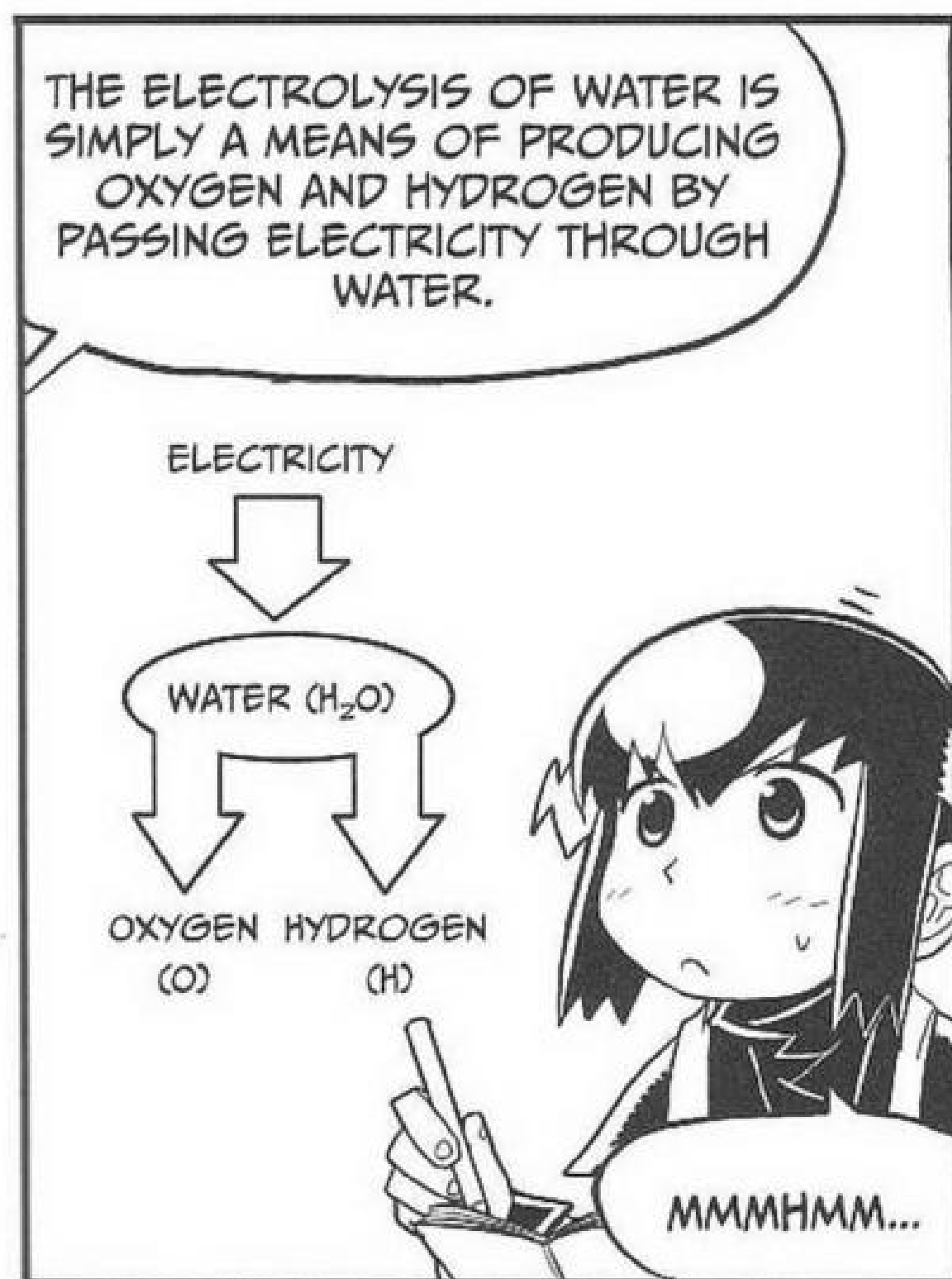




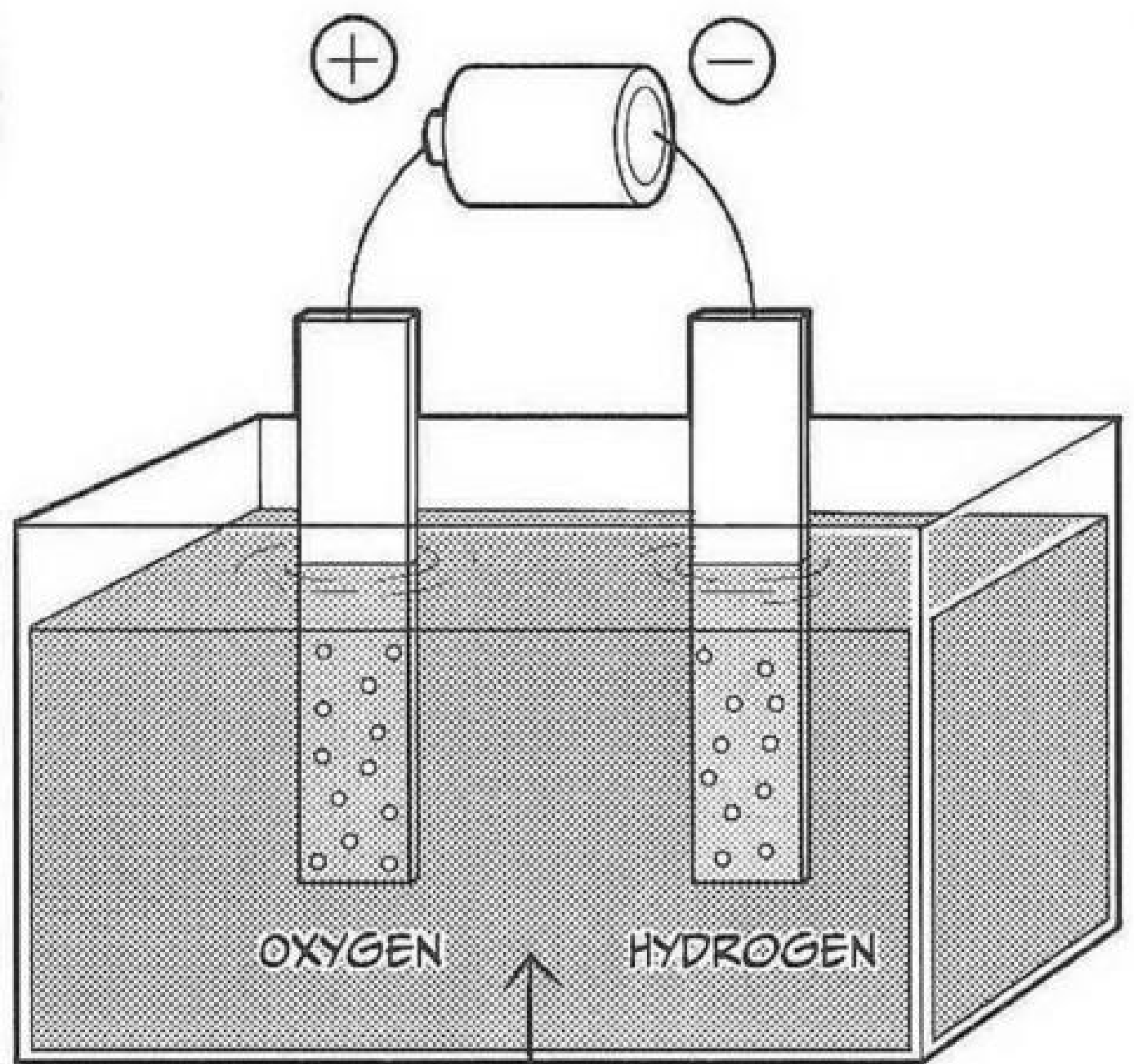
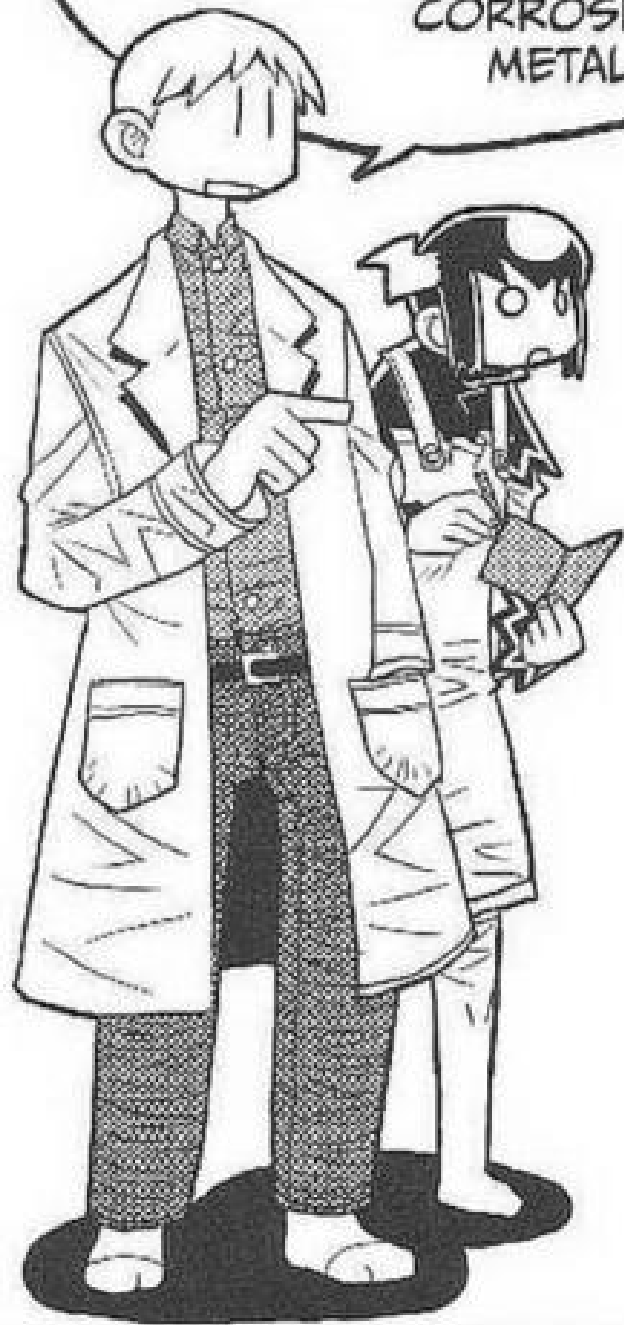








WHEN ELECTRICITY IS PASSED THROUGH IT, HYDROGEN AND OXYGEN ARE PRODUCED AT THE RESPECTIVE ELECTRODES, WHICH ARE PLATINUM OR ANOTHER NON-CORROSIVE METAL.



AQUEOUS SOLUTION OF SODIUM HYDROXIDE

INCIDENTALLY, IN ELECTROLYSIS, THE ELECTRODE THAT THE POSITIVE SIDE OF THE POWER SUPPLY IS CONNECTED TO IS CALLED THE ANODE...

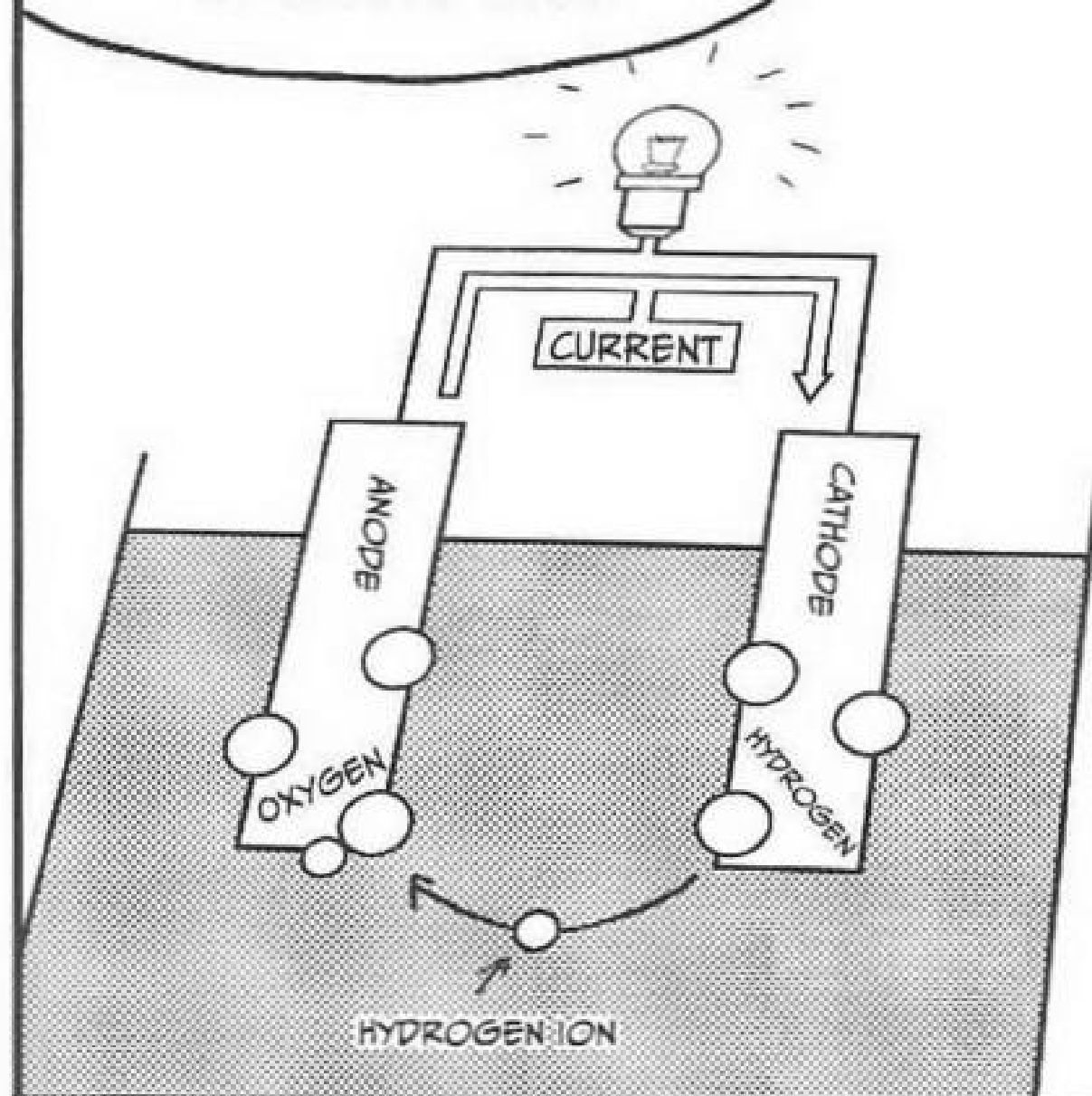
...AND THE ELECTRODE THAT THE NEGATIVE SIDE OF THE POWER SUPPLY IS CONNECTED TO IS CALLED THE CATHODE.

I SEE!

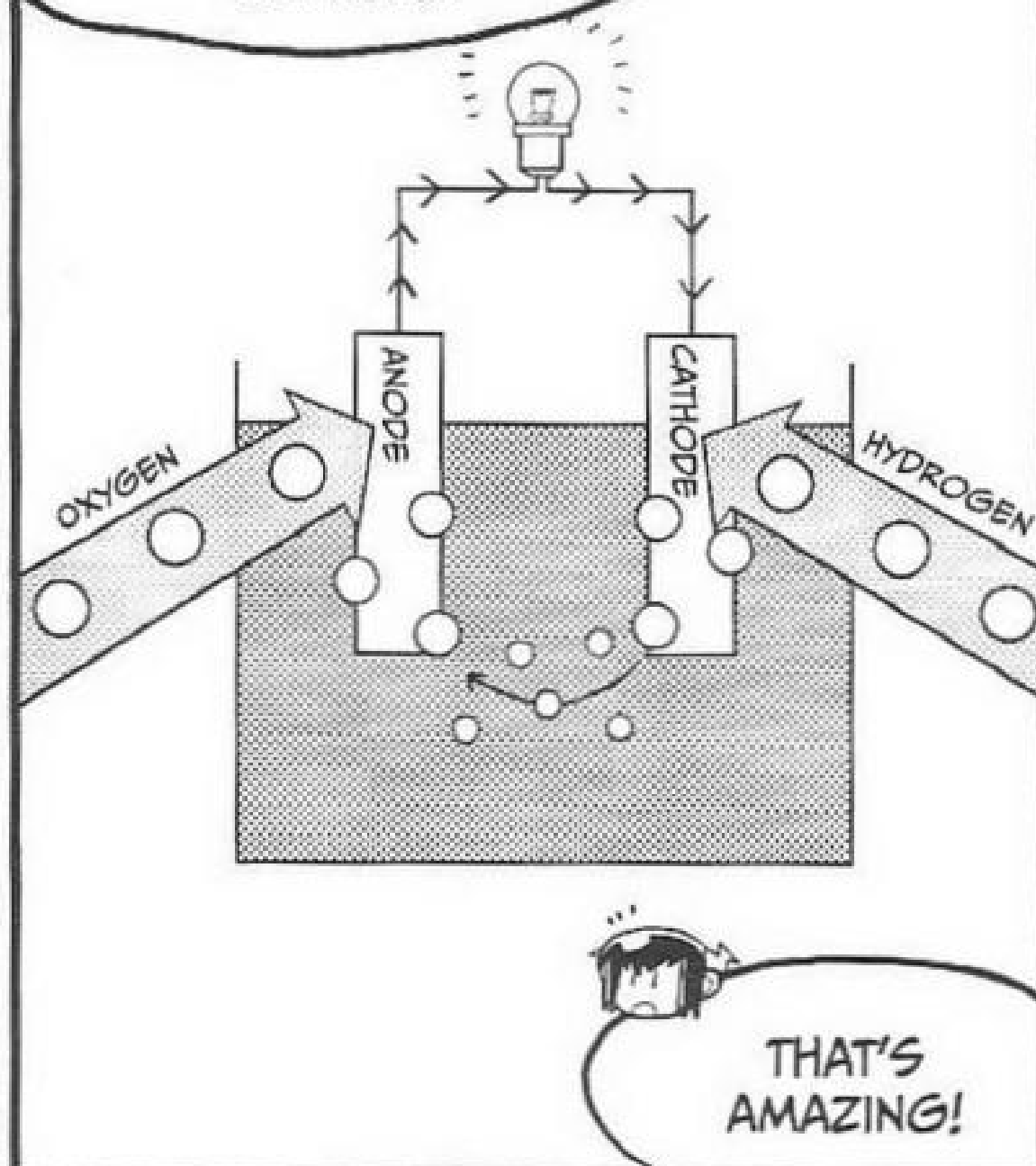
IF THE POWER SUPPLY IS REMOVED FROM THE ELECTROLYZED AQUEOUS SOLUTION...

...AND A LOAD IS CONNECTED...

...THE DECOMPOSED HYDROGEN AND OXYGEN WILL COMBINE TO PRODUCE ELECTRICITY, WATER, AND HEAT. THIS IS THE PRINCIPLE OF A FUEL CELL.

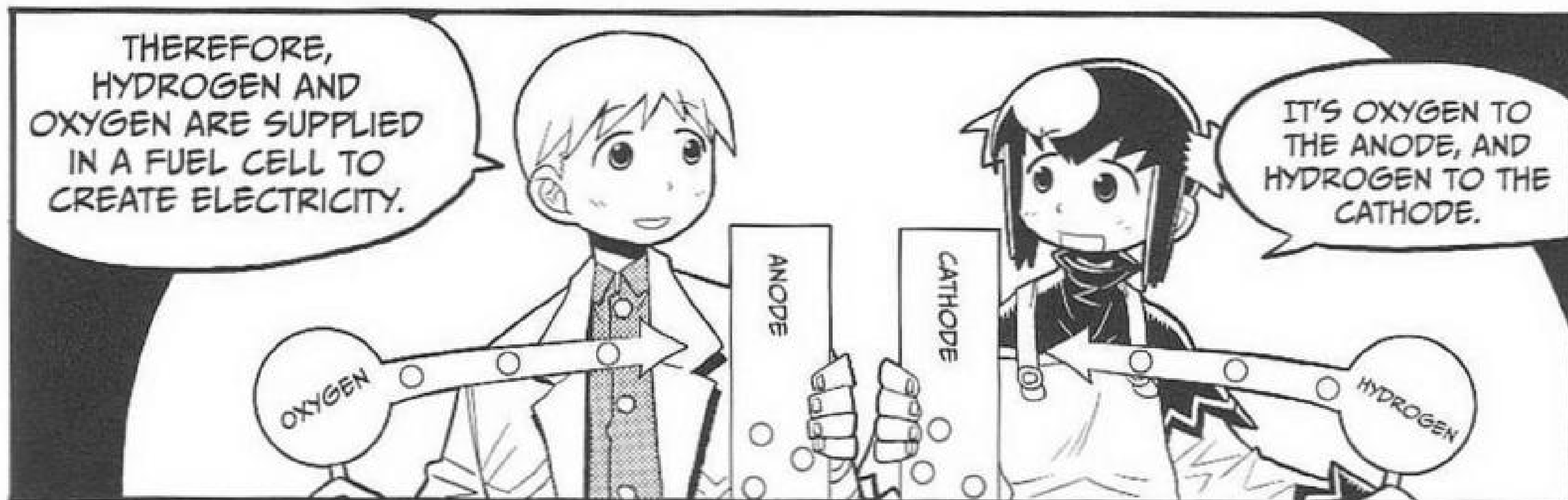


IF WE CONTINUE TO SUPPLY HYDROGEN AND OXYGEN, ELECTRICITY WILL CONTINUE TO BE CREATED.



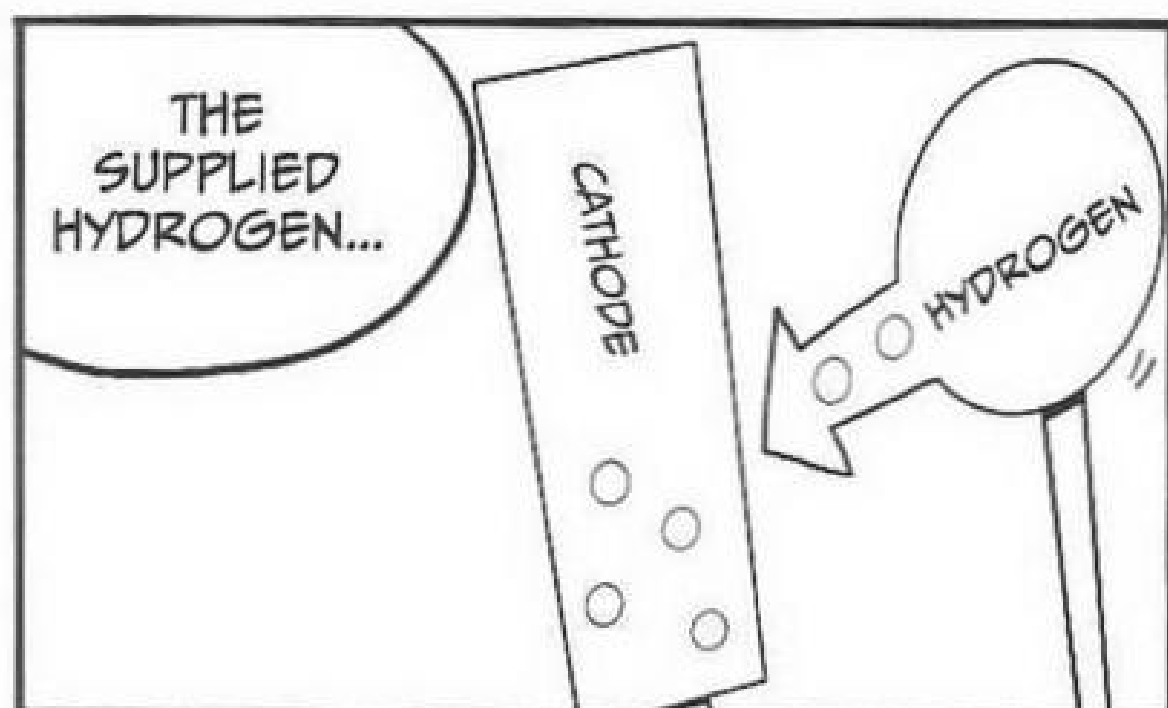
THAT'S AMAZING!

THEREFORE, HYDROGEN AND OXYGEN ARE SUPPLIED IN A FUEL CELL TO CREATE ELECTRICITY.

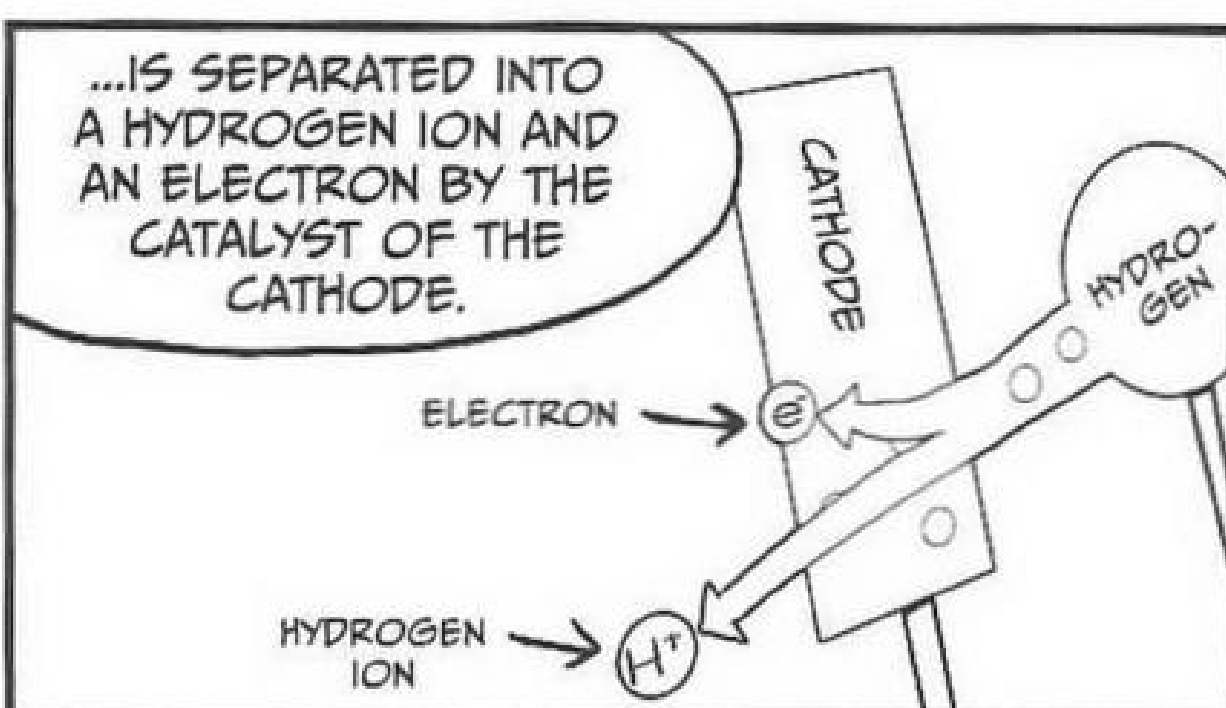


IT'S OXYGEN TO THE ANODE, AND HYDROGEN TO THE CATHODE.

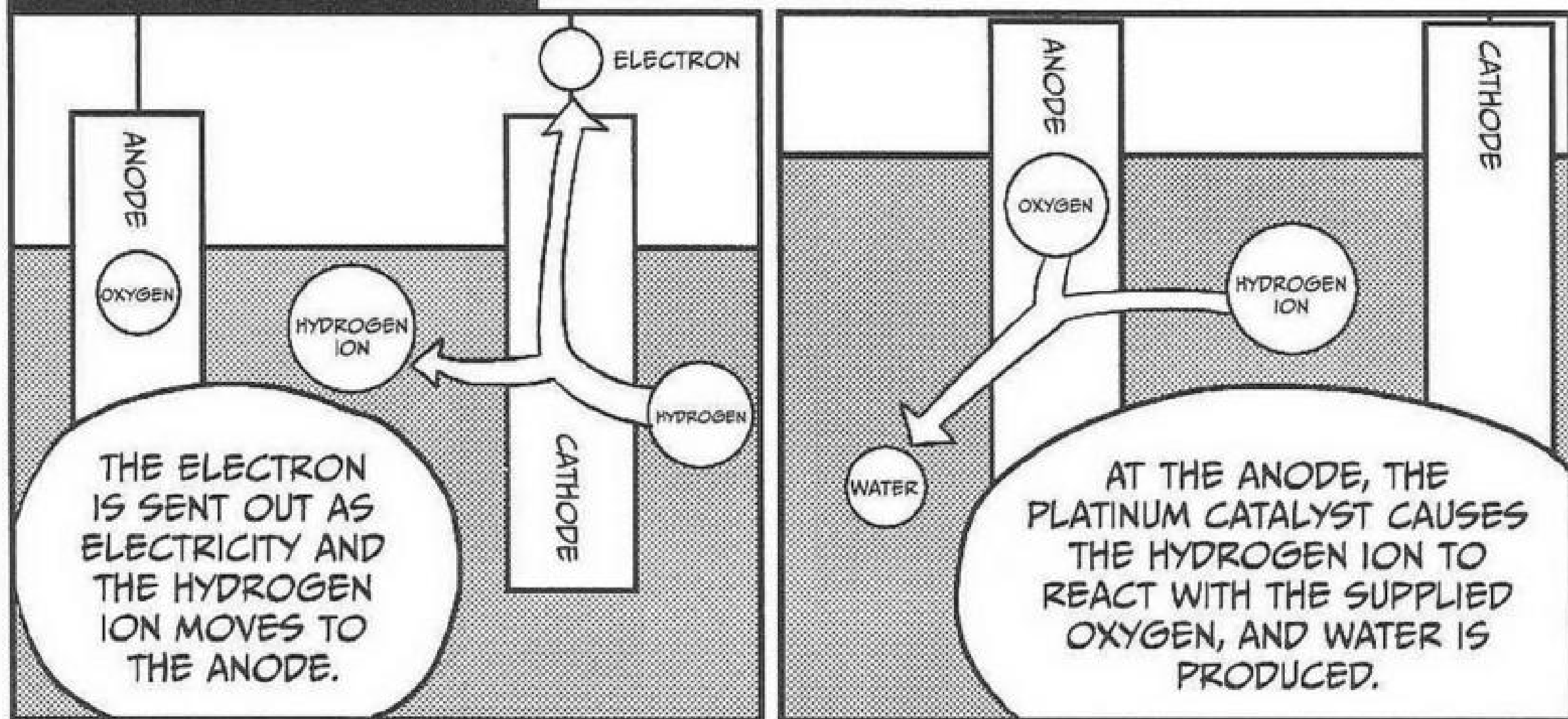
THE SUPPLIED HYDROGEN...



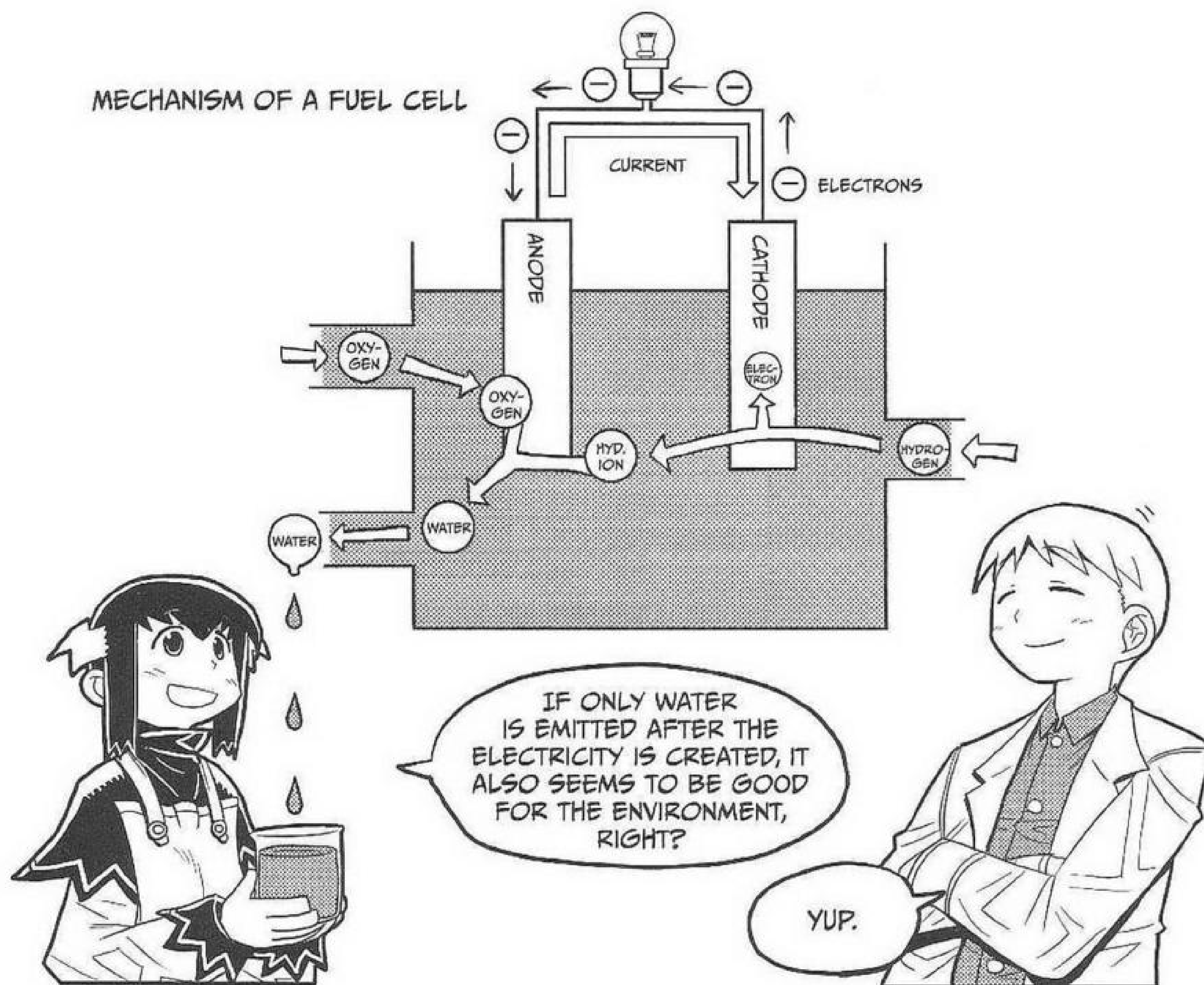
...IS SEPARATED INTO A HYDROGEN ION AND AN ELECTRON BY THE CATALYST OF THE CATHODE.



## ANODES AND CATHODES



## MECHANISM OF A FUEL CELL





THERE IS NO VIBRATION OR NOISE, AND WE CAN USE A TOOL CALLED A FUEL REFORMER TO EXTRACT THE HYDROGEN THAT WE NEED FOR THE FUEL FROM NATURAL GAS OR METHANOL, AND WE CAN SIMPLY USE OXYGEN FROM THE ATMOSPHERE.



IT LOOKS LIKE EVERYBODY WINS!

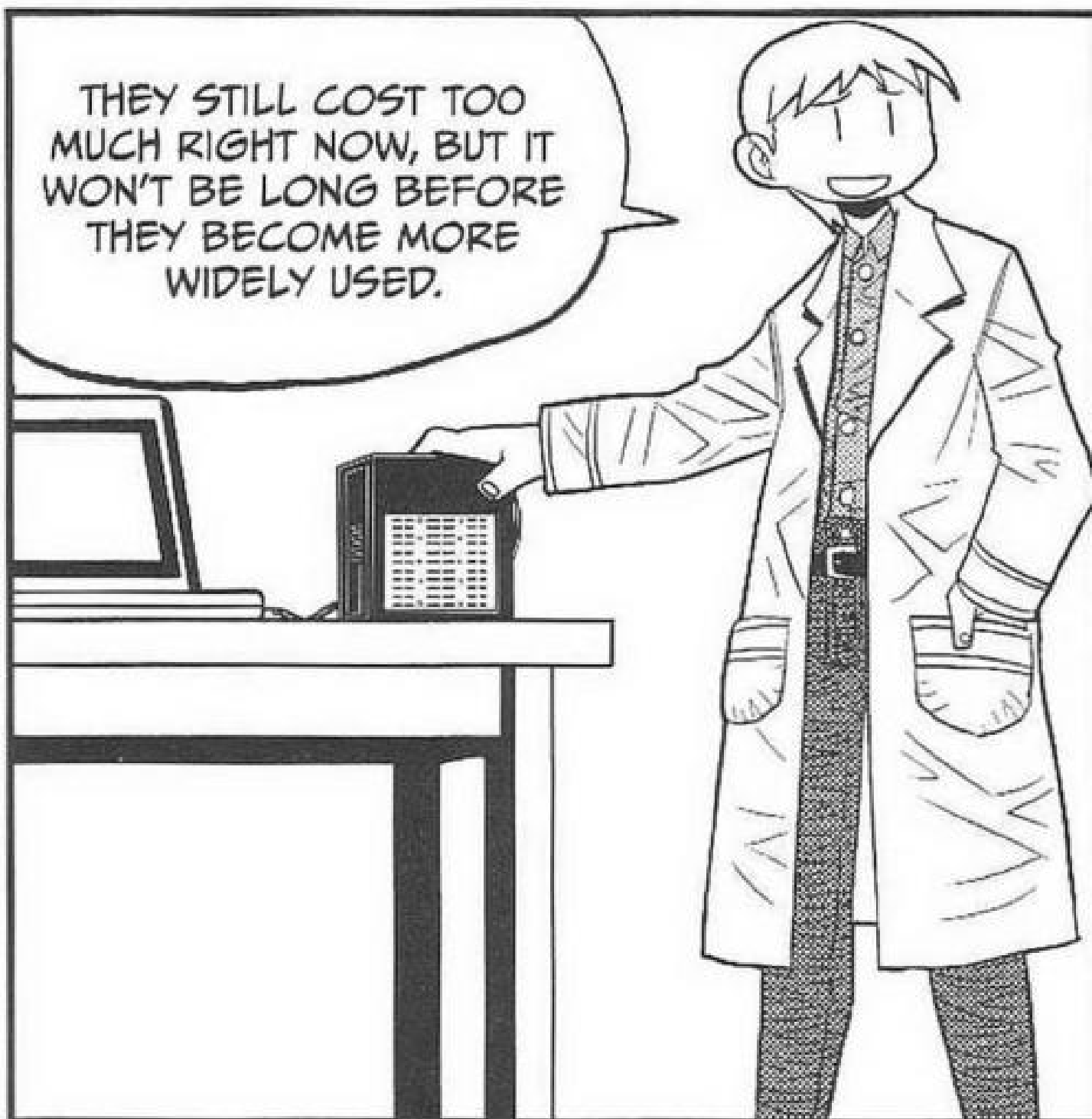
IF THE WASTE HEAT IS ALSO USED, IT IS VERY EFFICIENT, AND SINCE HYDROGEN FUEL CAN BE RETRIEVED IN VARIOUS WAYS, RESOURCES CAN EASILY BE GUARANTEED.

?



BUT...IF THESE BATTERIES ARE SO GREAT...HOW COME I'VE NEVER SEEN ONE?

THEY STILL COST TOO MUCH RIGHT NOW, BUT IT WON'T BE LONG BEFORE THEY BECOME MORE WIDELY USED.



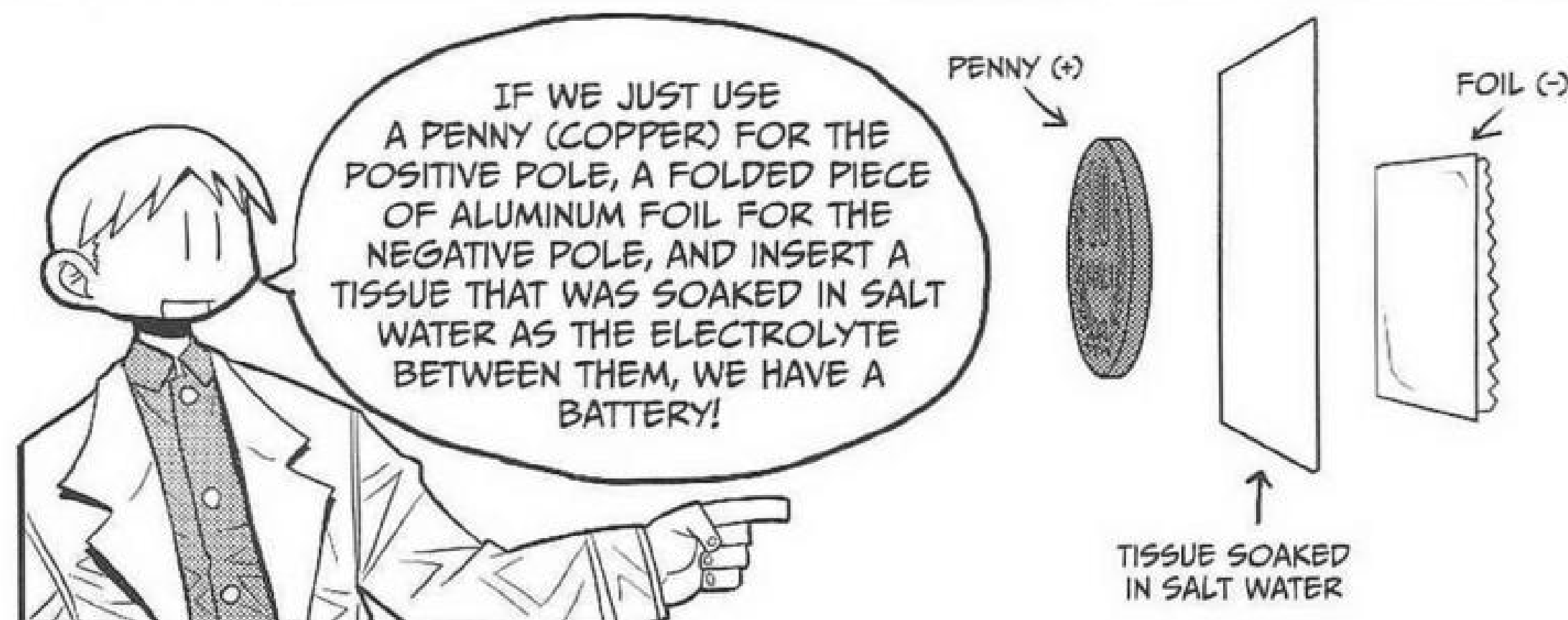
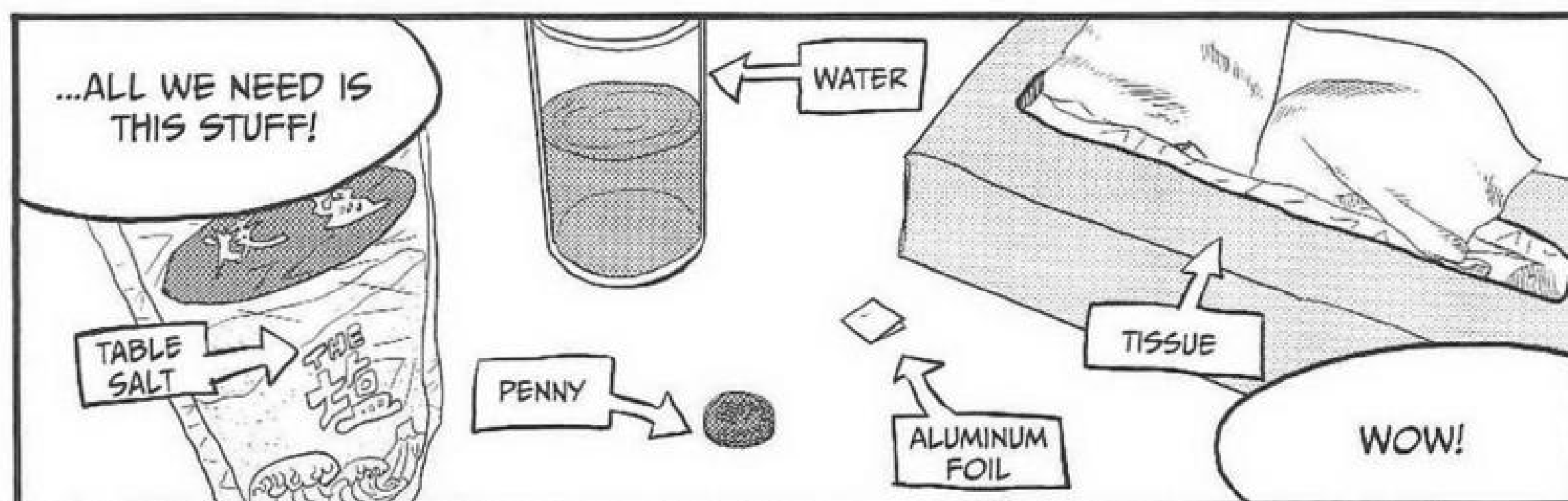
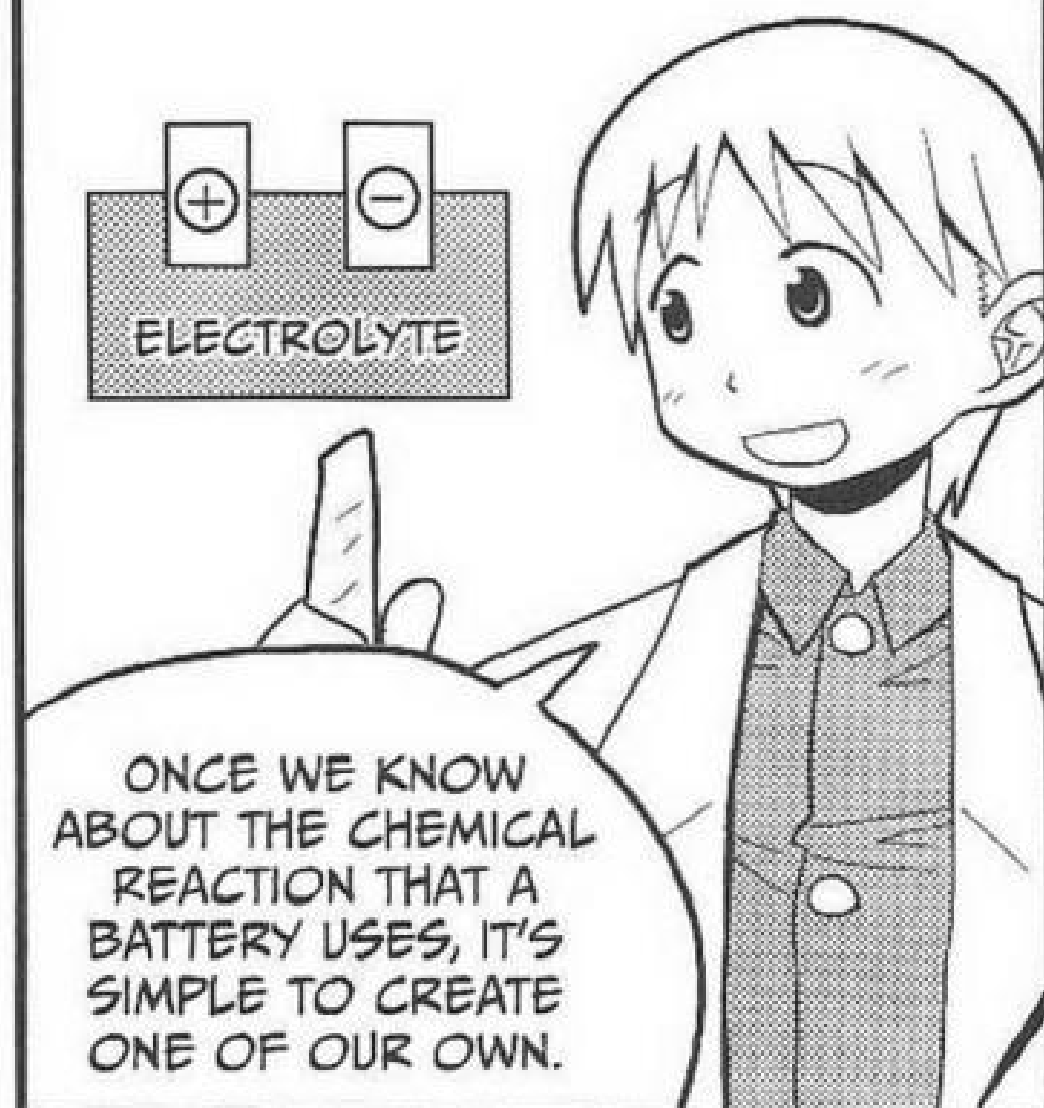
YOU MEAN THEY MIGHT BE USED MORE WIDELY IN THE NEAR FUTURE?

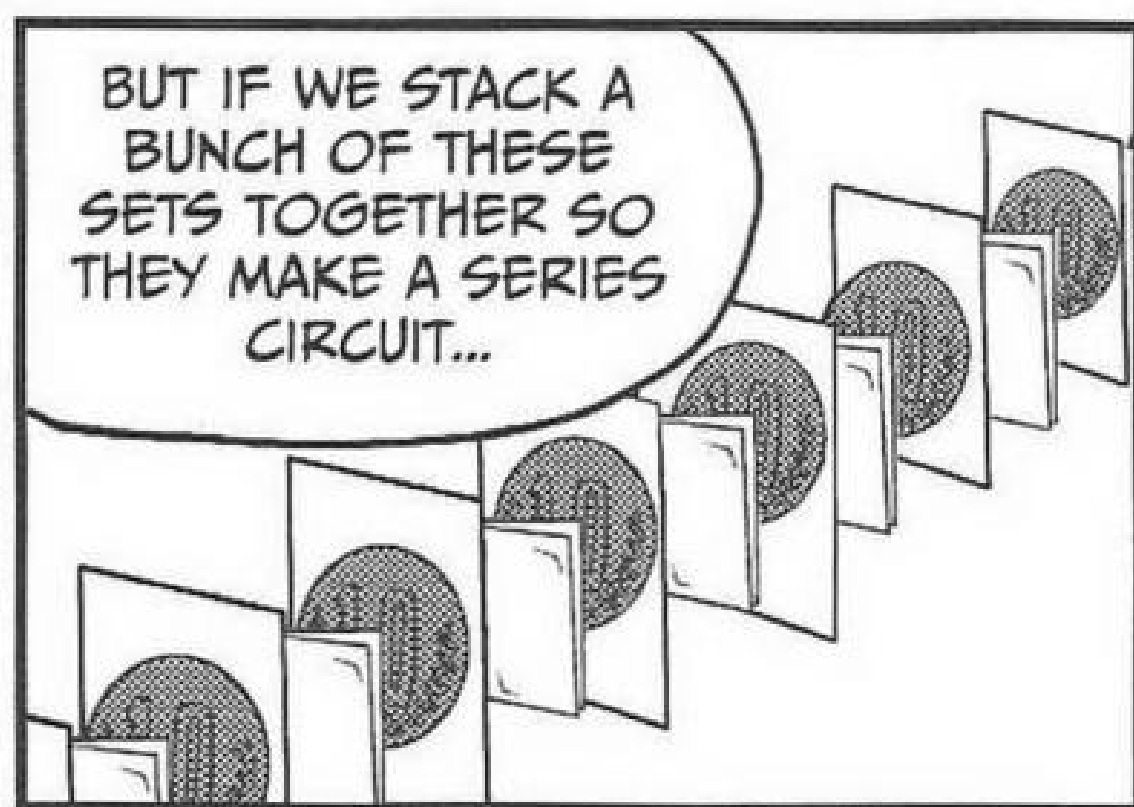
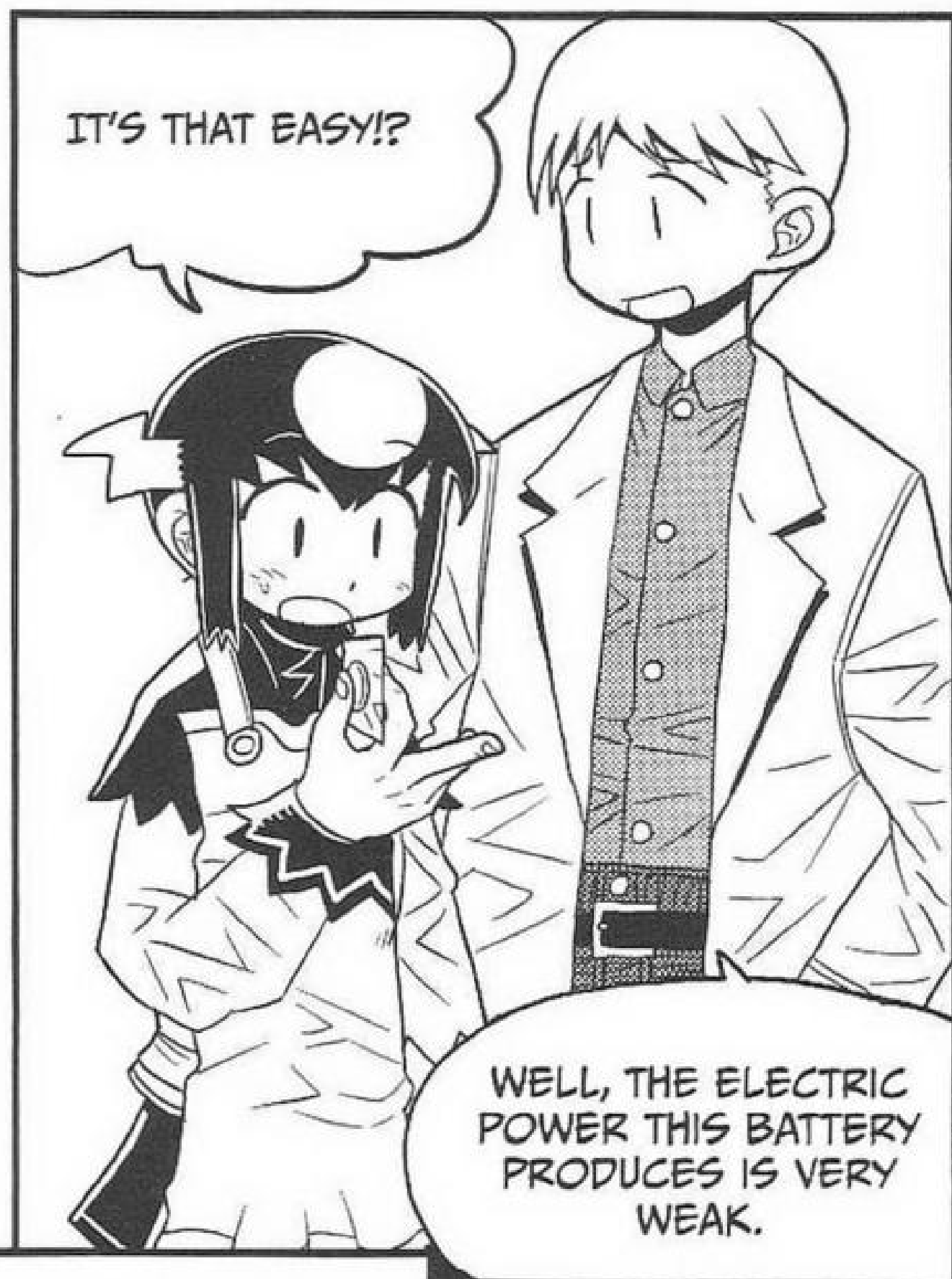


THAT'S RIGHT.



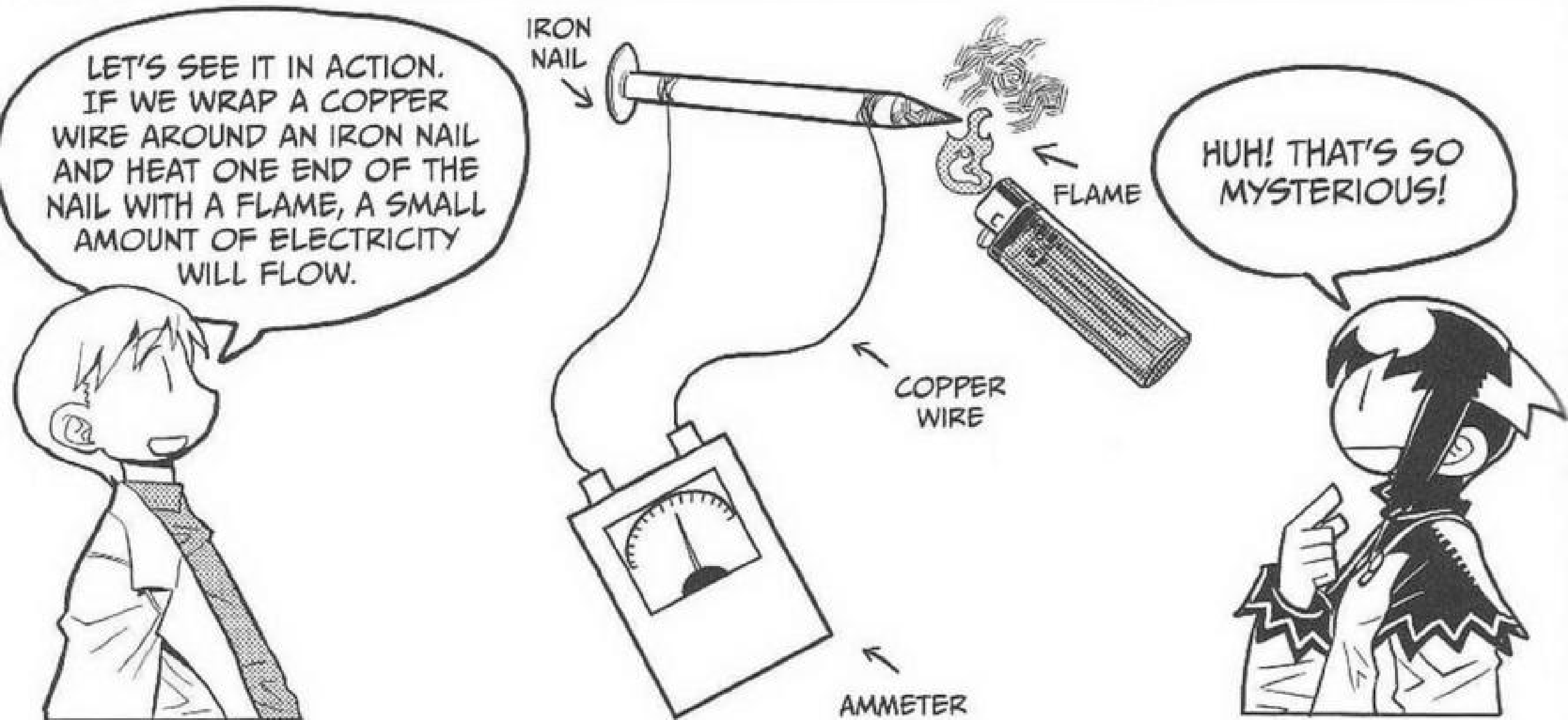
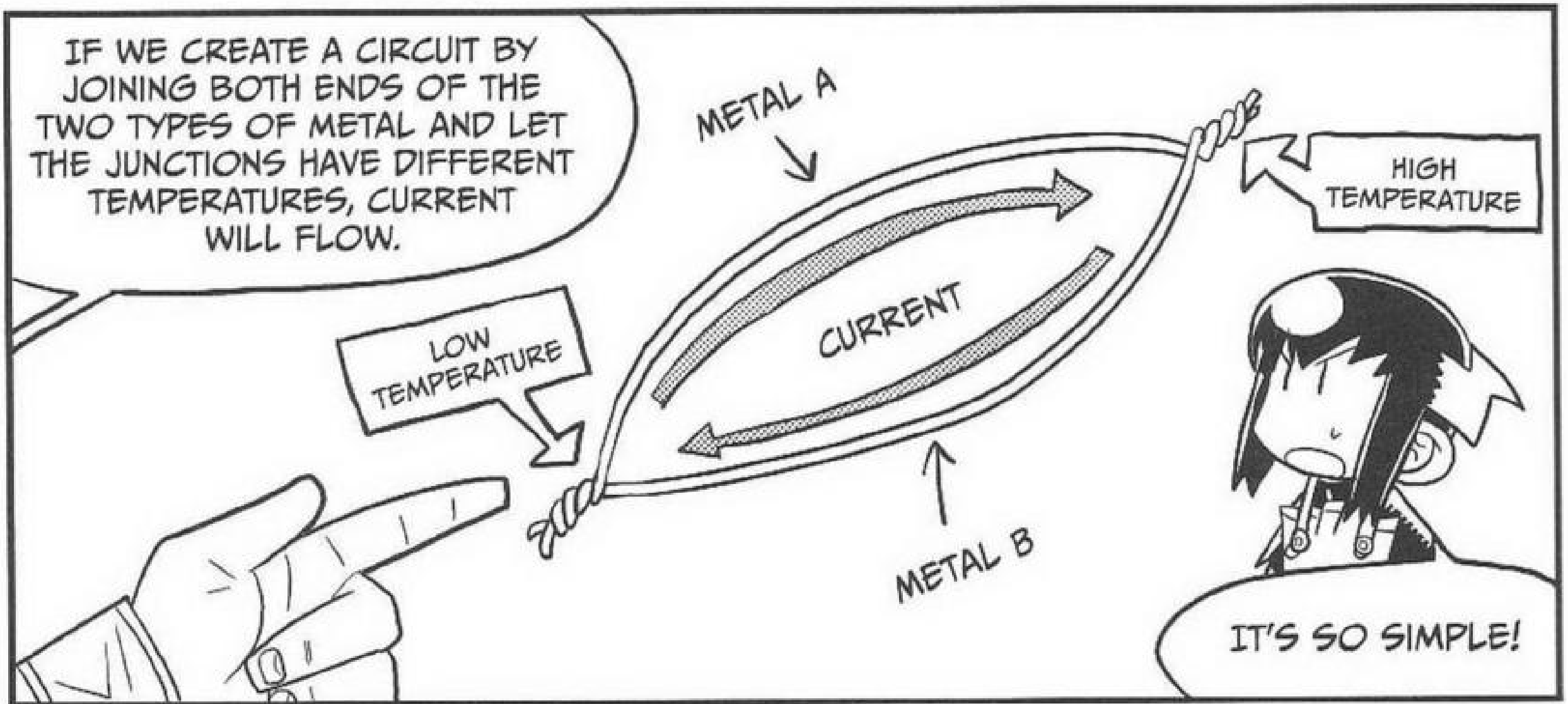
## CREATING YOUR OWN COIN BATTERY



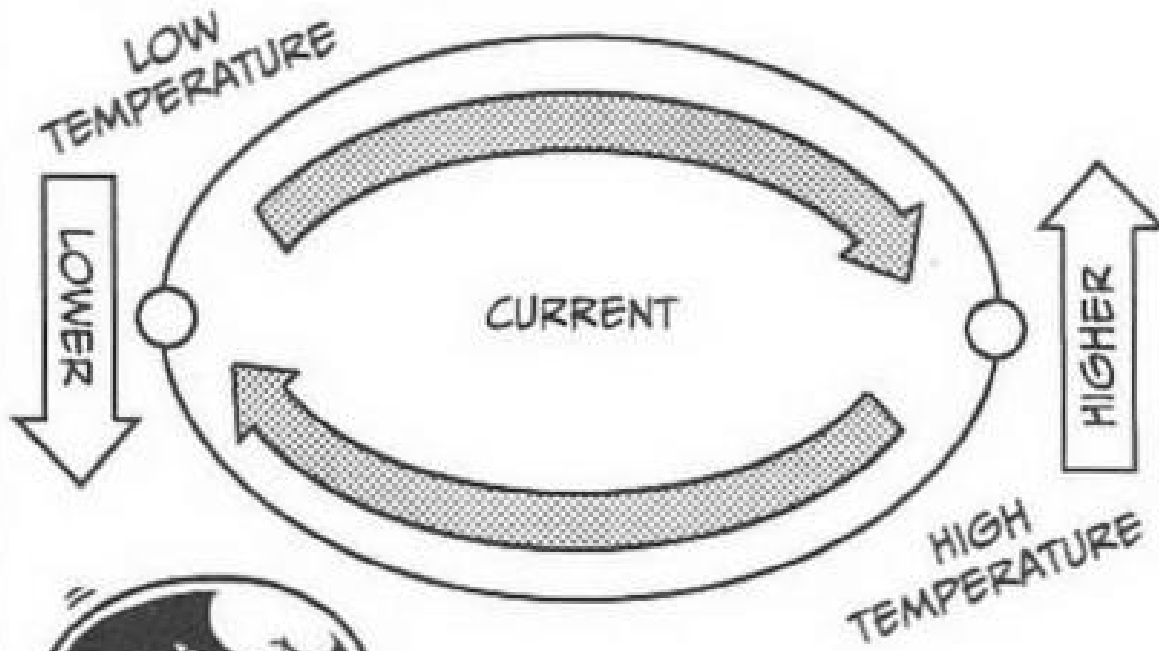


## THERMOPILES





THE GREATER THE TEMPERATURE DIFFERENCE BETWEEN THE JUNCTIONS, THE GREATER THE CURRENT THAT WILL FLOW. CURRENT WILL CONTINUE TO FLOW AS LONG AS THERE IS A TEMPERATURE DIFFERENCE.



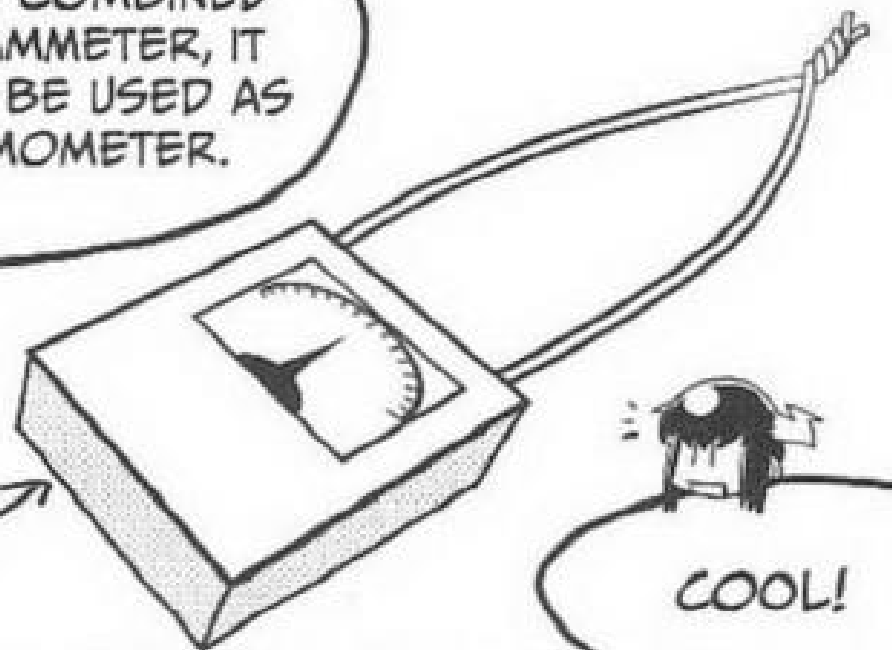
AHA!

THE JUNCTIONS OF THESE TWO TYPES OF METALS ARE CALLED THERMOCOUPLES.



IF THIS IS COMBINED WITH AN AMMETER, IT CAN ALSO BE USED AS A THERMOMETER.

AN AMMETER MEASURES CURRENT IN A CIRCUIT.



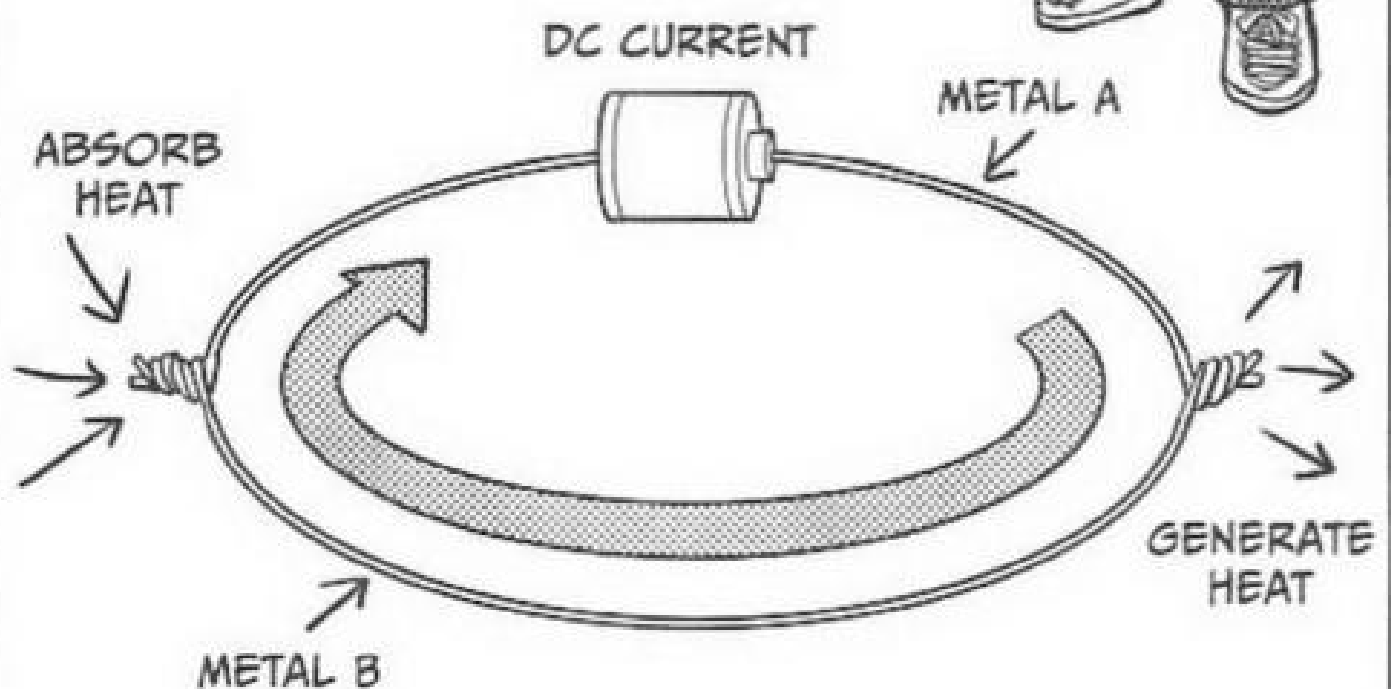
COOL!

THAT'S BECAUSE WE CAN TELL THE TEMPERATURE APPLIED TO THE THERMOCOUPLE BY CHECKING THE AMOUNT OF CURRENT, RIGHT?



EXACTLY!

THERE IS ALSO A PHENOMENON THAT IS THE REVERSE OF THE SEEBECK EFFECT. IF A DC CURRENT IS CONNECTED TO THE THERMOCOUPLES AND CURRENT FLOWS, THE THERMOCOUPLE AT ONE SIDE WILL ABSORB HEAT AND THE OTHER ONE WILL GENERATE HEAT.



WOW...SO WE SHOULD BE ABLE TO APPLY THIS TO WARM AND COOL OBJECTS, RIGHT?

RIGHT! THIS IS CALLED THE PELTIER EFFECT.

THE HEAT-ABSORBING SIDE OF A PELTIER DEVICE, WHICH IS A SEMICONDUCTOR DEVICE, IS USED IN AN APPLIANCE SUCH AS A SMALL REFRIGERATOR THAT DOES NOT NEED A MOTOR.

PHENOMENA SUCH AS THE SEEBECK EFFECT OR PELTIER EFFECT ARE COLLECTIVELY KNOWN AS THERMOELECTRIC PHENOMENA.

THANKS... THAT'S ALL FOR TODAY.

ALL RIGHT. I REALLY LEARNED A LOT!

MMMHMM.

♪ RING, RING ♪

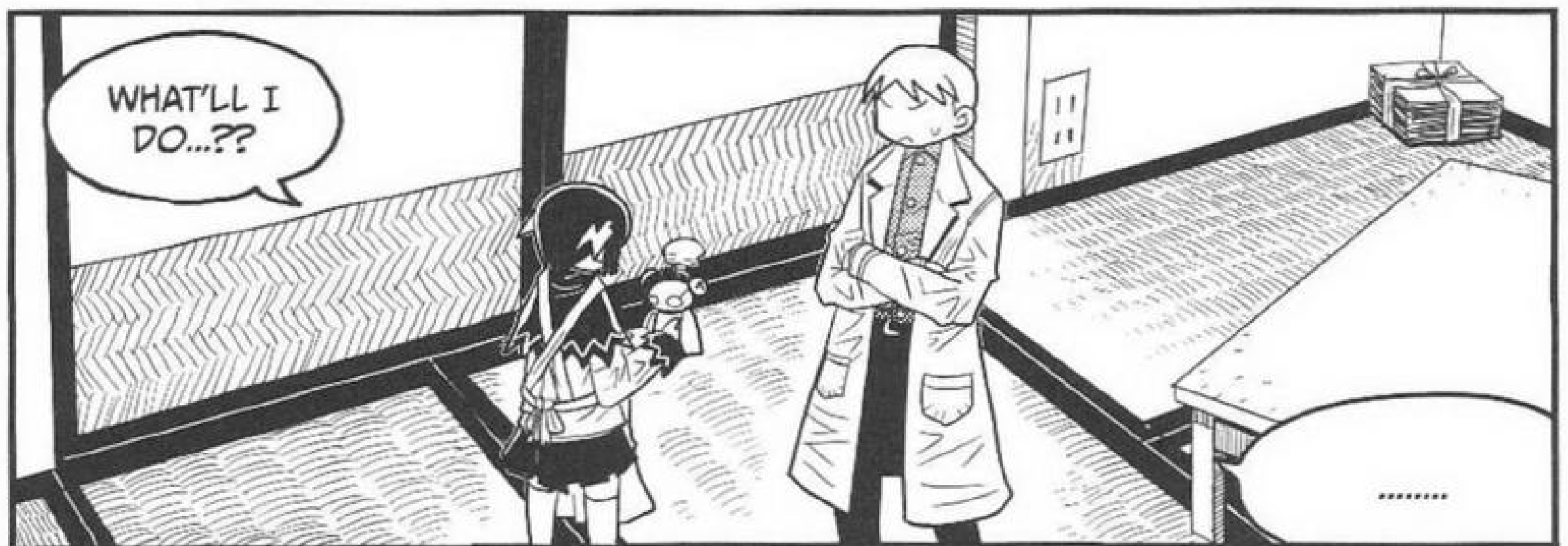
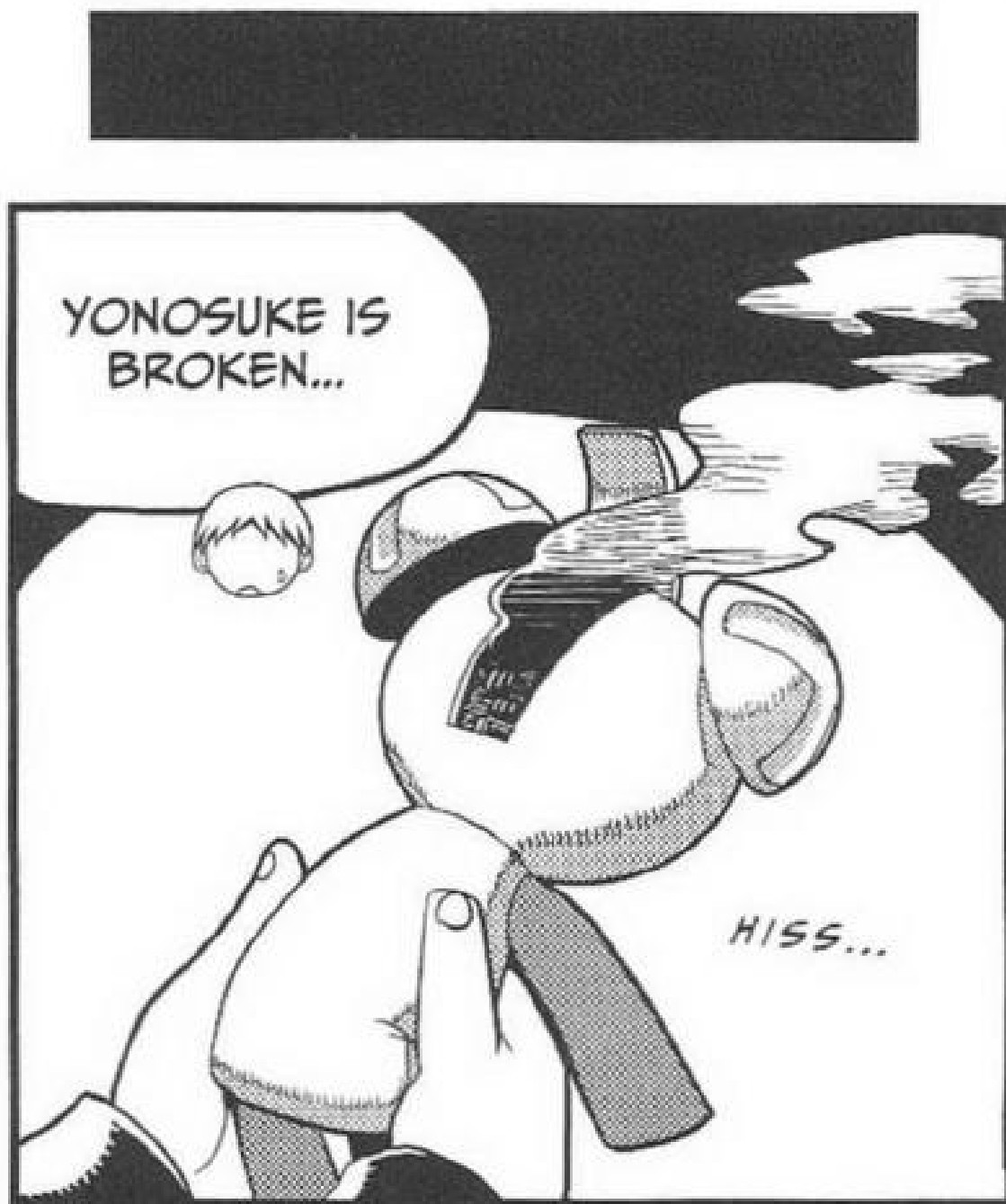
AH! TETEK A SENSEI IS CALLING.

RING, RING



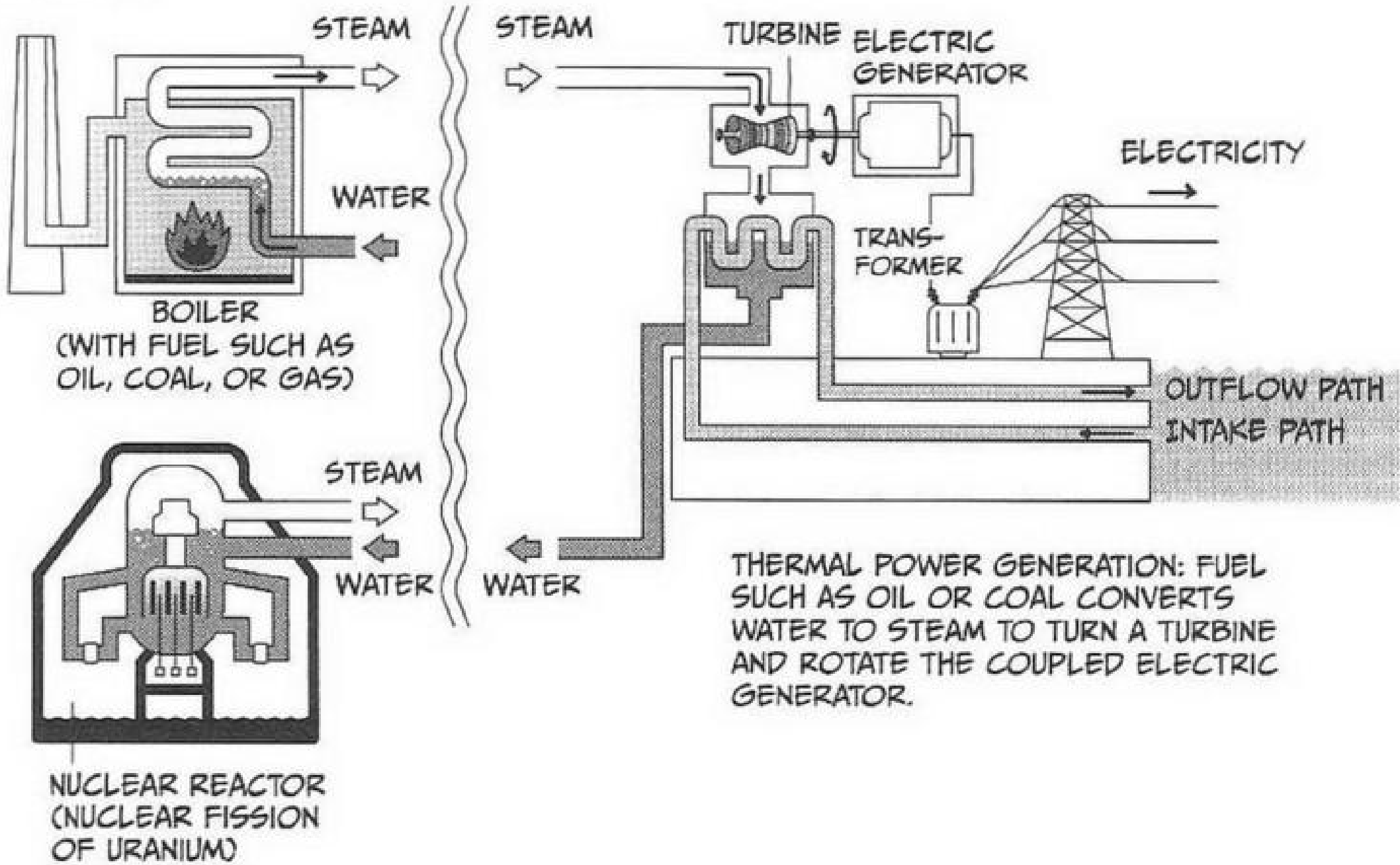
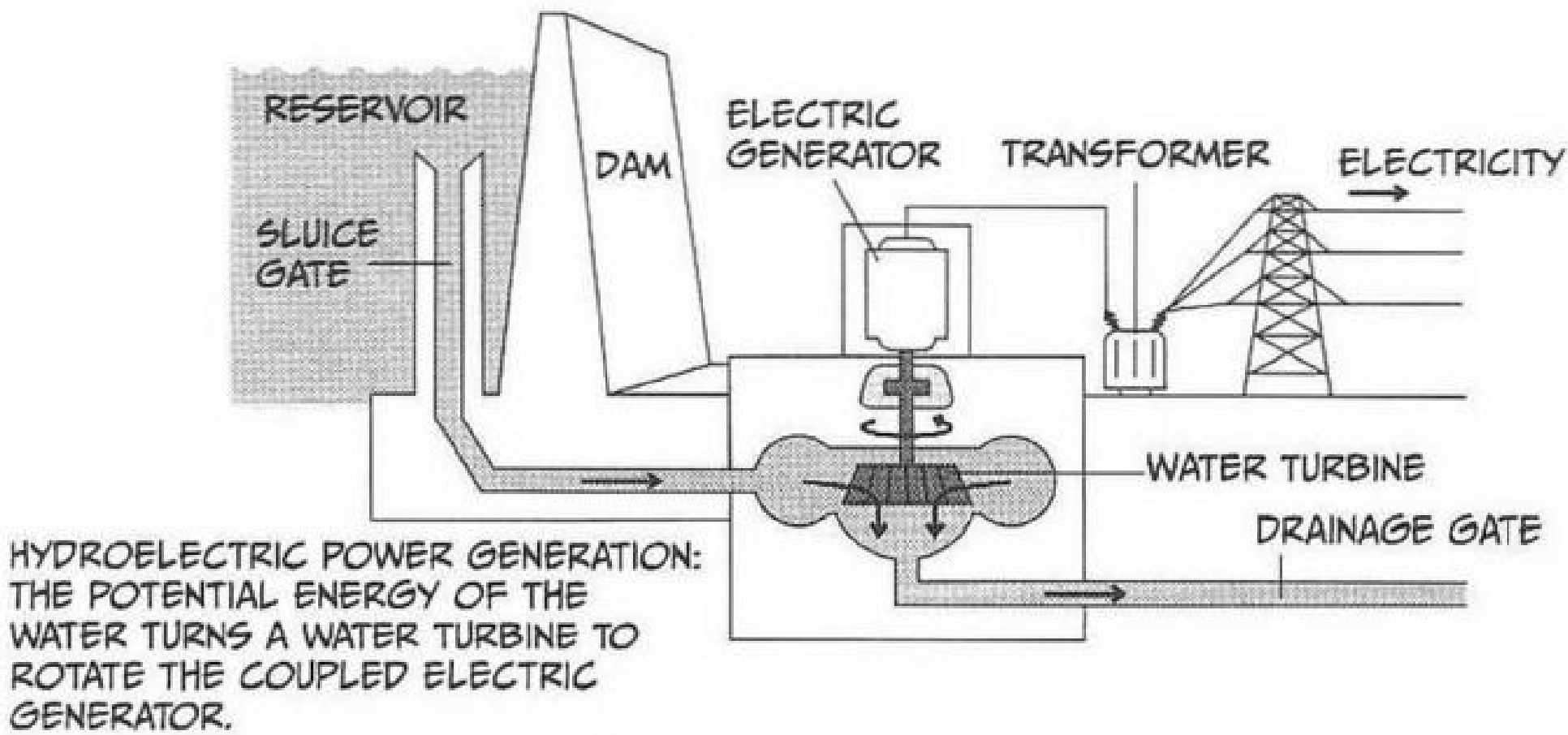




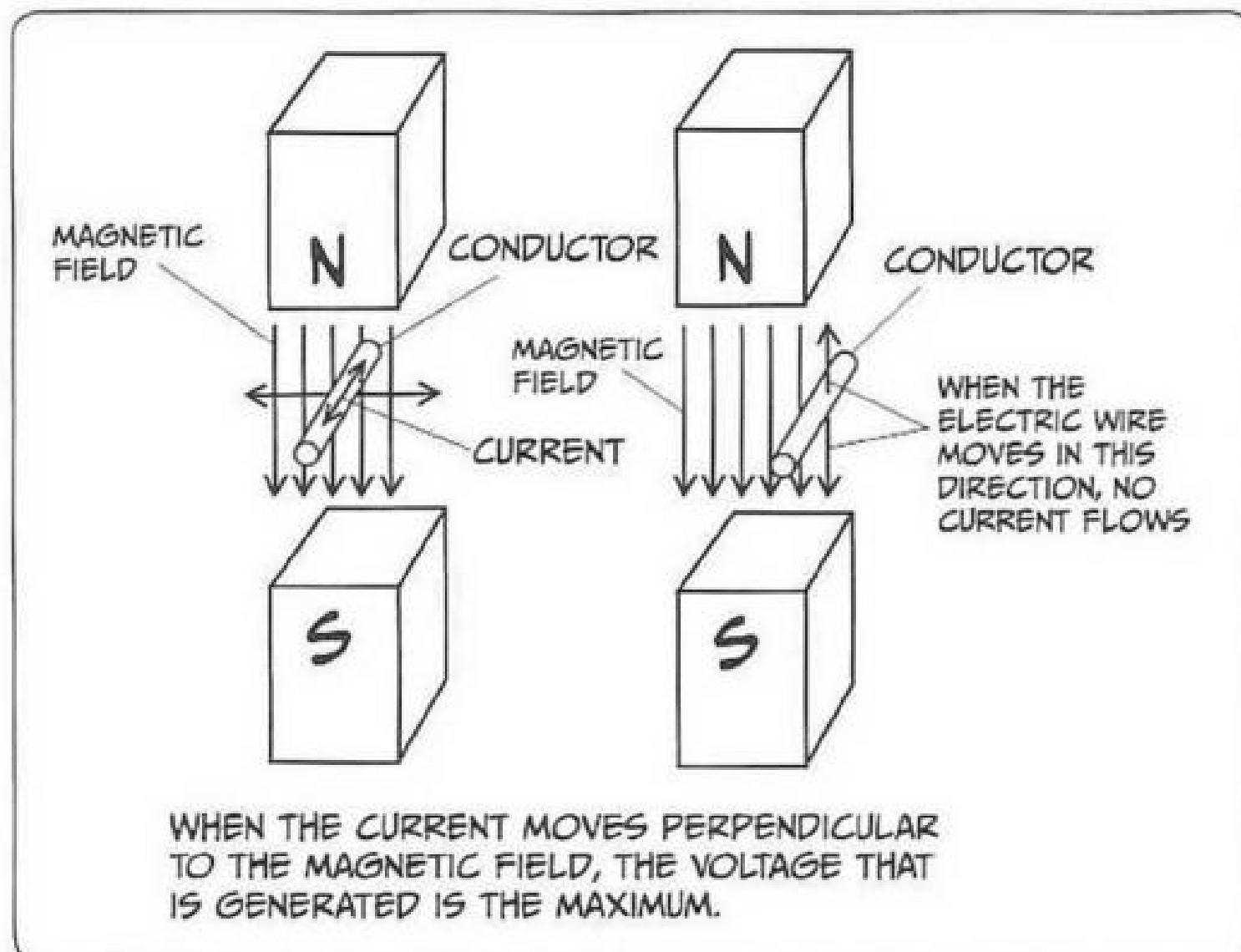


# ELECTRICITY CREATED BY A POWER PLANT

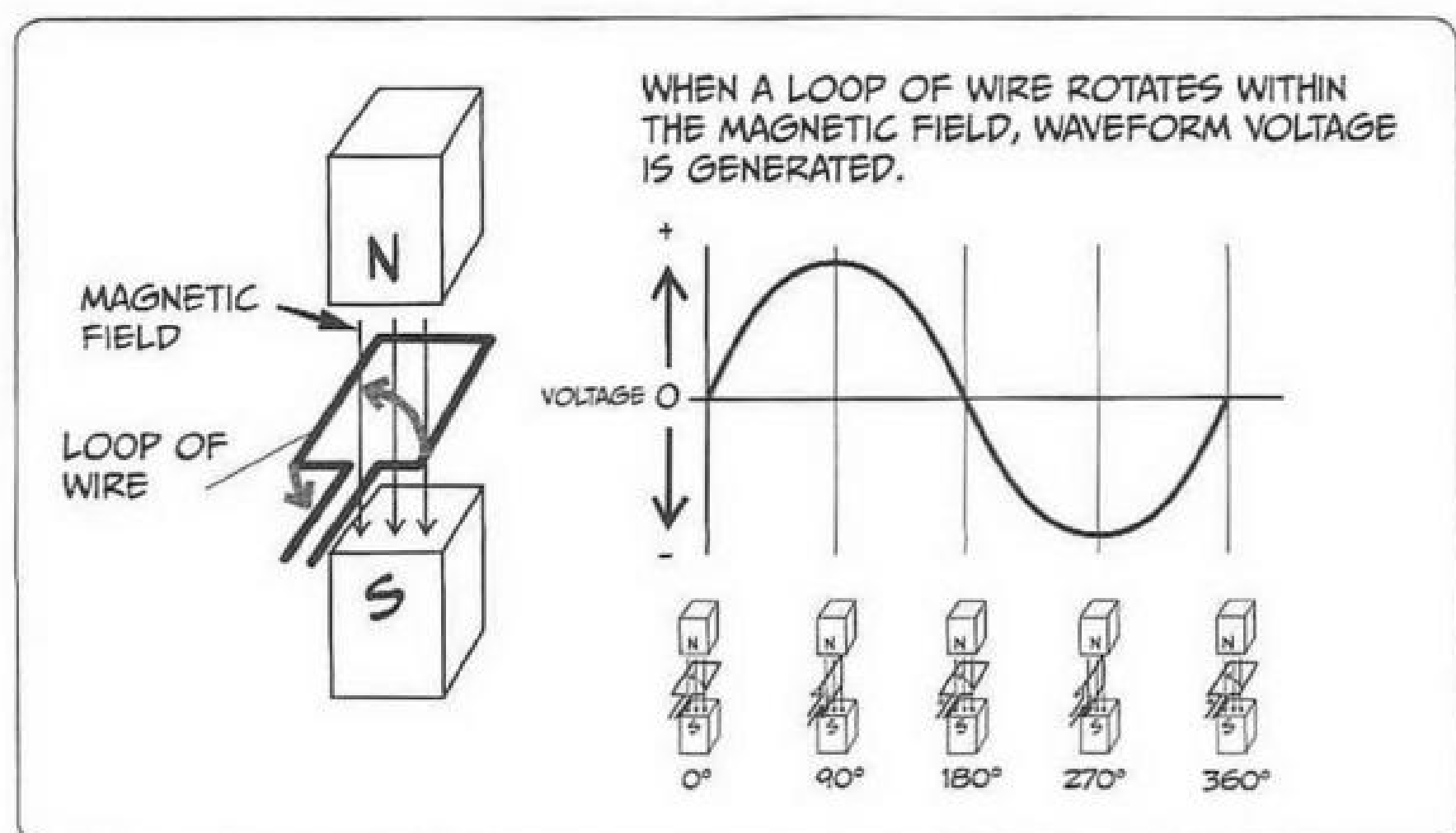
In power plants, no matter what the source of motion, a turbine spins, which generates electricity in a generator.



An electric generator creates electricity according to Fleming's right-hand rule. And since the conductor is rotating within the magnetic field, both the magnitude and direction of the electricity's flow vary repeatedly like a wave. The maximum voltage is generated when the loop of wire cuts through the magnetic field at a right angle, and the voltage is zero when the direction of the magnetic field and the direction of the loop's movement are the same.



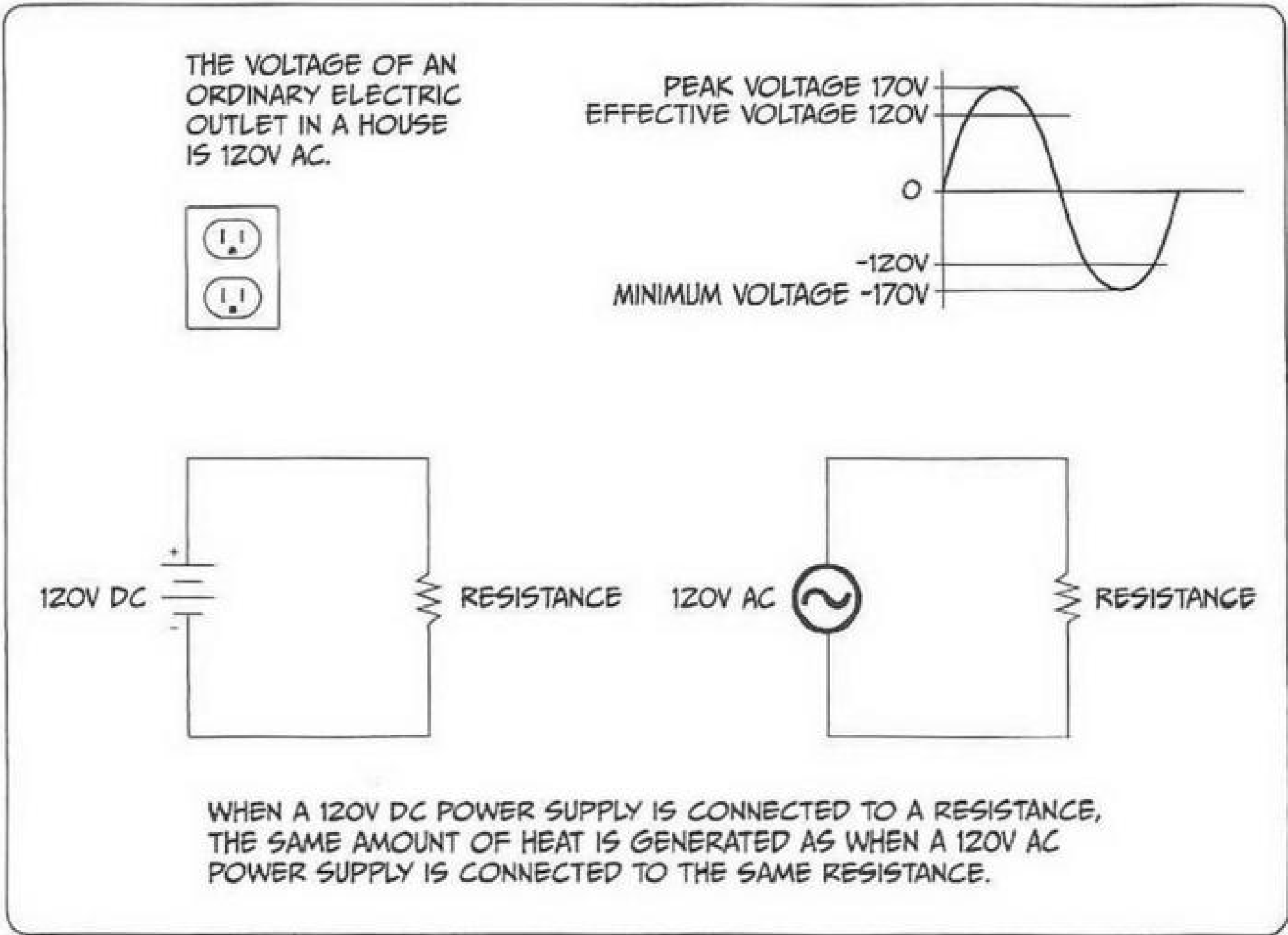
*Electricity generated in a conductor*



*Electricity created by an electric generator*

The electricity that is created by this process is called *alternating current (AC)*. This is the electricity that comes from a household electric outlet. One wave is created by one rotation of the conductor within the magnetic field. If the conductor rotates 60 times per second, 60 waves are produced per second. This would be electricity with a frequency of 60 hertz (Hz).

The voltage of an ordinary household electric outlet is 120V AC. The *peak voltage* of the wave of this electricity is approximately 170V. The value of 120V represents the *effective voltage*, which is the value for which direct current (DC) electricity does the same work—in other words, the amount of heat generated when 120V AC is applied to a resistance is the same as the amount of heat generated when 120V DC is applied to the same resistance.



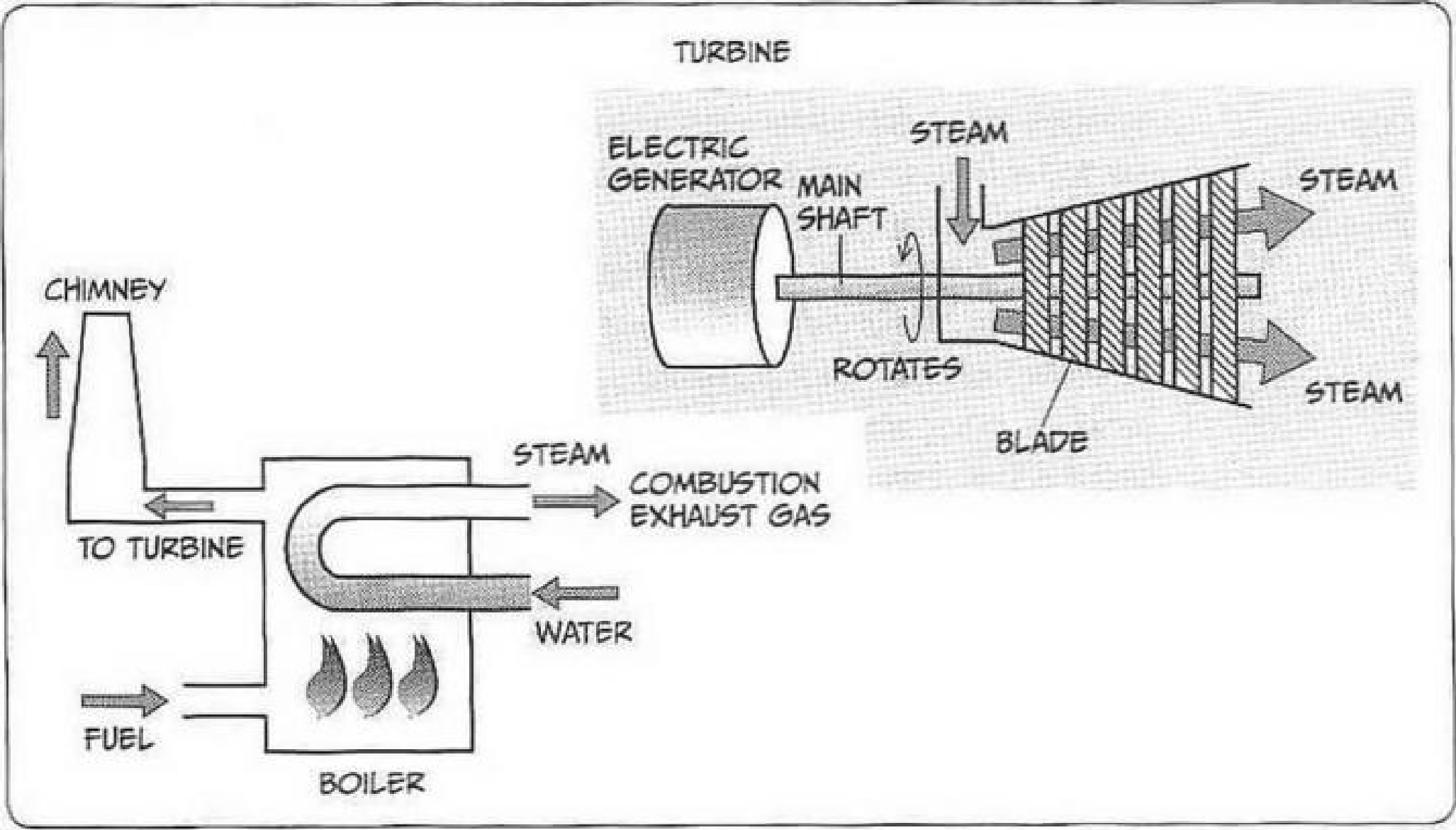
AC voltage and effective voltage

## THERMAL POWER GENERATION

The types of thermal power generation that generate the most electrical power are steam generation, internal combustion generation, gas turbine generation, and combined cycle generation.

*Steam generation* burns fuel such as oil, coal, or liquefied natural gas (LNG) in a boiler to generate high-temperature, high-pressure steam. The force of that steam turns a turbine that is coupled with an electric generator to generate electricity.

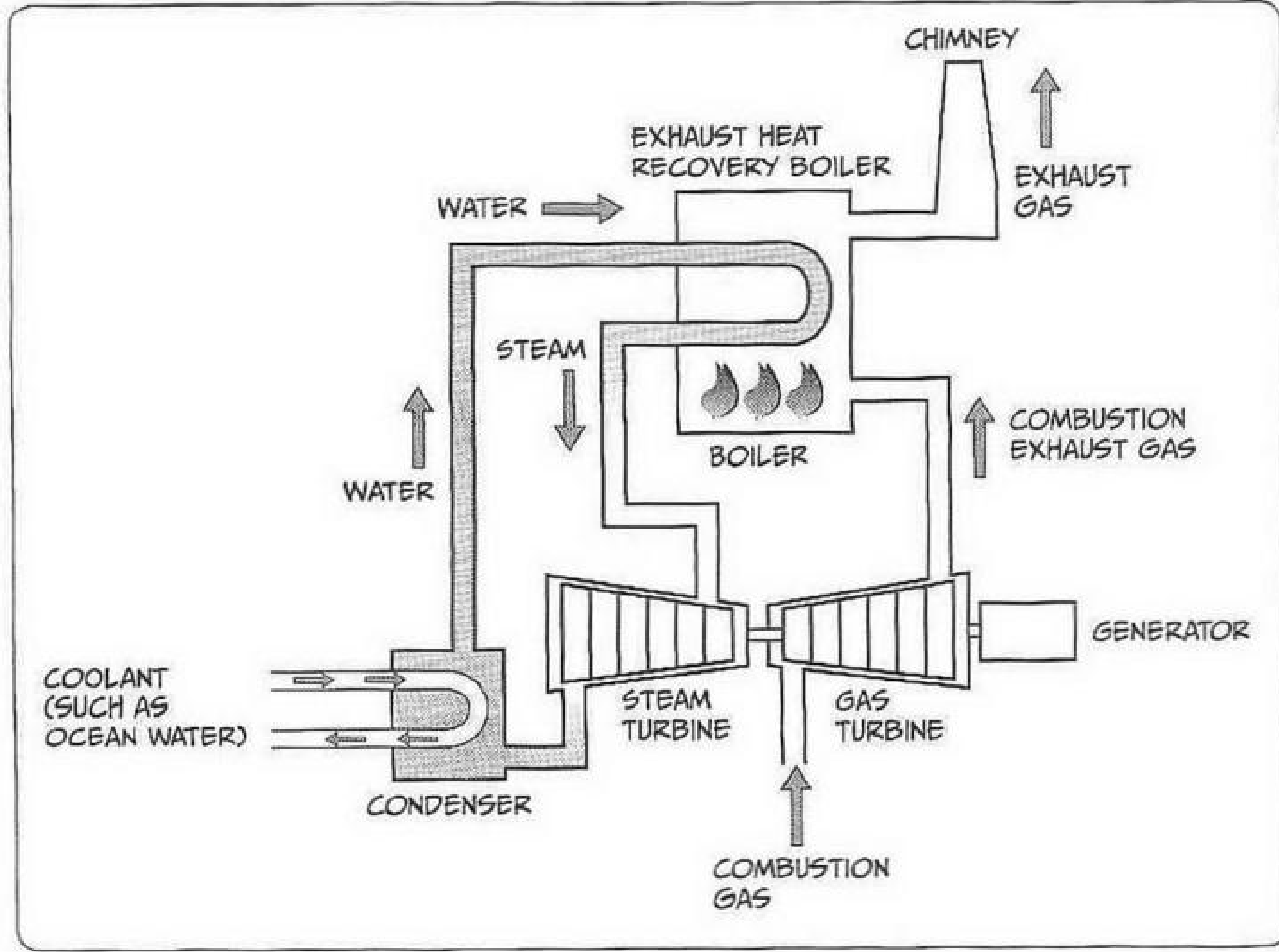
The steam that was used to generate electricity is cooled in a device called a *condenser*; once it returns to liquid water, it is then sent to the boiler again.



*Turbine and steam power generation*

*Internal combustion generation* uses an internal combustion engine (like a diesel engine) to generate electricity.

*Gas turbine generation* uses a combustion gas such as kerosene or diesel oil to turn a gas turbine and create electricity.



*Combined cycle generation*

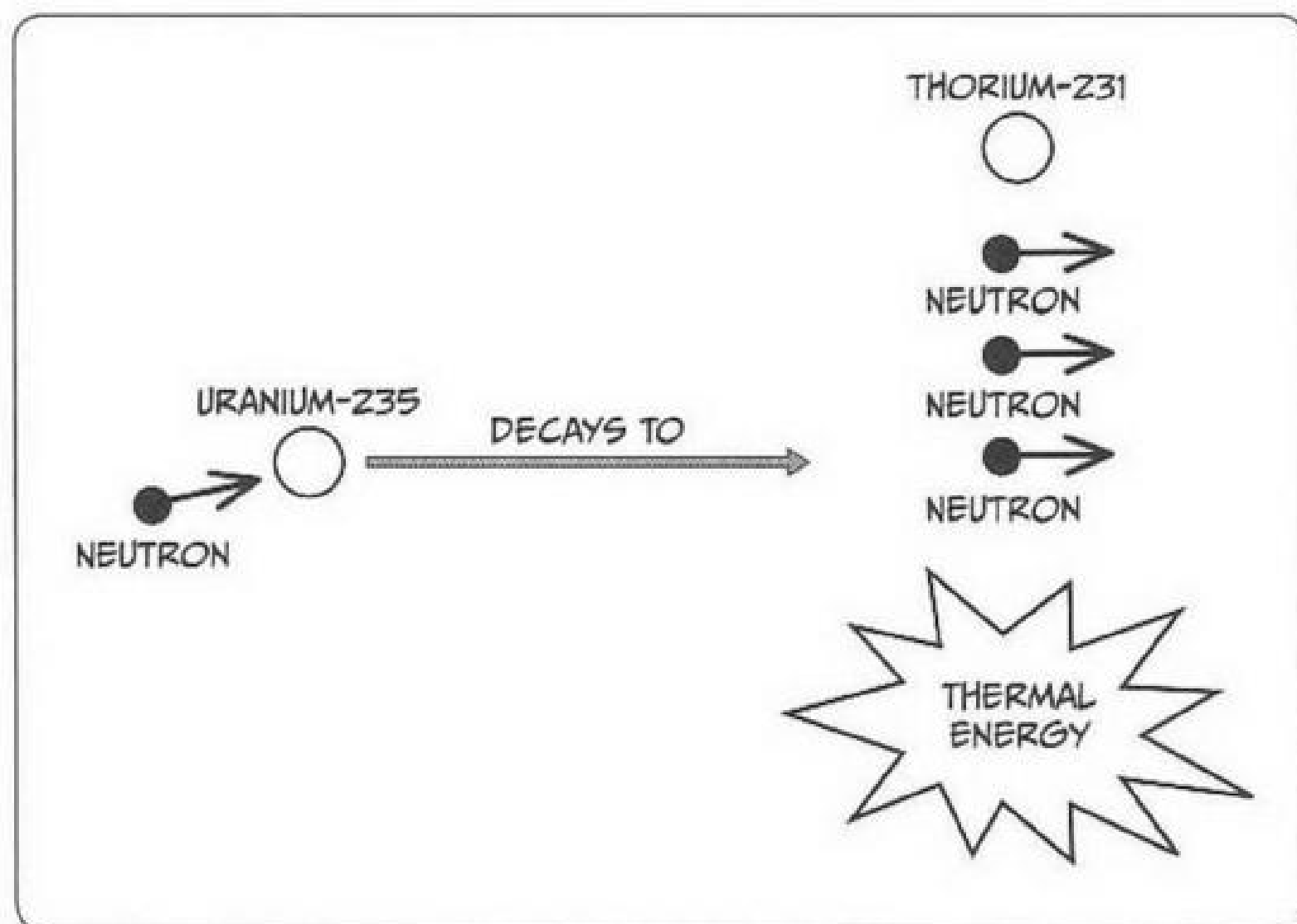


*Combined cycle generation* combines steam generation and gas turbine generation. Electricity is generated by a gas turbine, and then the heat of the exhaust gas is used to create steam to turn a steam turbine and generate more electricity; this is an efficient method of generating electricity.

## NUCLEAR POWER GENERATION

*Nuclear power generation* uses the heat generated when the nuclear fission of uranium occurs in a nuclear reactor to create high-temperature, high-pressure steam, which turns a turbine and creates electricity. When a neutron collides with uranium-235, it decays to thorium-231; several neutrons as well as heat are emitted. The neutrons successively collide with other uranium-235 nuclei, causing *nuclear fission* to occur and generating a great deal of thermal energy.

Nuclear power generation uses this heat to create steam, which turns a turbine and generates electricity in a manner similar to thermal power generation. *Control rods*, which absorb neutrons, and a *moderator*, which reduces the speed of the neutrons, are used in the nuclear reactor to control nuclear fission and regulate the reactor's output.

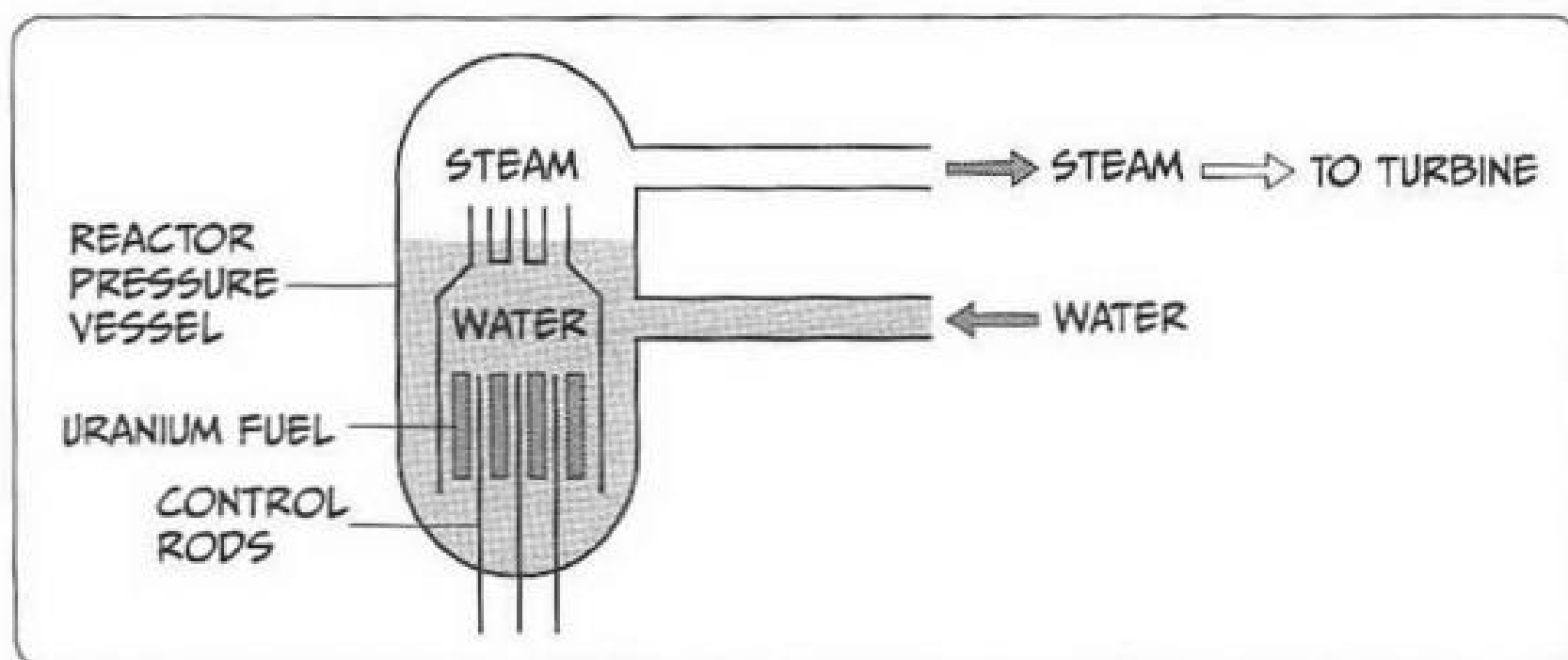


*The nuclear fission of uranium-235 leads to more neutrons, which may strike other U-235 atoms, causing a chain reaction.*

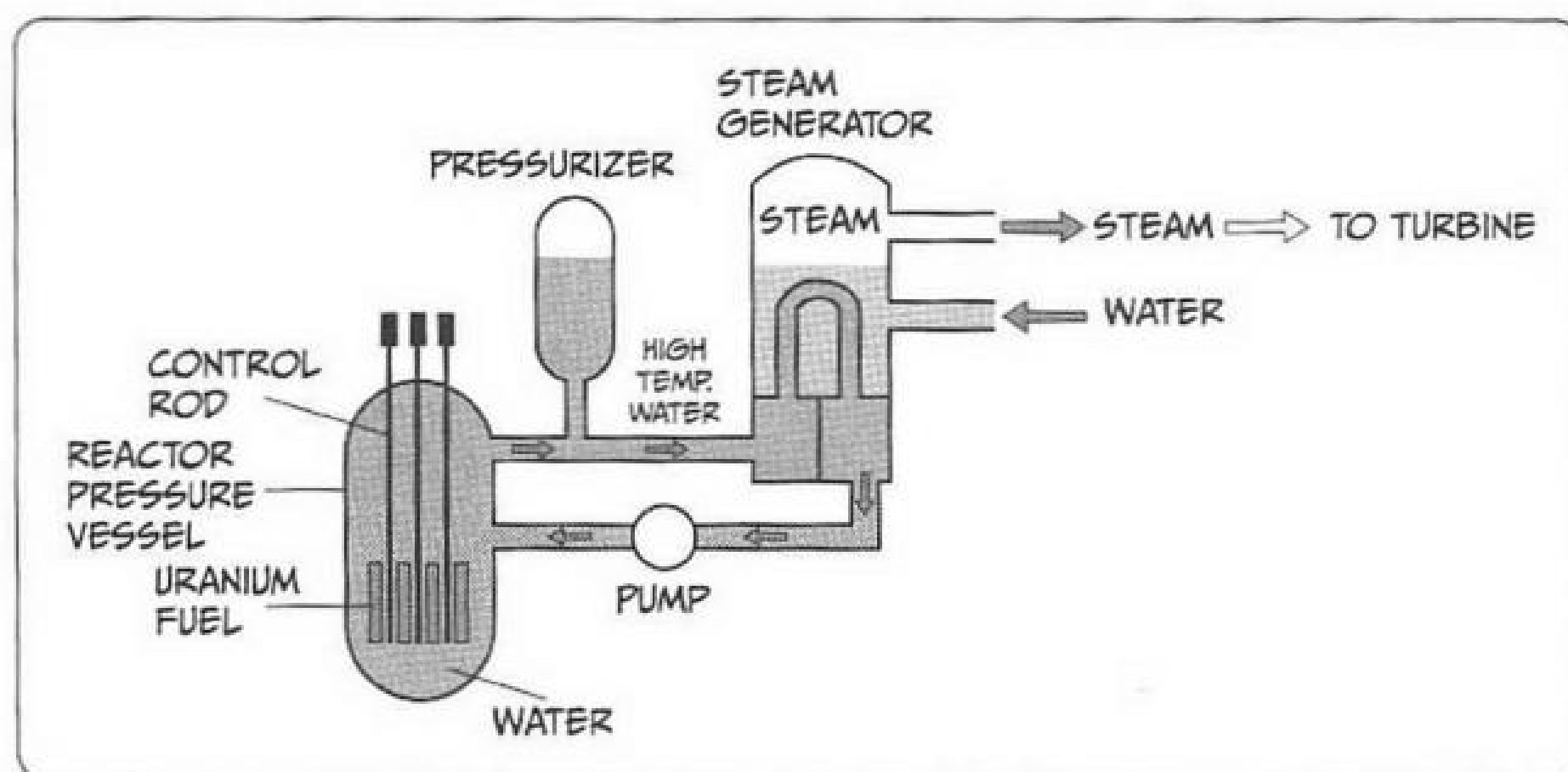
There are various types of nuclear reactors. Currently, the type that is used most often is called a *light water reactor*, which uses light water (ordinary water) as a moderator and coolant. Light water reactors include boiling water reactors and pressurized water reactors.

A *boiling water reactor* sends steam that was generated in the reactor pressure vessel directly to the turbine; after it turns the turbine, the steam turns back into liquid water in a device called a condenser, and the water is reused. A *condenser* uses ocean water to cool the steam so it turns back into liquid water and can be reused.

A *pressurized water reactor* passes boiling water that was created in the reactor pressure vessel to the steam generator, where water from a separate system is changed to steam, which turns the turbine.



*Boiling water reactor*



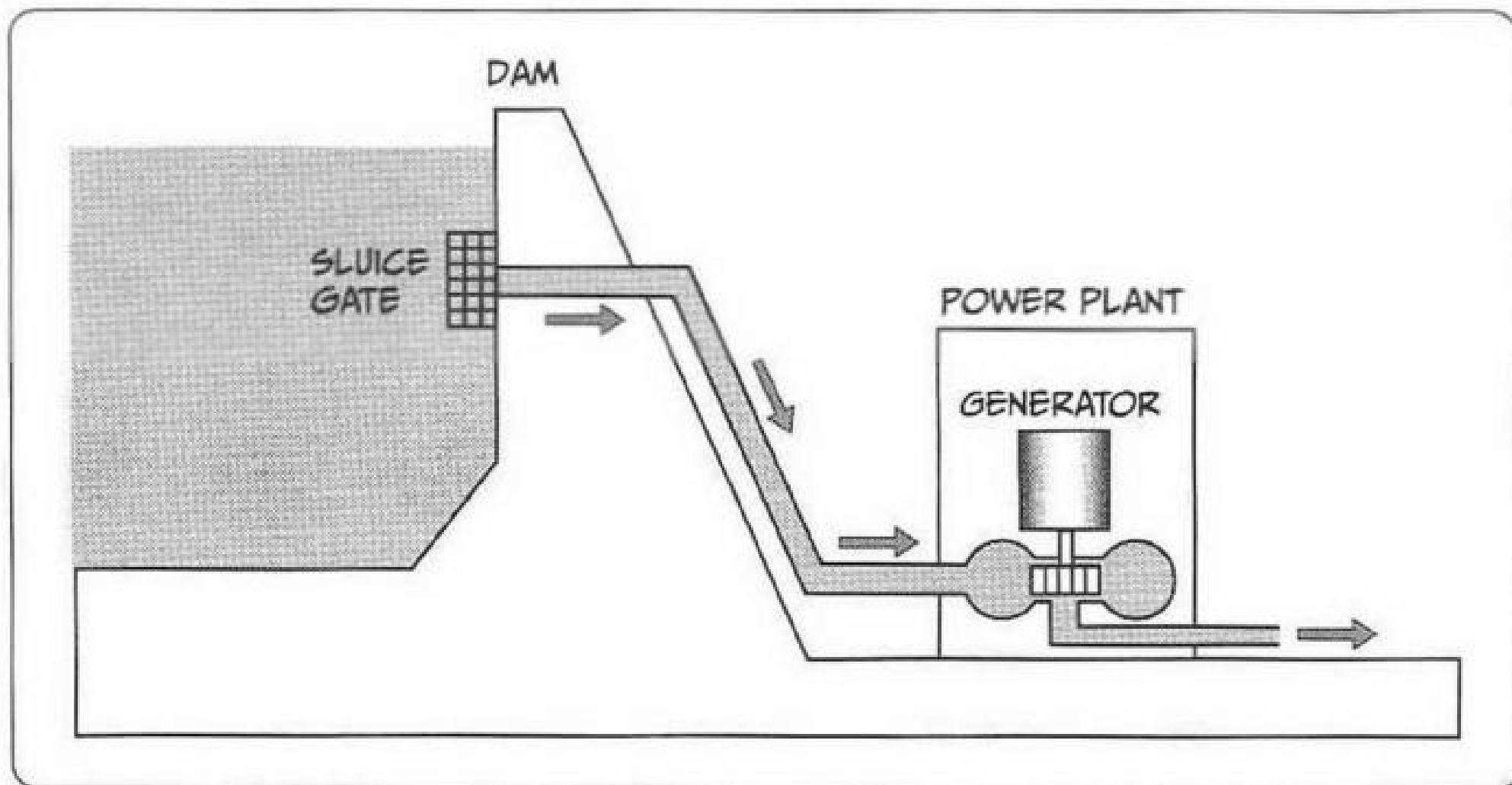
*Pressurized water reactor*

## HYDROELECTRIC POWER GENERATION

*Hydroelectric power generation* uses the potential energy of water to generate electricity. *Dam-type power generation* stores water at a high location and lets the water drop from there to turn a water turbine coupled with an electric generator to generate electricity.

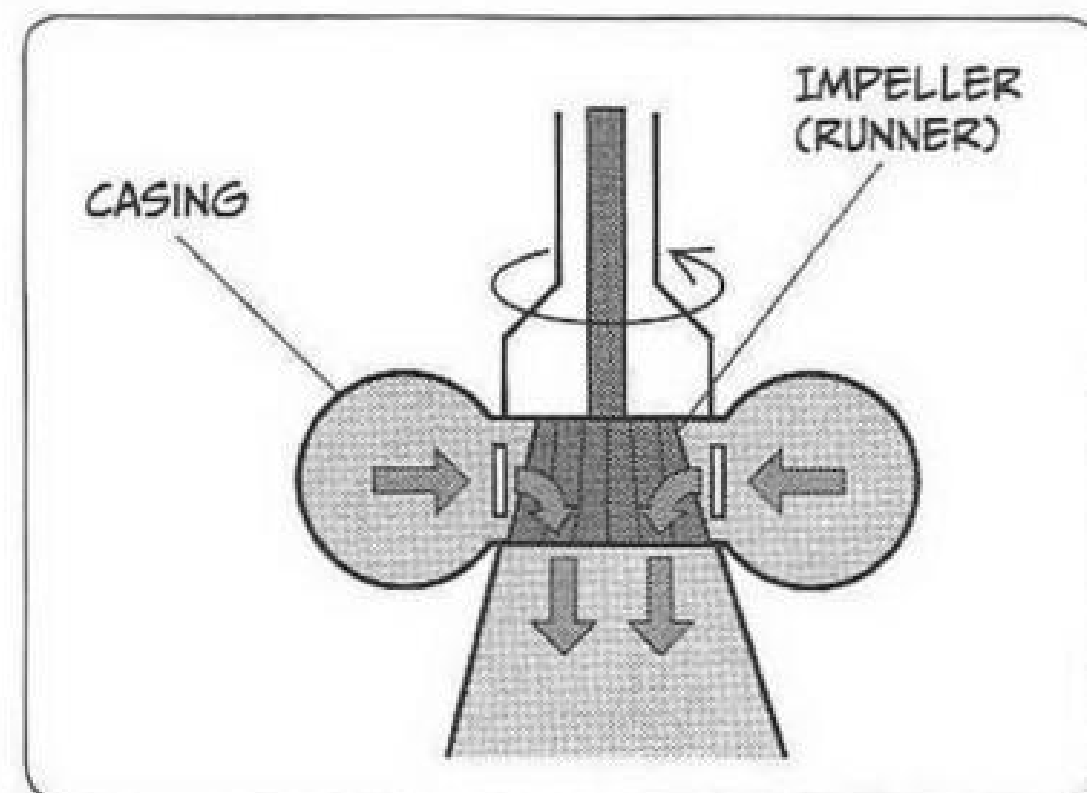
Since it is easier to start and stop power generation and to increase or decrease the amount of power generated via hydroelectric power generation than it is to do so for thermal or nuclear power generation, hydroelectric power can be generated corresponding to varying power demands. Also, during periods of low power demand, a lift pump can be used to draw water up to the higher location to store it as potential energy.

For hydroelectric power generation to use the energy of water efficiently, several types of water turbines are used for different purposes according to the *head (height difference)* or amount of water.



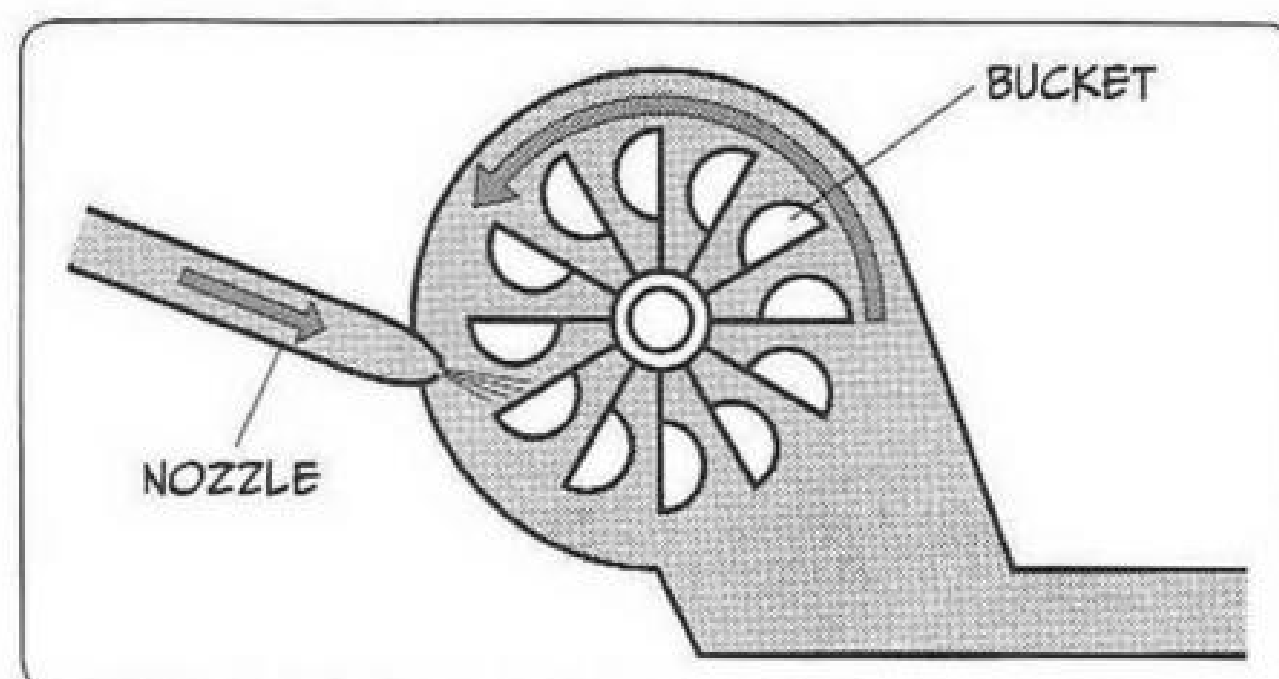
*Dam-type power plant*

A *Francis turbine* is used for a large amount of running water and a medium to high head. This type of water turbine is used for approximately 70 percent of the hydroelectric power generation in Japan. The water is directed perpendicular to the main shaft from all directions, the blades inside the turbine change the water's direction to the axial direction, and the turbine is rotated by hydraulic power when the water is discharged.



*Francis turbine*

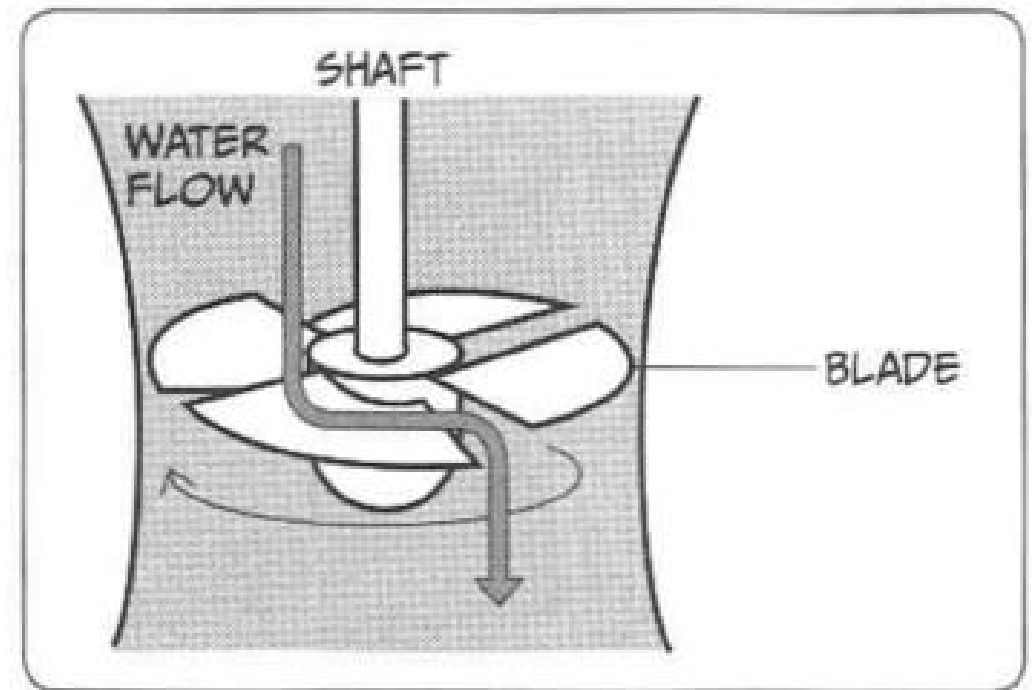
A *Pelton wheel* is a water turbine that rotates from the recoil that occurs when water sprayed from a nozzle hits a spoon-shaped bucket (blade). It is useful in locations that have a high head.



*Pelton wheel*

A *Kaplan turbine* is a water turbine that rotates because several propeller blades connected to a shaft adjust their angles according to variations in the amount of water flowing or the head. This kind of turbine is useful in locations having a low head. A type of Kaplan turbine that does not adjust the angle of the blades is called a *propeller turbine*.

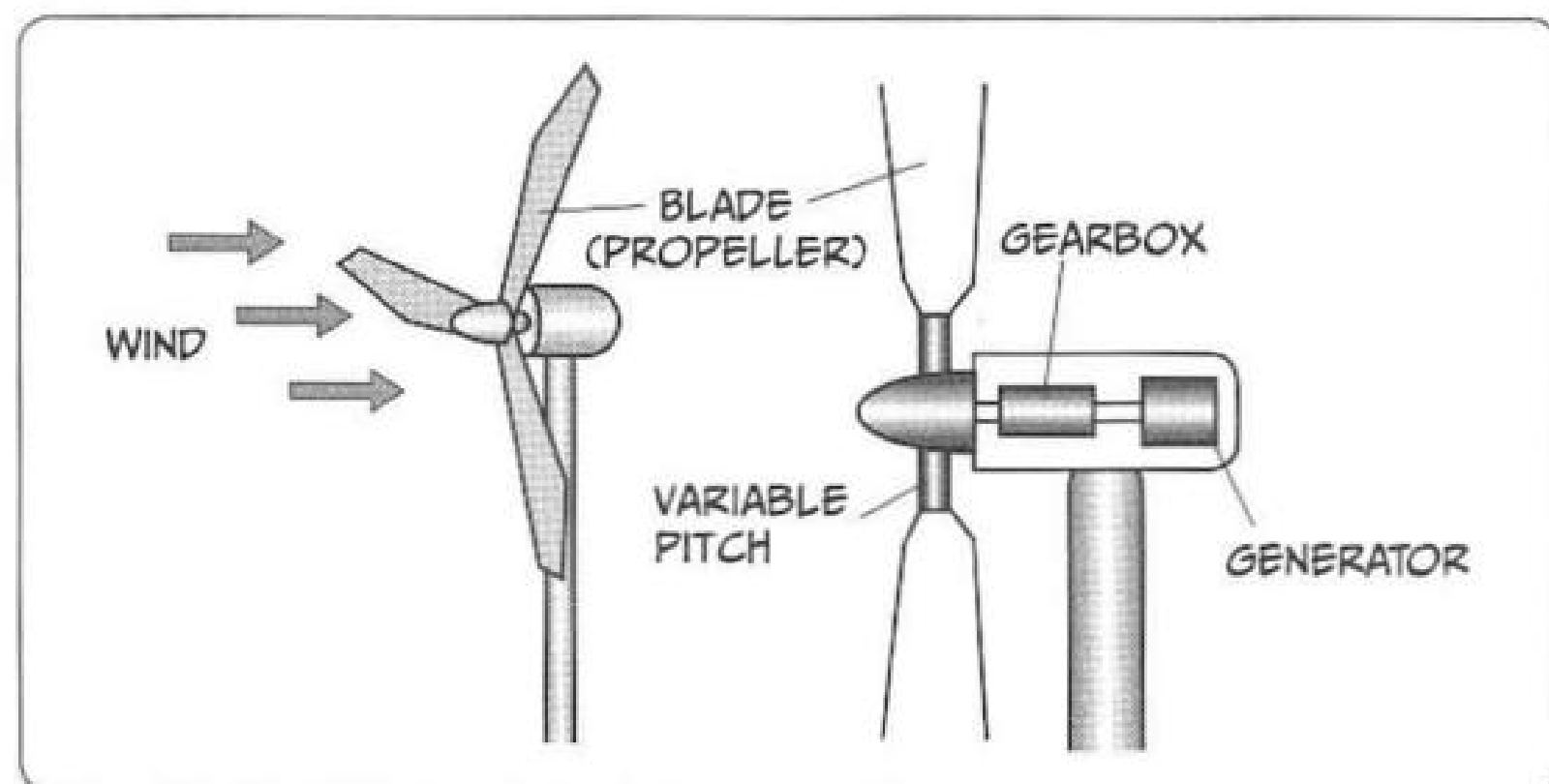
Although hydroelectric power generation accounts for only 10 percent of Japan's power generation, it is a valuable method for a country with few resources.



*Kaplan turbine*

## WIND POWER GENERATION

Wind power generation uses wind power to turn a turbine; the turbine in turn rotates an electric generator to create electricity.



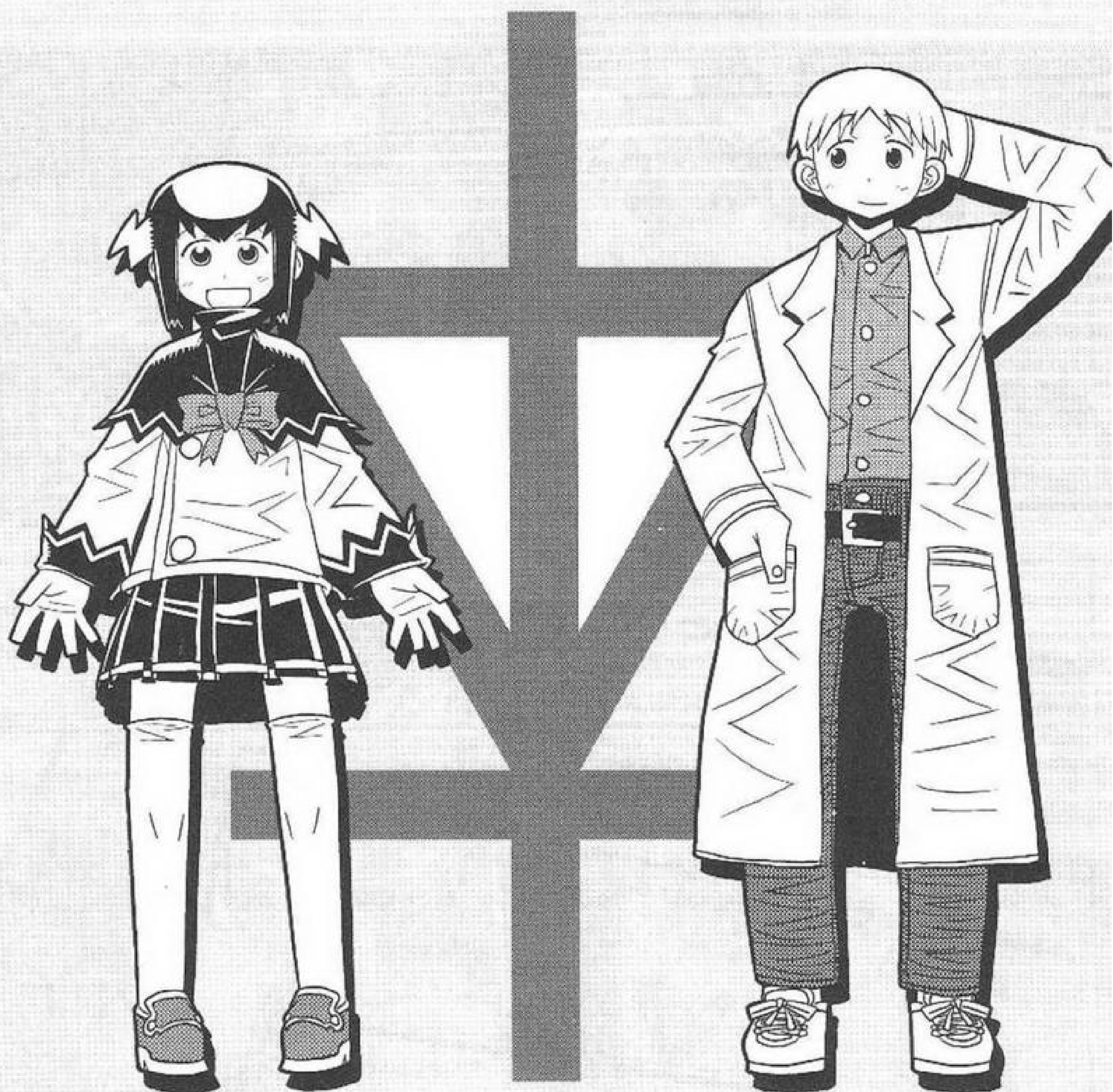
*Mechanism of wind power generation (propeller wind turbine)*

There are various types of wind turbines for wind power generation. A *propeller wind turbine*, which uses wind power energy very efficiently, is common. When wind hits the turbine's blades, it creates rotational motion, and the rotation speed is increased by a gearbox to turn an electrical generator. An *anemoscope* (wind vane) and an *anemometer* (wind gauge) constantly measure the wind conditions, and the direction of the propeller and angle of the blades are adjusted to the optimum state to use the wind power most effectively.

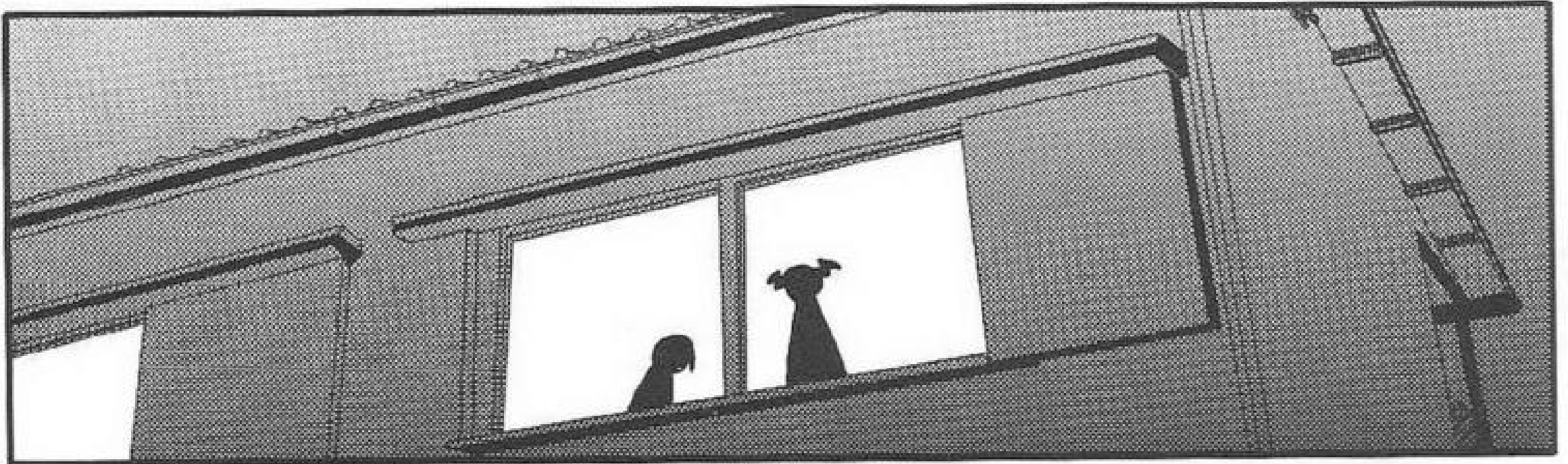
Although the power supplied by wind power generation is greatly affected by variations in the direction and speed of the wind, and the noise that is generated when the wind turbine rotates can be a problem, this is a clean, environmentally friendly power generation method that requires no fuel and produces no exhaust gases.

5

HOW CAN YOU CONVENIENTLY USE  
ELECTRICITY?



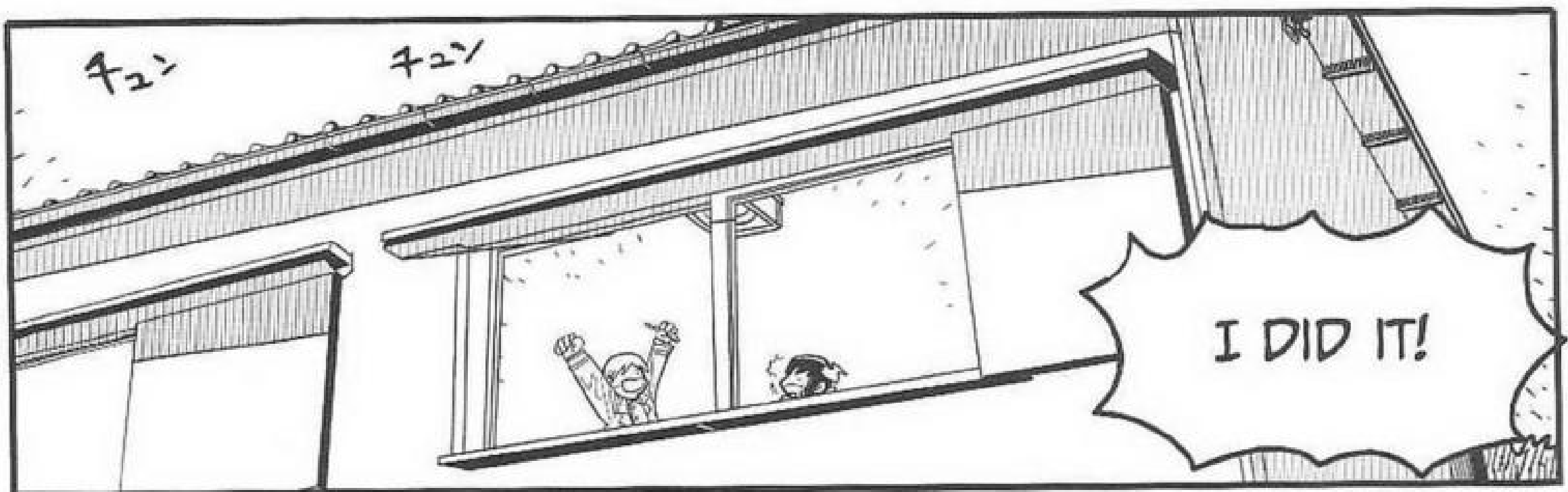
FORTUNATELY, HIKARU WAS ABLE TO REPAIR  
YONOSUKE'S BREAKDOWN WITH THE  
TECHNOLOGY AVAILABLE ON EARTH.



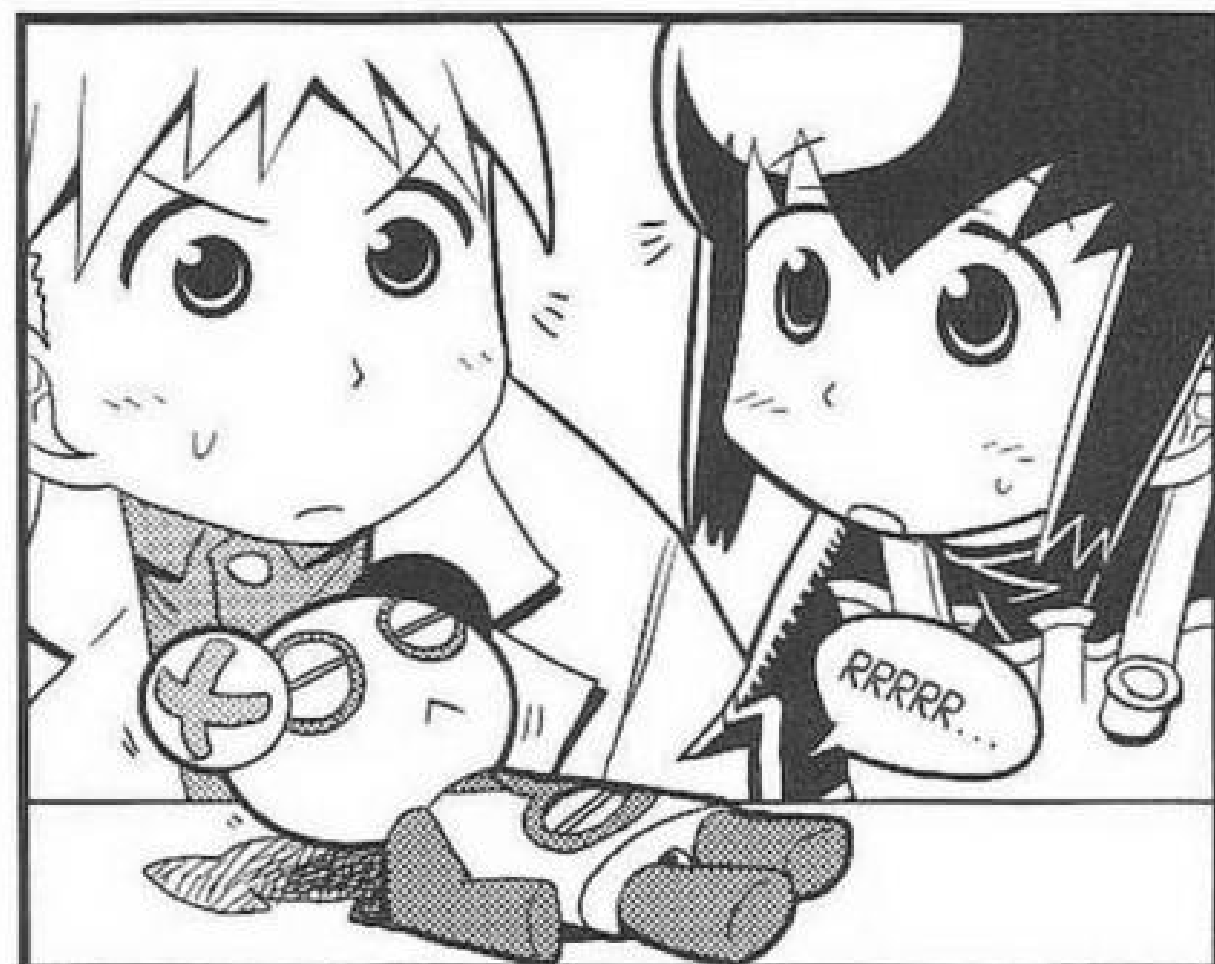
HE WORKED ON YONOSUKE EVERY NIGHT...



AND SEVERAL DAYS LATER...







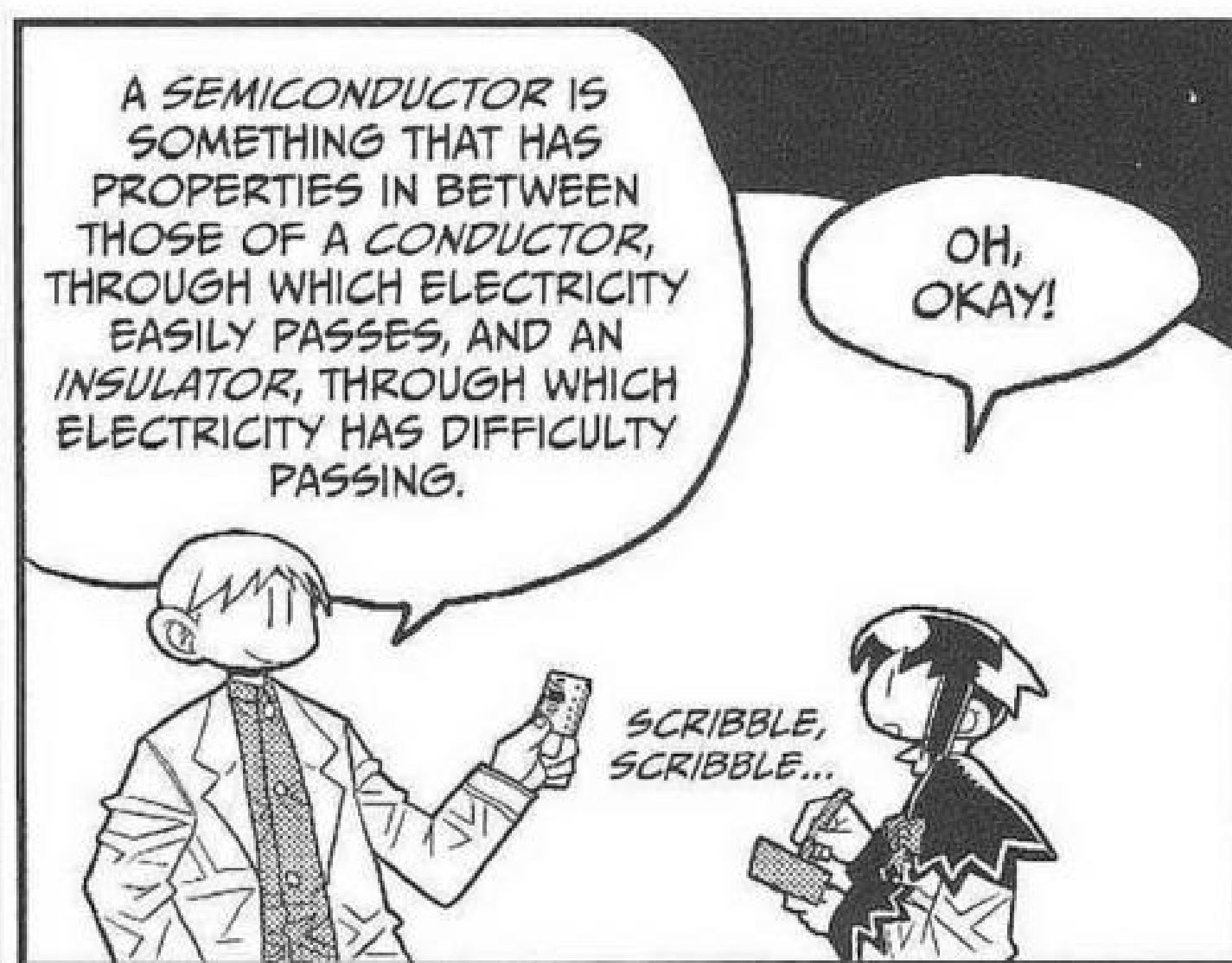
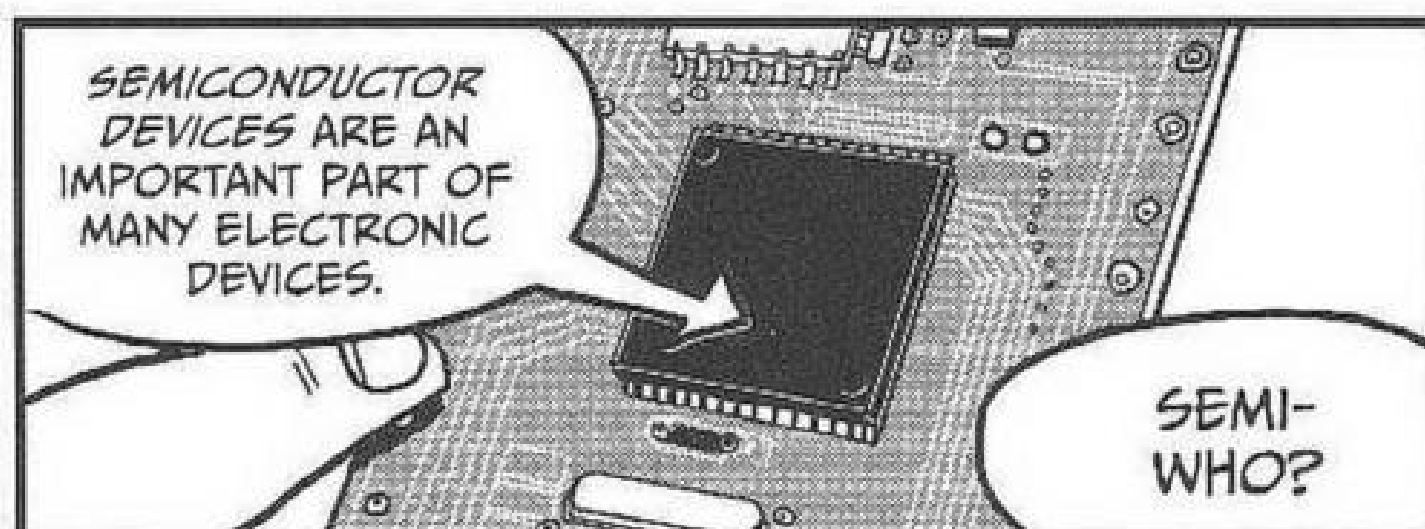


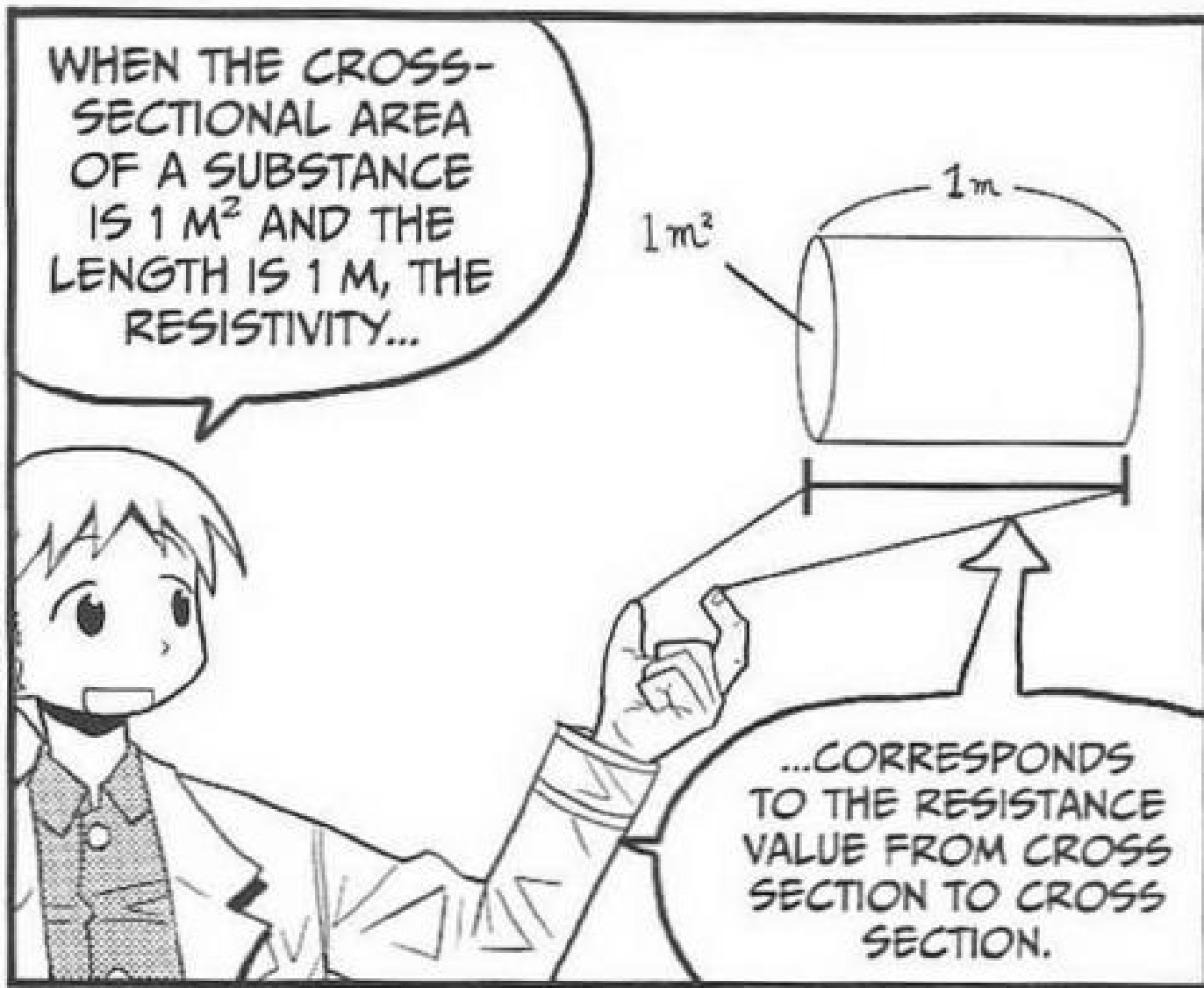






# WHAT ARE SEMICONDUCTORS?

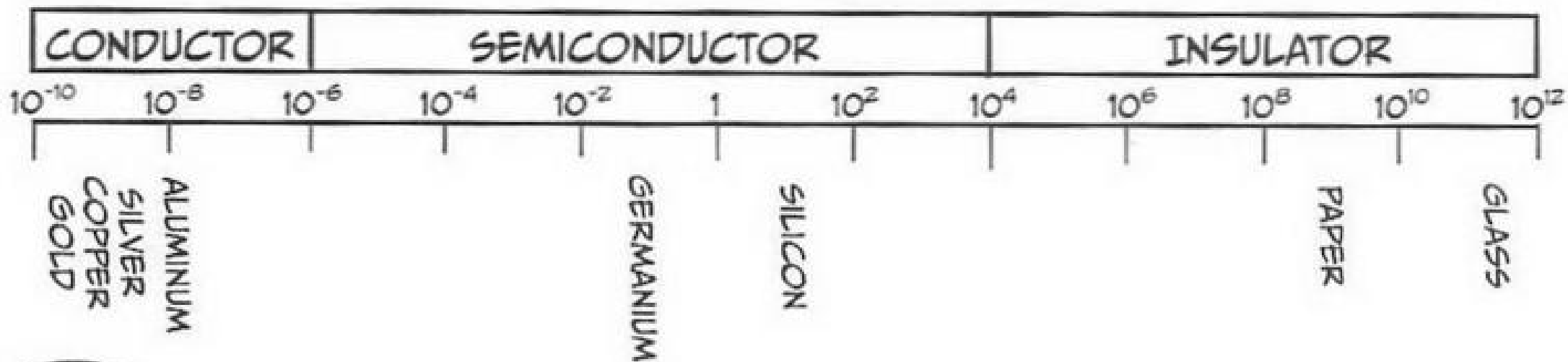




ELECTRICITY FLOWS EASILY

RESISTIVITY IN  $\Omega \text{ M}$

ELECTRICITY HAS DIFFICULTY FLOWING



THE DISTRIBUTION OF RESISTIVITIES OF VARIOUS SUBSTANCES LOOKS LIKE THIS.





IN PARTICULAR,  
SEMICONDUCTORS  
ARE SUBSTANCES  
WHOSE ELECTRICAL  
CHARACTERISTICS CHANGE  
DUE TO THE EFFECTS  
OF HEAT, LIGHT, OR  
ELECTRICITY.

THEY  
SOUND  
MYSTERIOUS!

SEMICONDUCTORS  
MAY CONTAIN  
SUBSTANCES SUCH  
AS SILICON OR  
GERMANIUM.

CHEMICAL SYMBOL

**Ge**      **Si**  
GERMANIUM   SILICON

DIODES

TRANSISTORS

COMPONENTS SUCH AS  
DIODES OR TRANSISTORS,  
WHICH ARE CREATED USING  
SEMICONDUCTORS, ARE  
CALLED SEMICONDUCTOR  
DEVICES.

WHEN YOU PUT IT  
THAT WAY, IT'S EASY  
TO UNDERSTAND!

Ge

Si

SILICON OR  
GERMANIUM ARE  
ELEMENTS, BUT...

...A SEMICONDUCTOR  
THAT IS MADE UP  
OF TWO OR MORE  
ELEMENTS SUCH AS  
GALLIUM ARSENIDE IS  
CALLED A COMPOUND  
SEMICONDUCTOR.

GALLIUM + ARSENIC  
=  
GALLIUM ARSENIDE

BOINK

Ga

As

THAT MAKES  
SENSE!

THERE ARE ALSO CASES IN WHICH A SMALL AMOUNT OF AN IMPURITY IS MIXED WITH THE SILICON OR GERMANIUM.

THIS PROCESS IS CALLED **DOPING**, AND THE RESULT IS CALLED AN **EXTRINSIC SEMICONDUCTOR**.

A SEMICONDUCTOR WITH NO IMPURITY MIXED IN IS CALLED AN **INTRINSIC SEMICONDUCTOR**.

THERE SURE ARE A LOT OF TYPES OF SEMICONDUCTORS!

THE RAW MATERIAL MOST OFTEN USED IN SEMICONDUCTORS IS **SILICON**.

**SILICON** IS AN ELEMENT REPRESENTED BY THE SYMBOL **Si**.

**Si**  
SILICON

I SEE!

NORMALLY, SILICON IS FOUND IN A SUBSTANCE CALLED **SILICON DIOXIDE**, WHICH IS A REFINED PRODUCT OFTEN USED AS THE RAW MATERIAL FOR SEMICONDUCTOR DEVICES.

THE PURITY OF THIS REFINED SILICON IS 99.999999999 PERCENT, WHICH IS SOMETIMES REFERRED TO AS **ELEVEN-NINE**.

THIS IS EXTREMELY CLOSE TO 100 PERCENT!!!

9 x 11  
**99.999999999%**

ONE, TWO, THREE...

A SILICON ATOM HAS FOUR VALENCE ELECTRONS IN ITS OUTERMOST SHELL.

THESE ATOMS JOINTLY CONTRIBUTE FOUR ELECTRONS TO FORM A FIRM, REGULAR CRYSTAL.

COOL!

\*WELL-BUILT

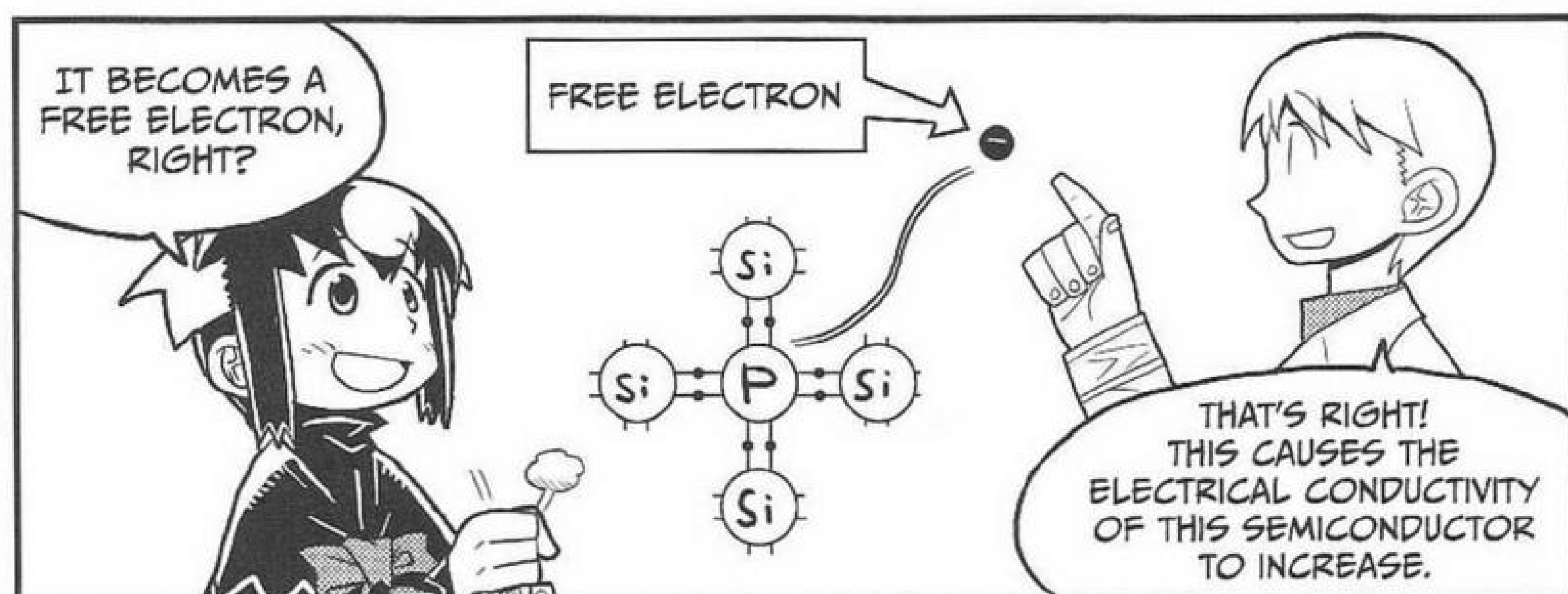
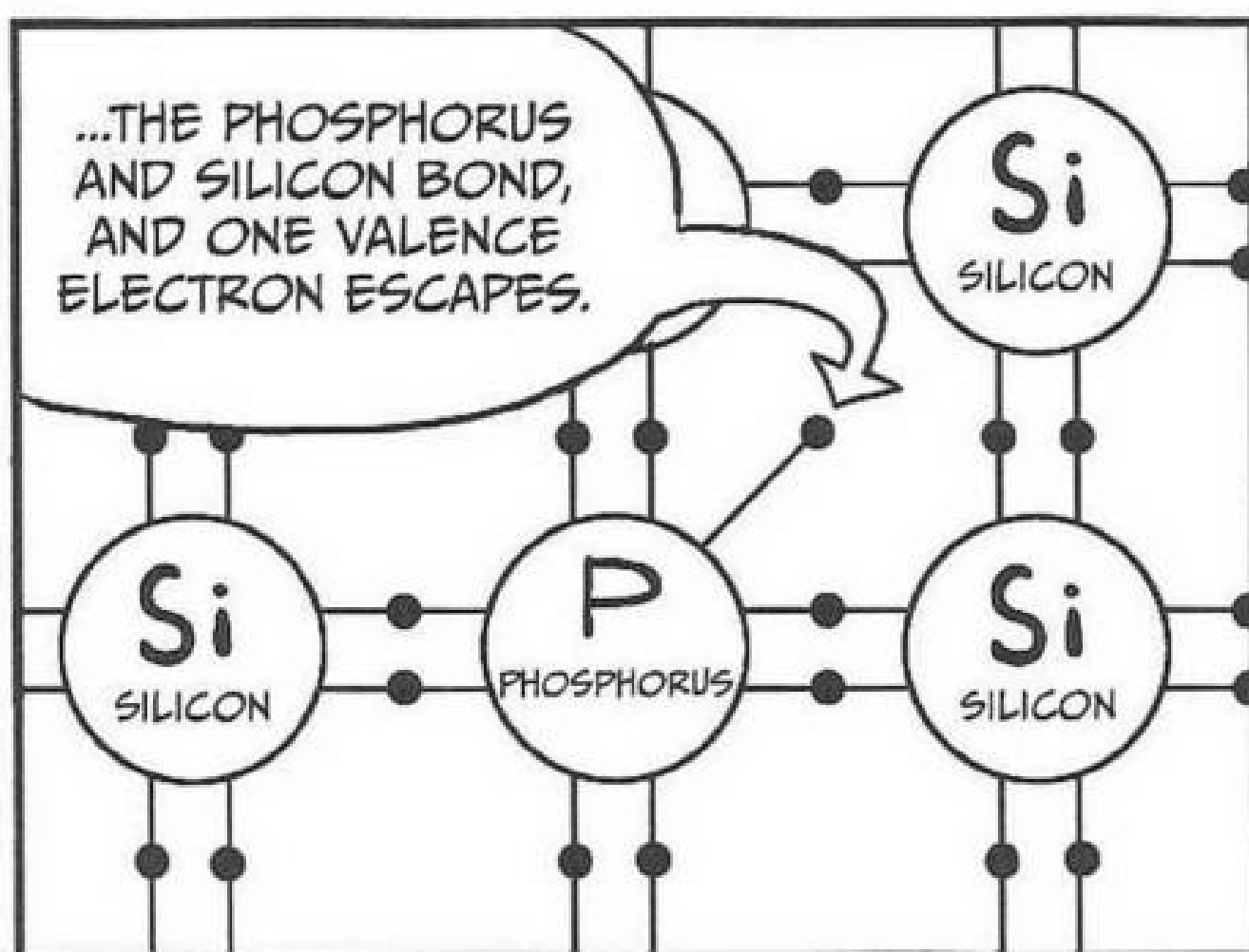
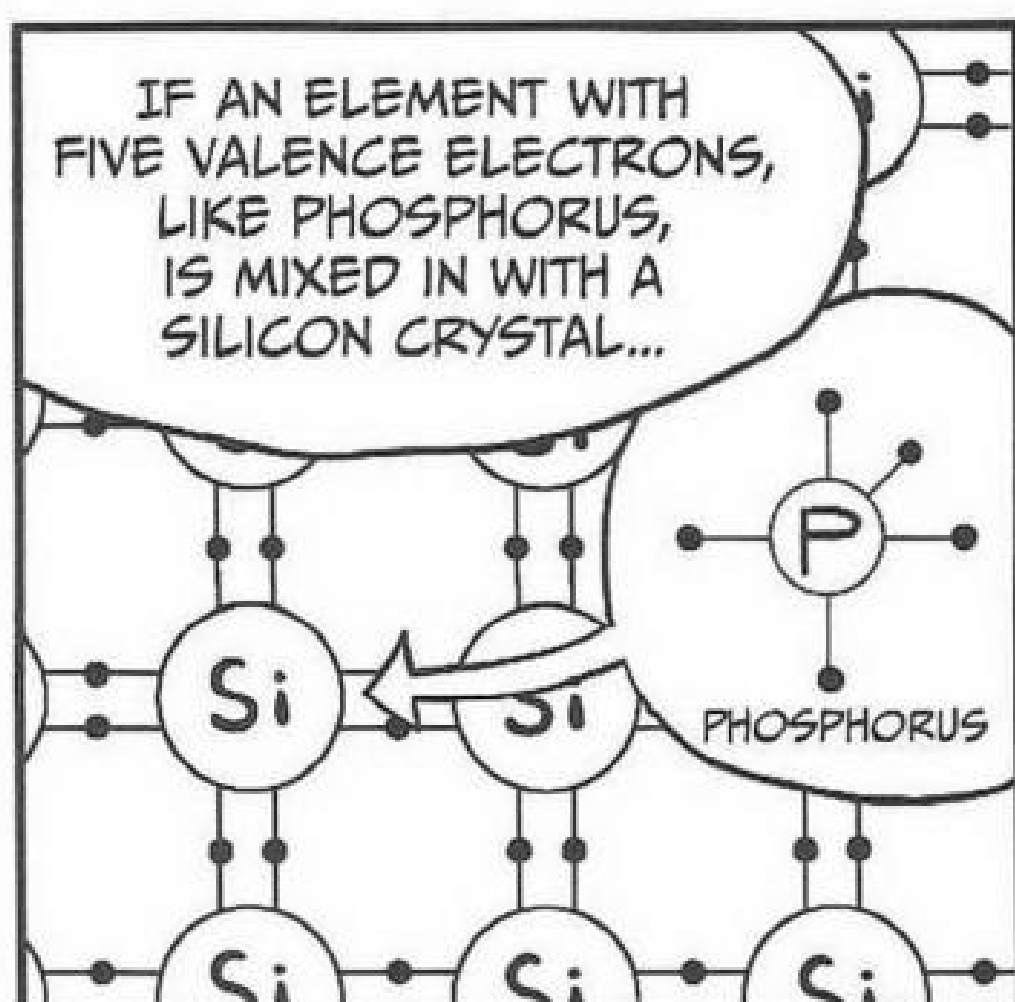
IT'S LIKE THEY'RE HOLDING HANDS! LIKE THIS!

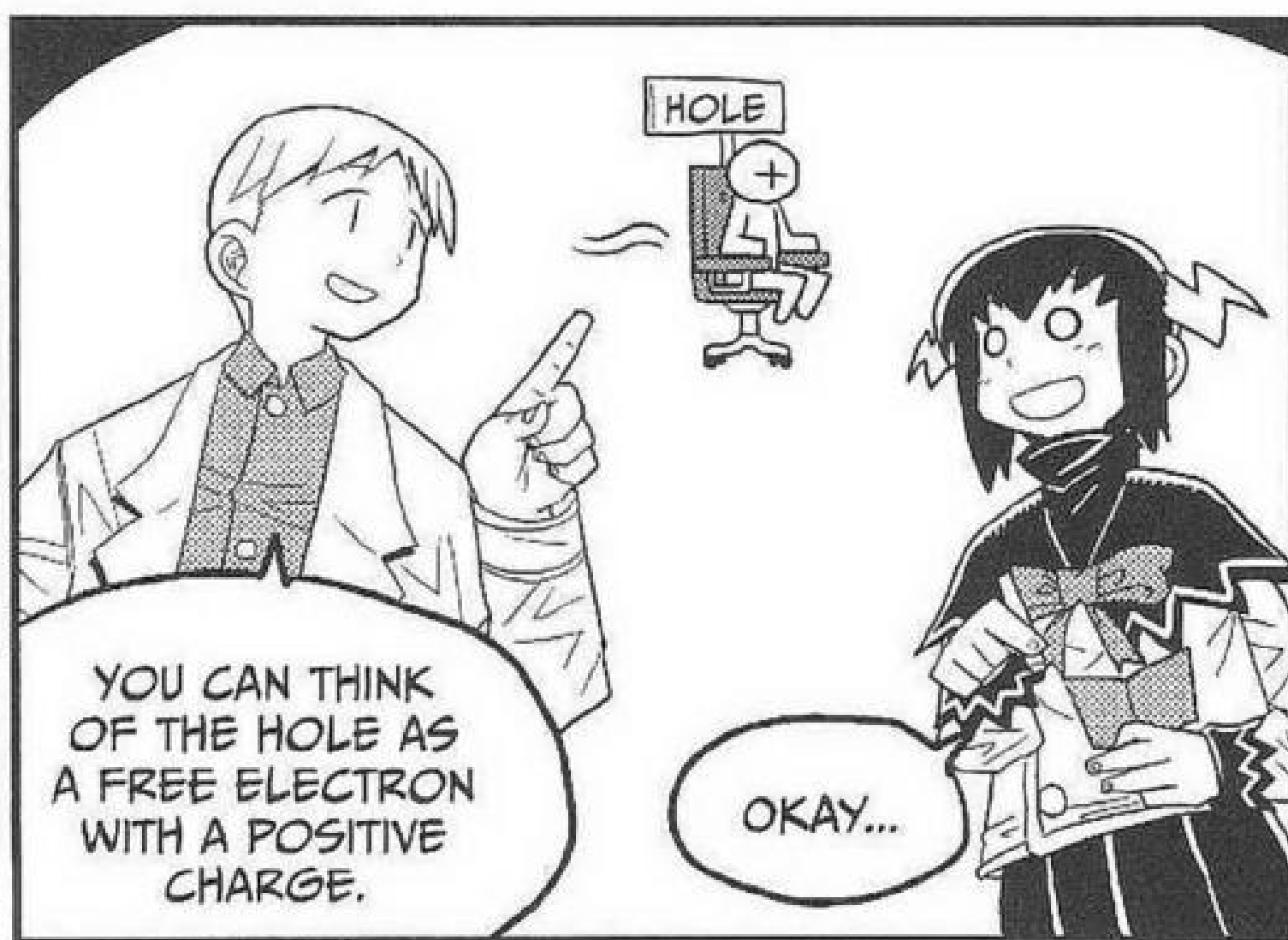
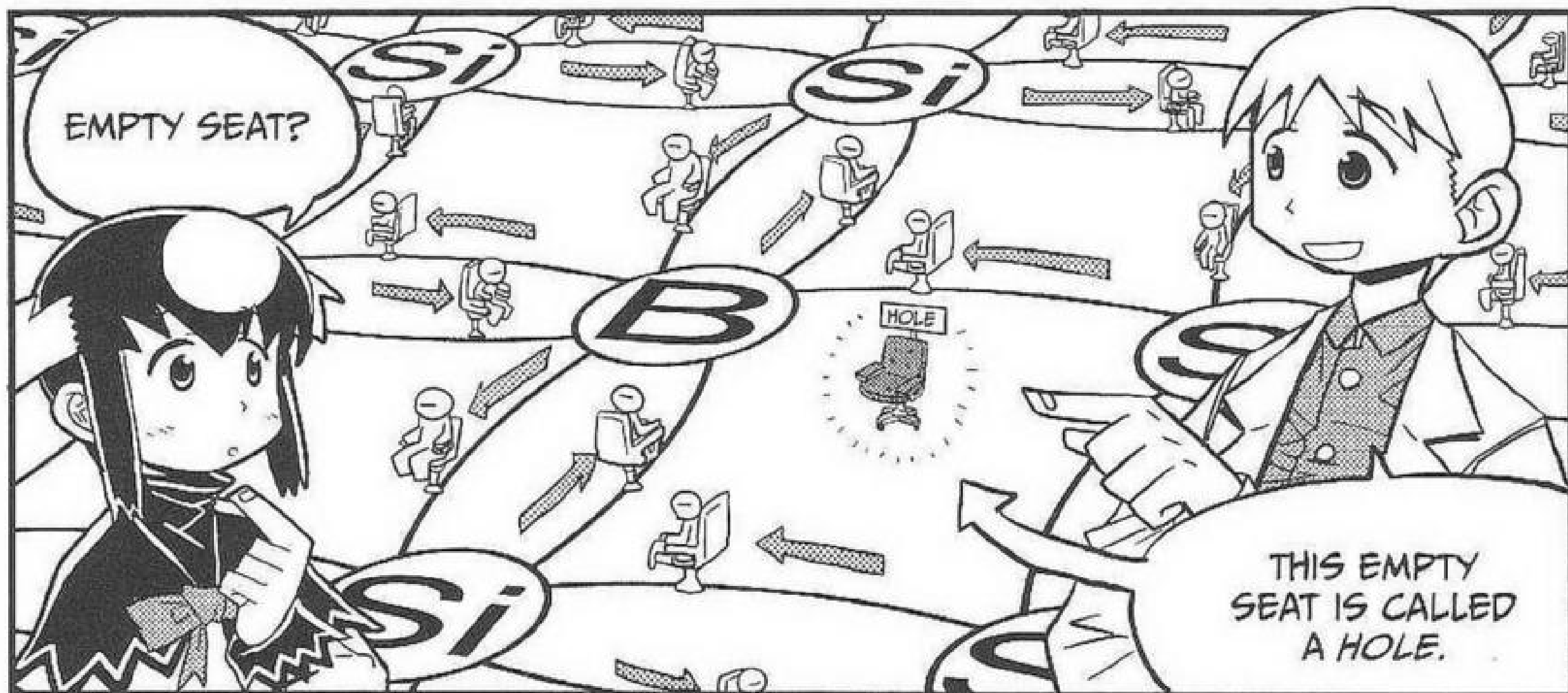
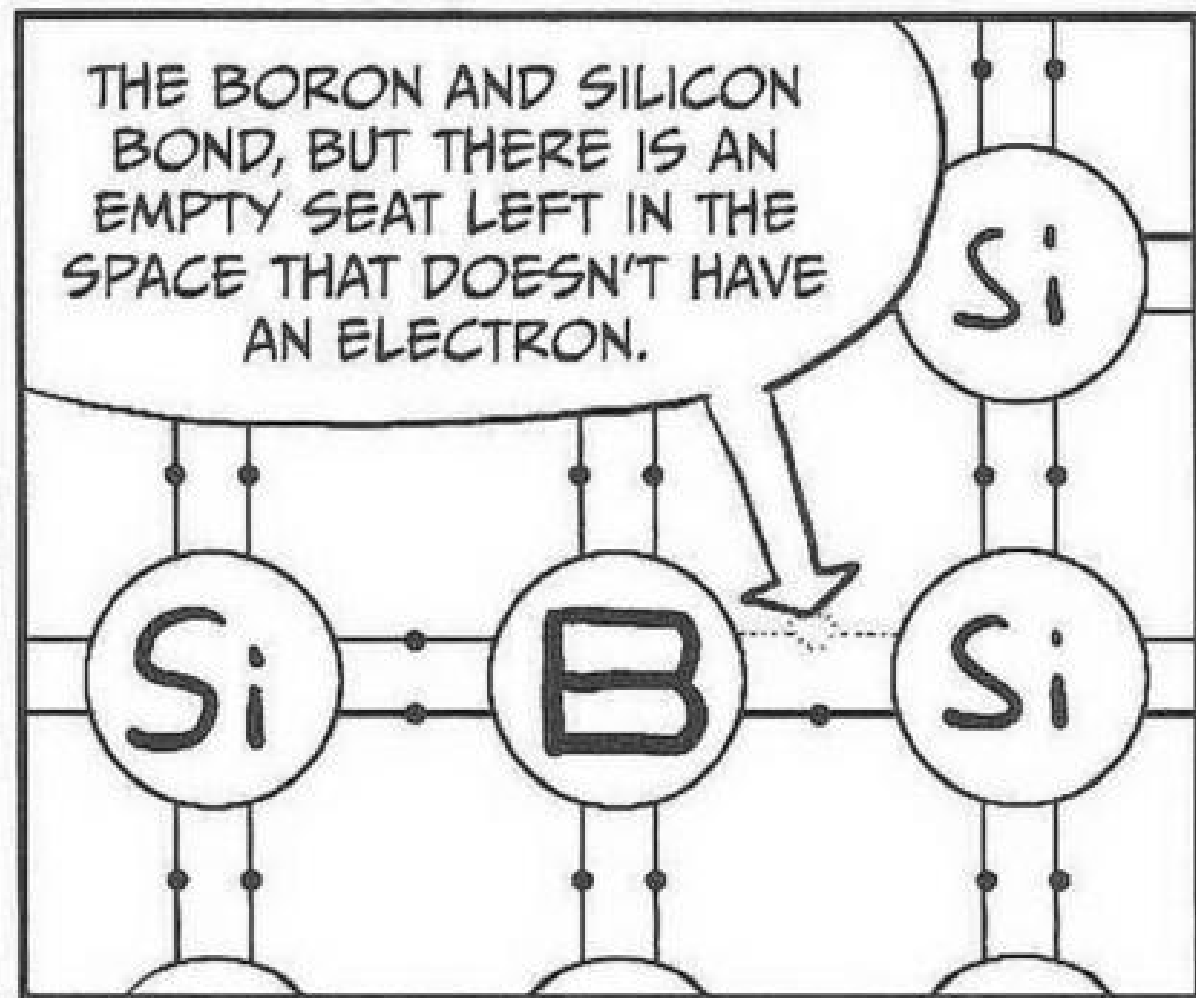
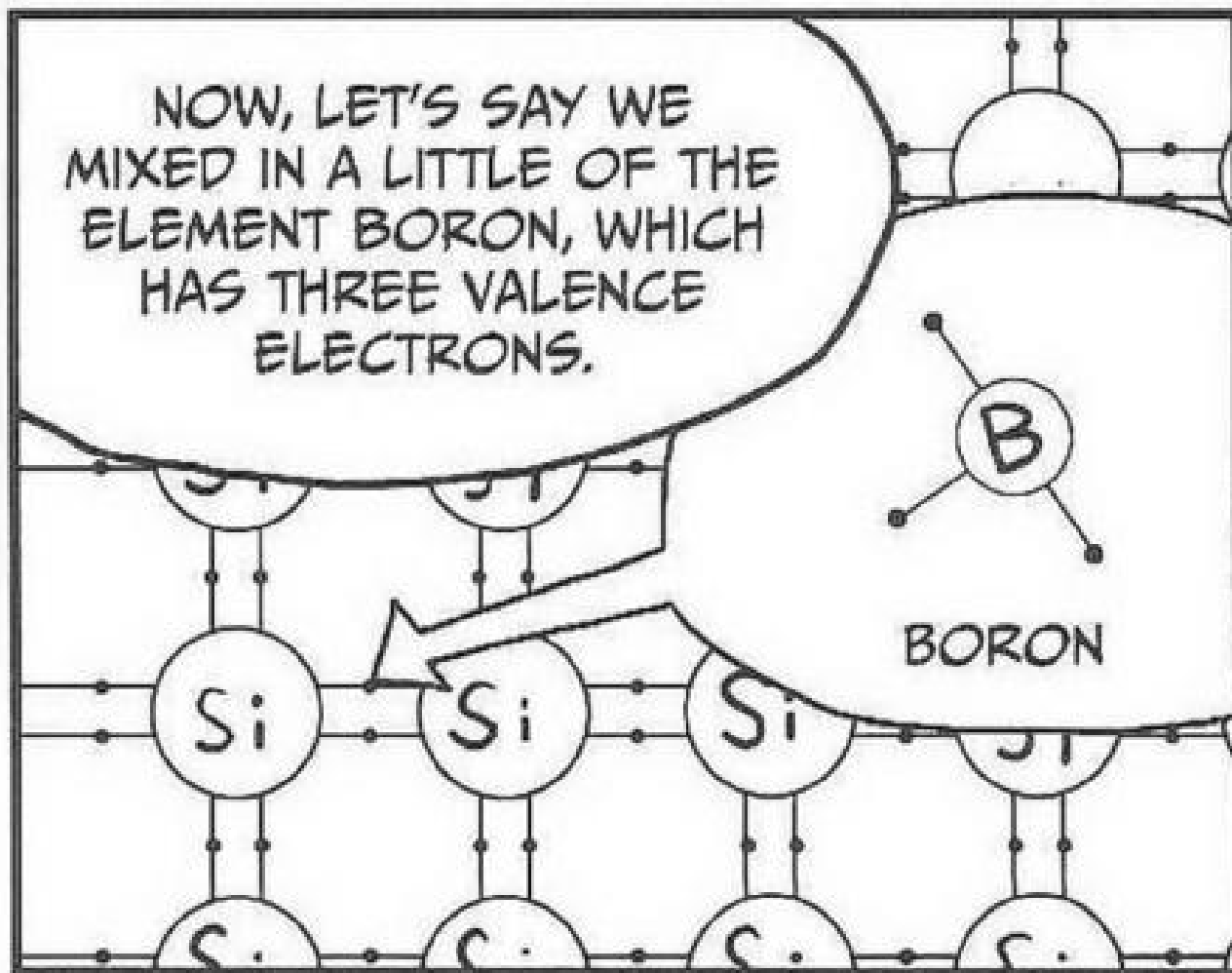
YEAH...UH... LIKE THAT.

A SILICON CRYSTAL DOES NOT HAVE ANY ELECTRONS THAT CAN FREELY MOVE AROUND, SO ELECTRICITY WILL HARDLY PASS THROUGH IT.

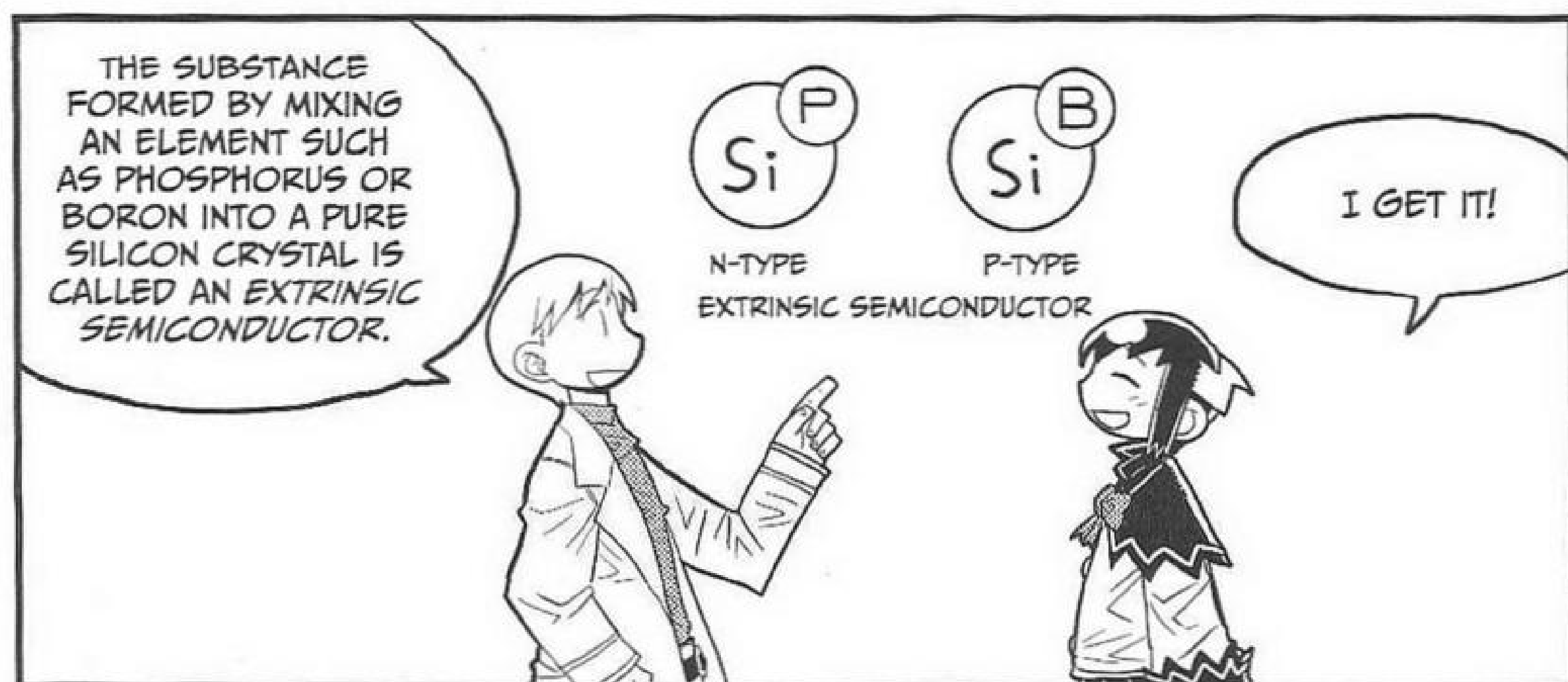
THAT'S BECAUSE THE VALENCE ELECTRONS OF THE SILICON ATOMS ARE HOLDING HANDS!

THAT'S RIGHT!



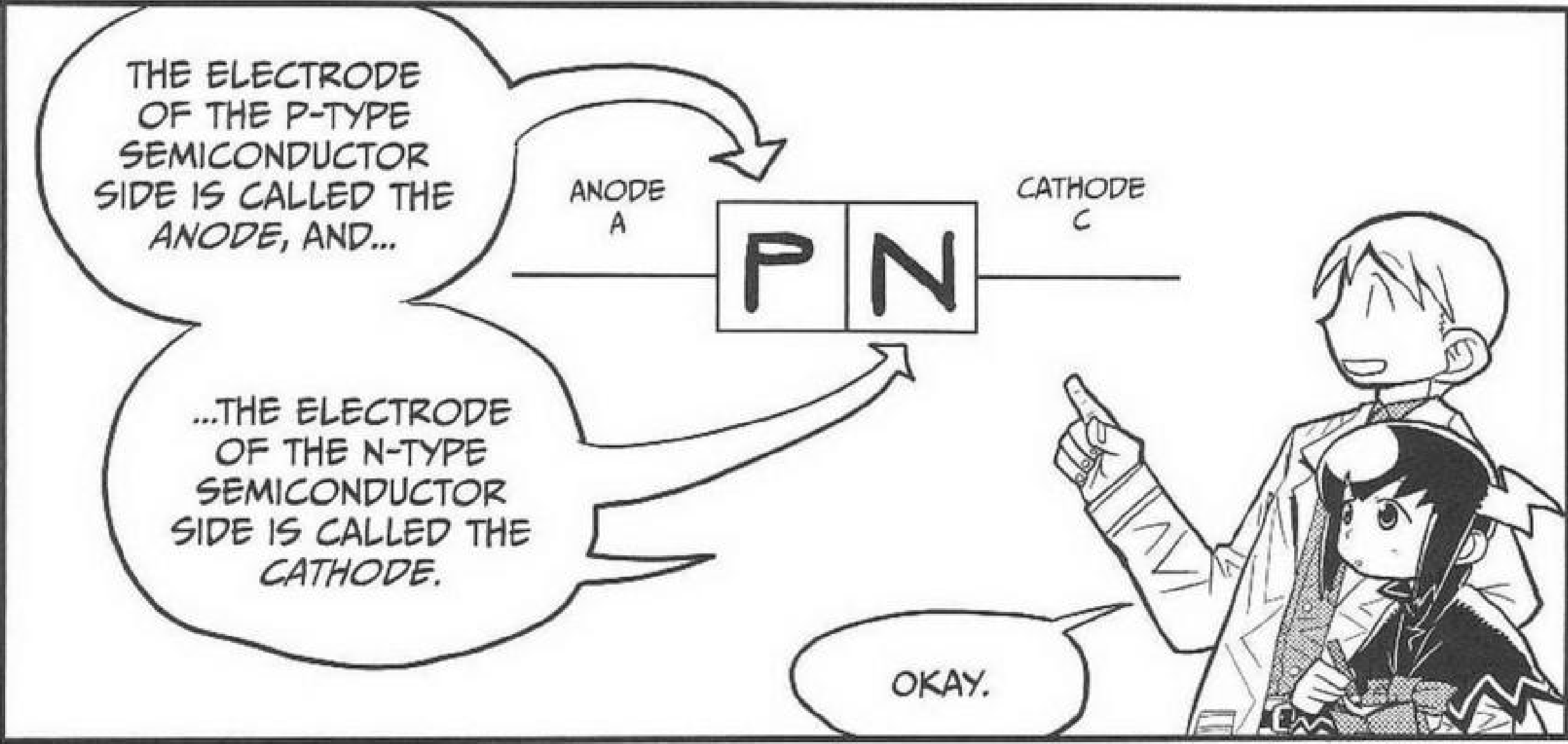
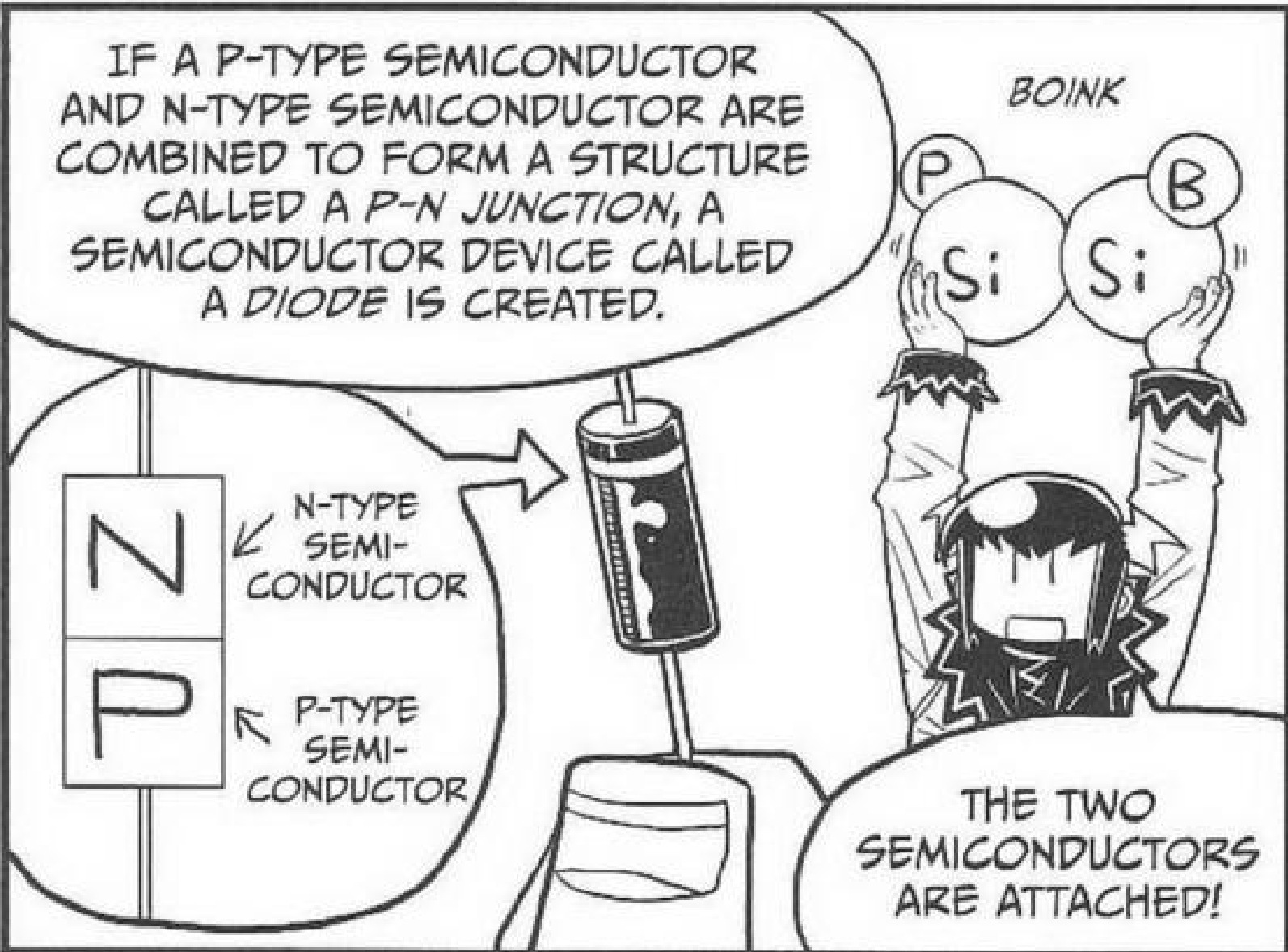
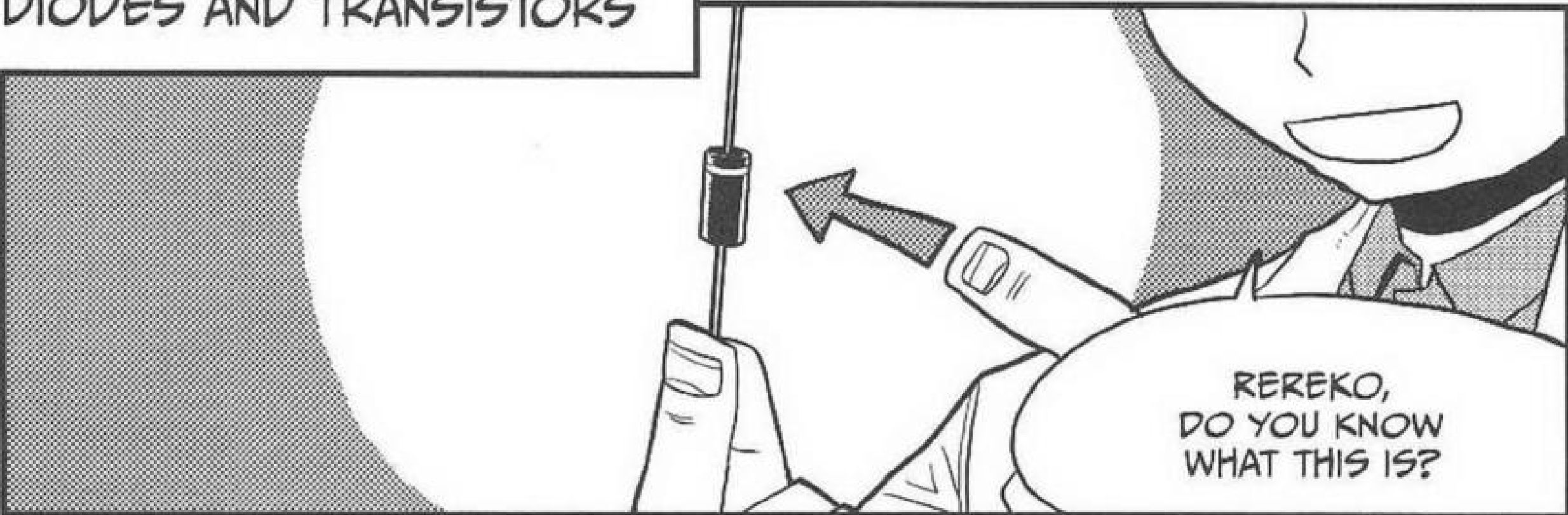


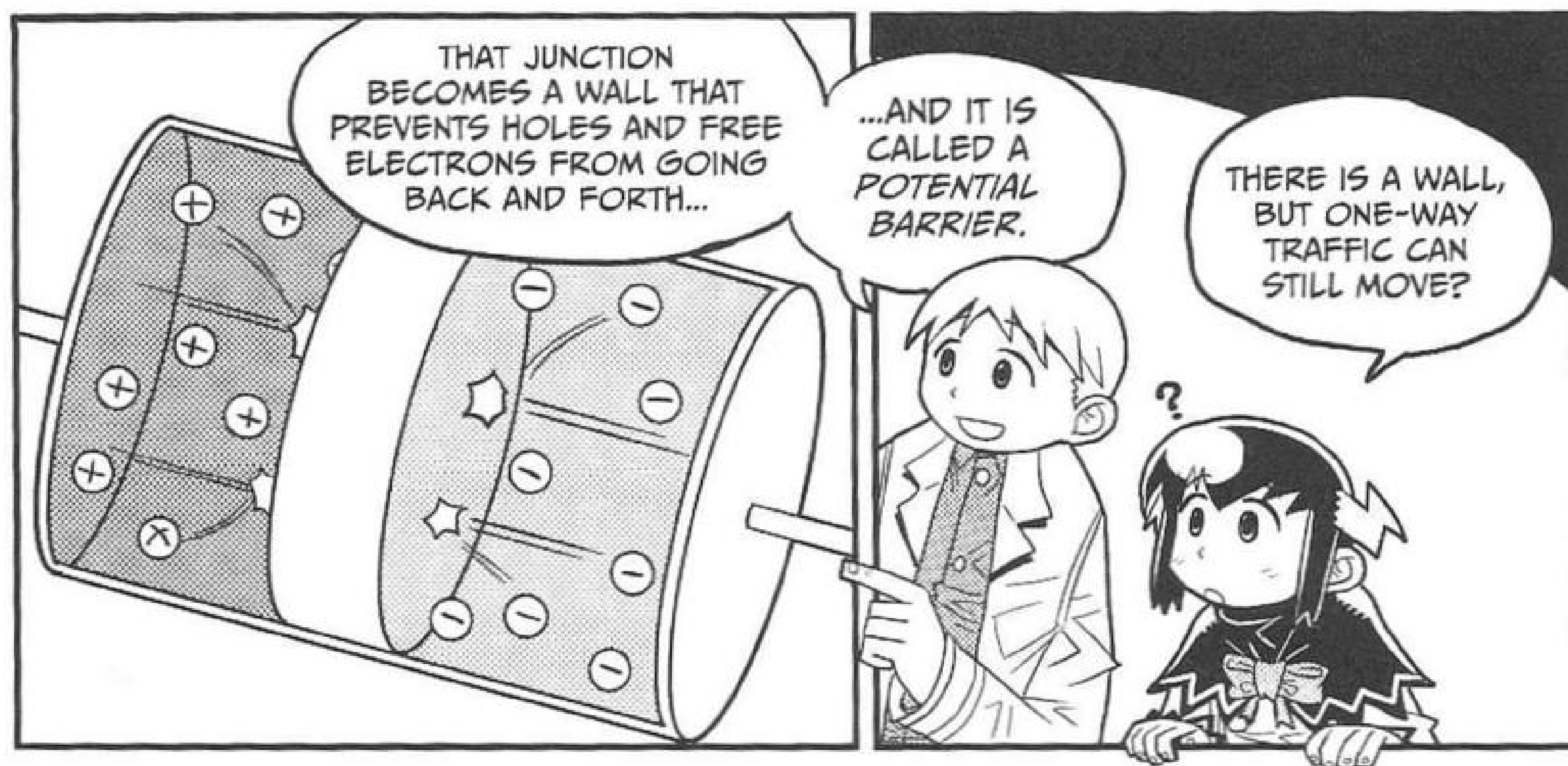
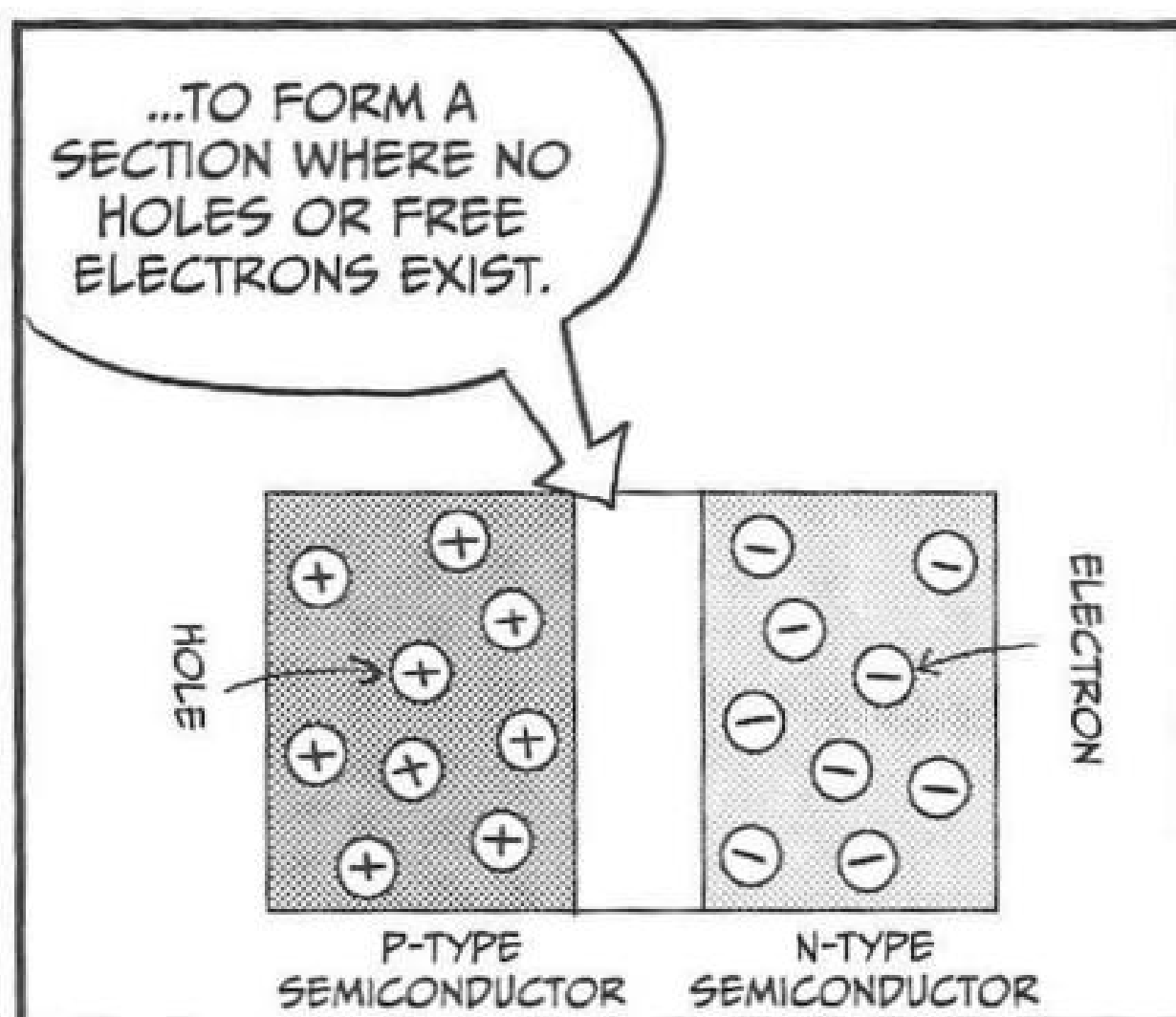
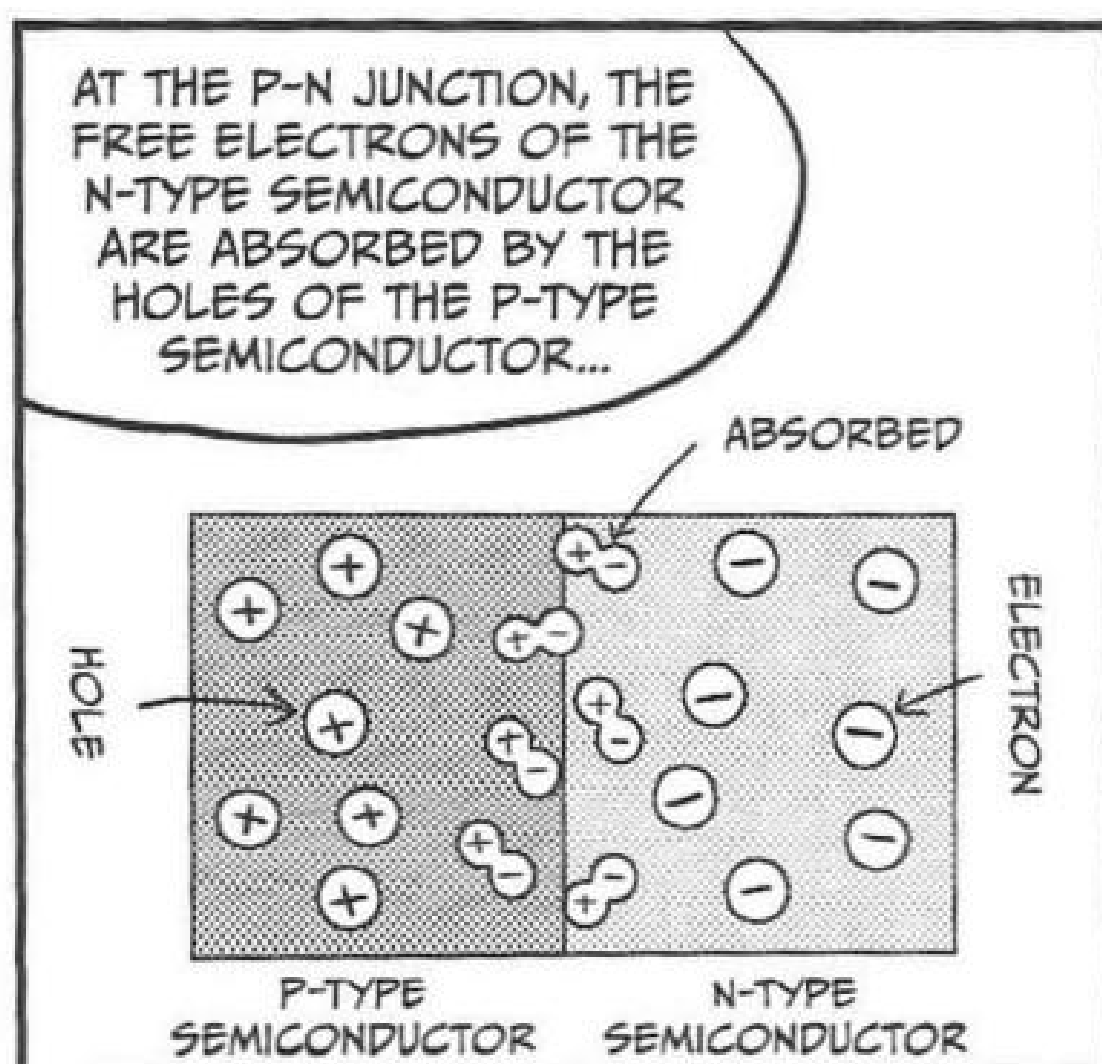
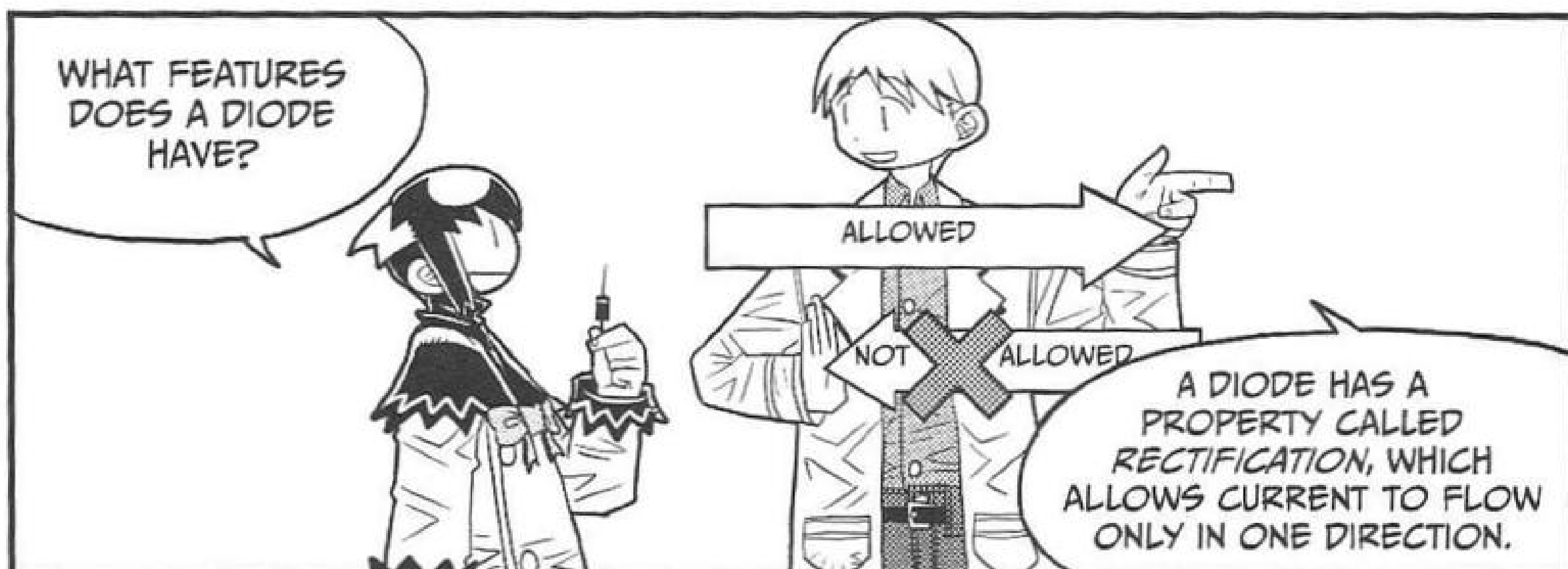


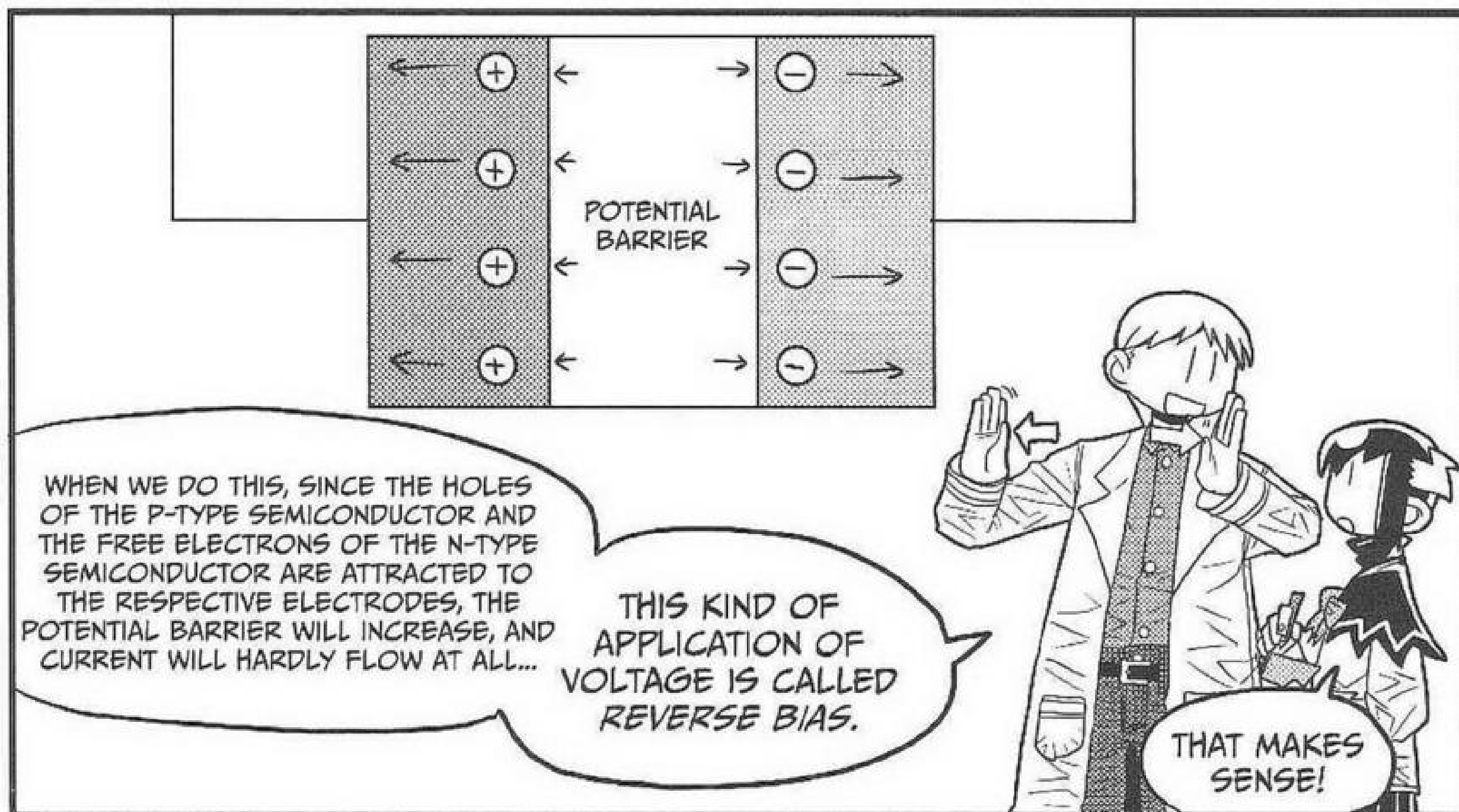
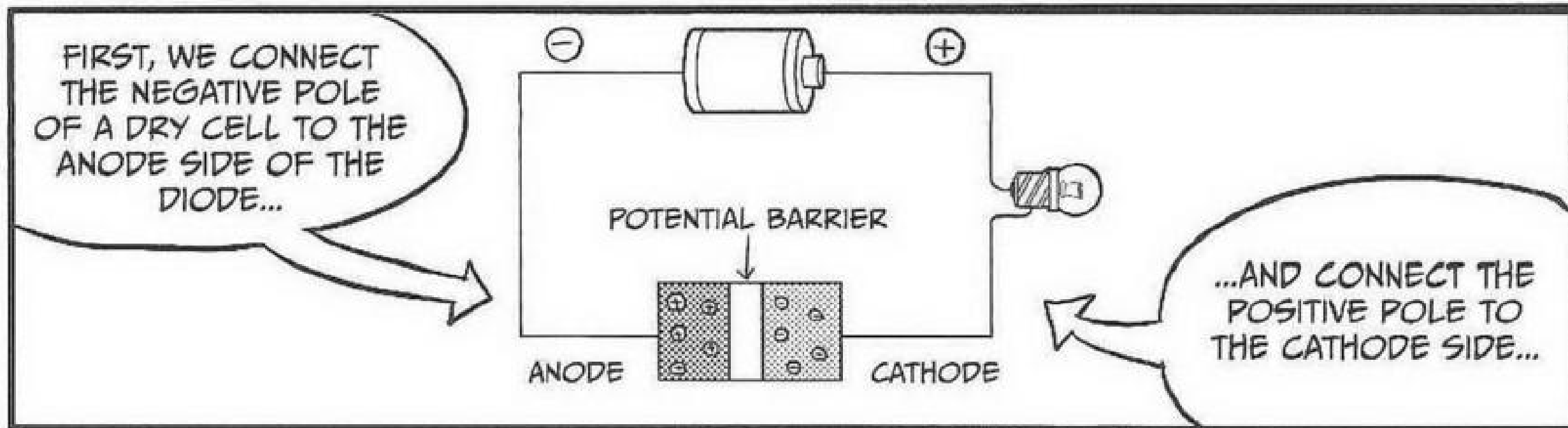
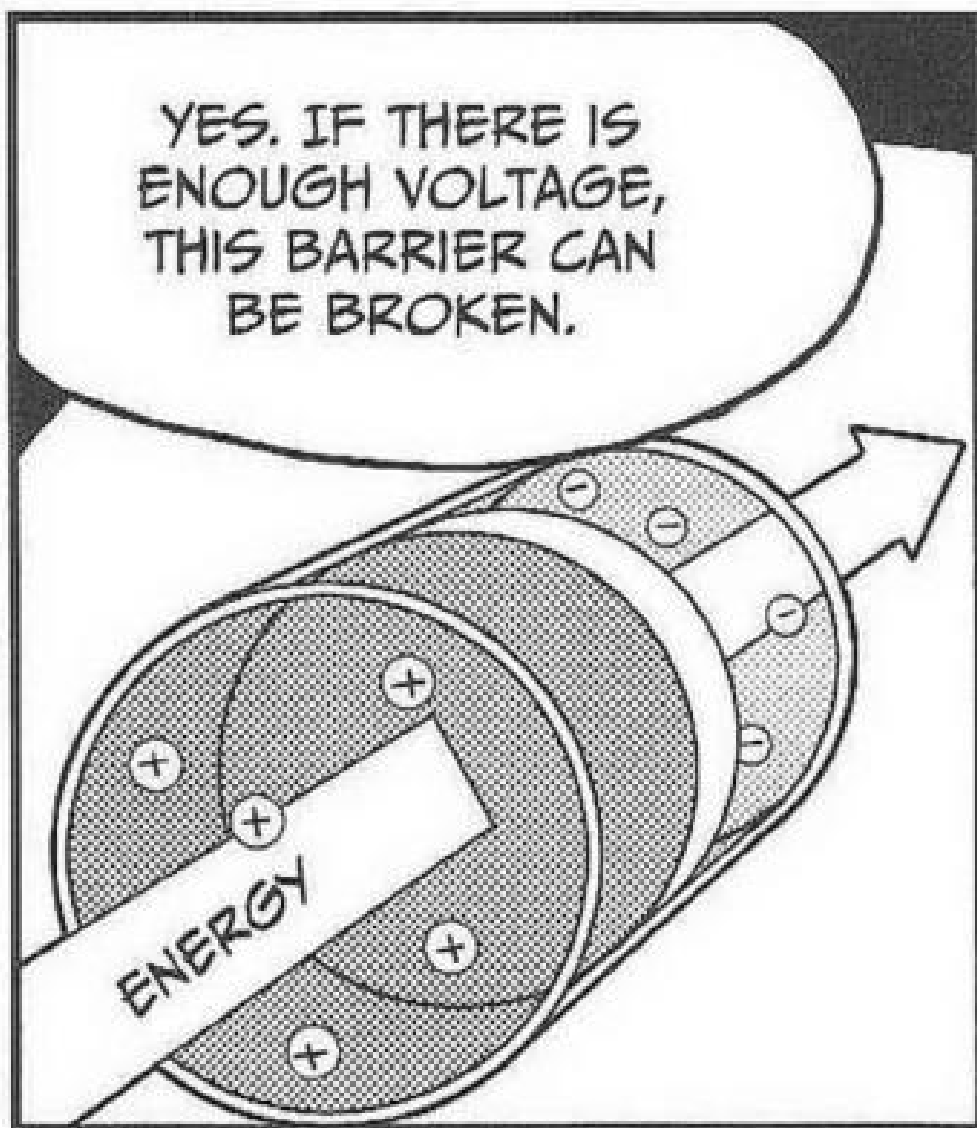




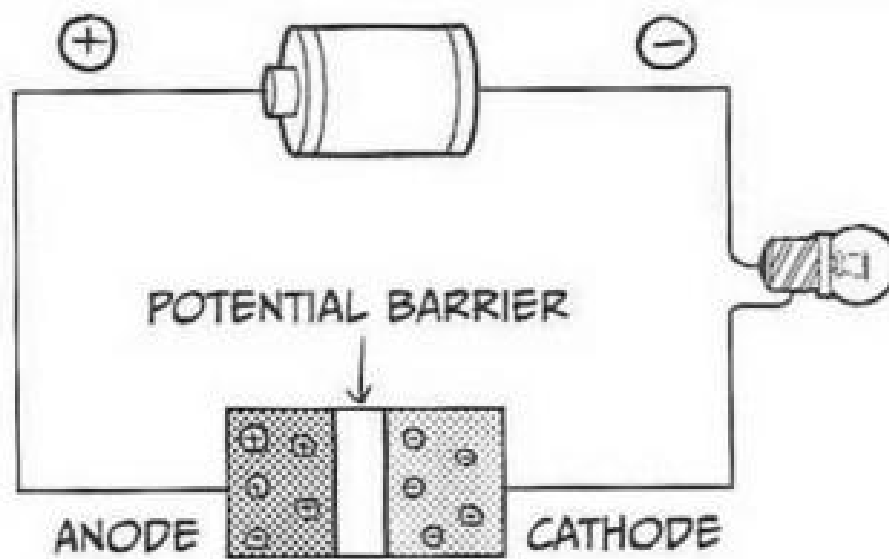
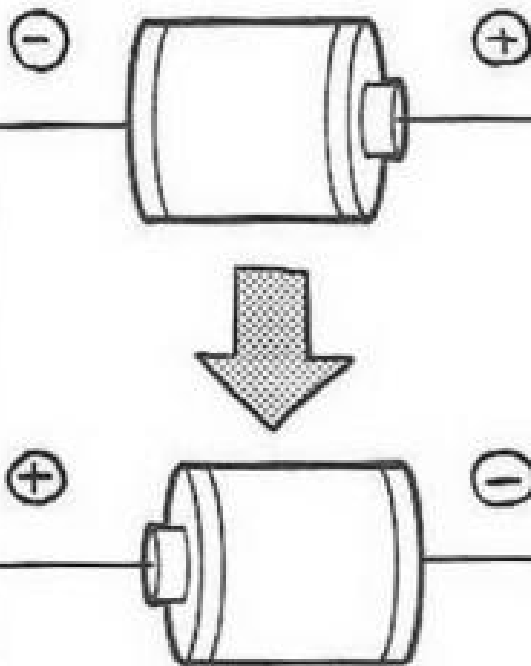
DIODES AND TRANSISTORS







NEXT, LET'S TRY REVERSING THE DIRECTION OF THE DRY CELL.

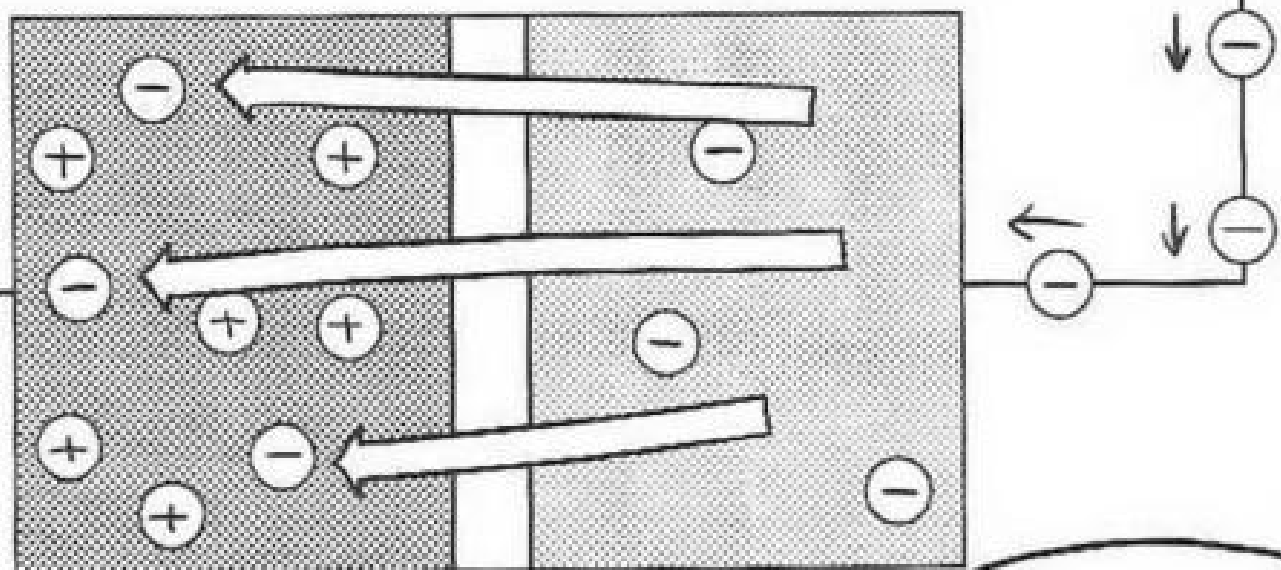


THE POSITIVE POLE IS CONNECTED TO THE ANODE SIDE, AND THE NEGATIVE POLE IS CONNECTED TO THE CATHODE SIDE, RIGHT?

YUP!

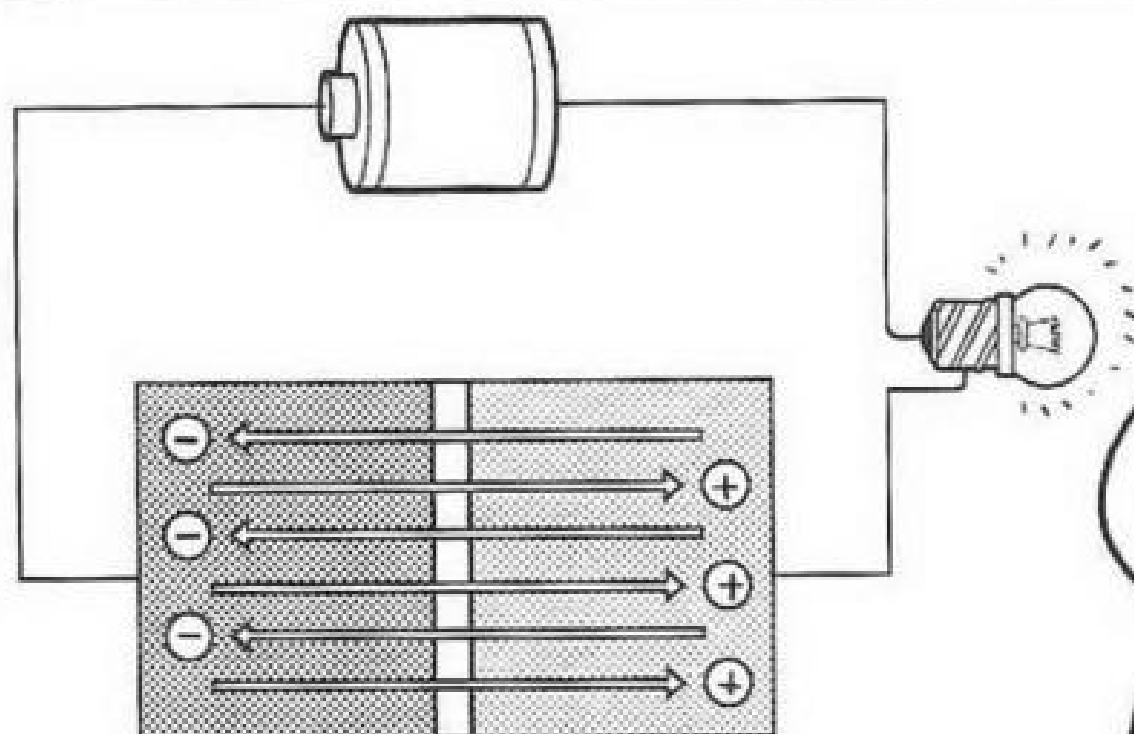


IN THIS CASE, THE FREE ELECTRONS OF THE N-TYPE SEMICONDUCTOR ARE PUSHED BY THE ELECTRONS THAT WERE DELIVERED FROM THE NEGATIVE POLE OF THE DRY CELL. THEY OVERCOME THE POTENTIAL BARRIER AND MOVE TO THE ANODE.



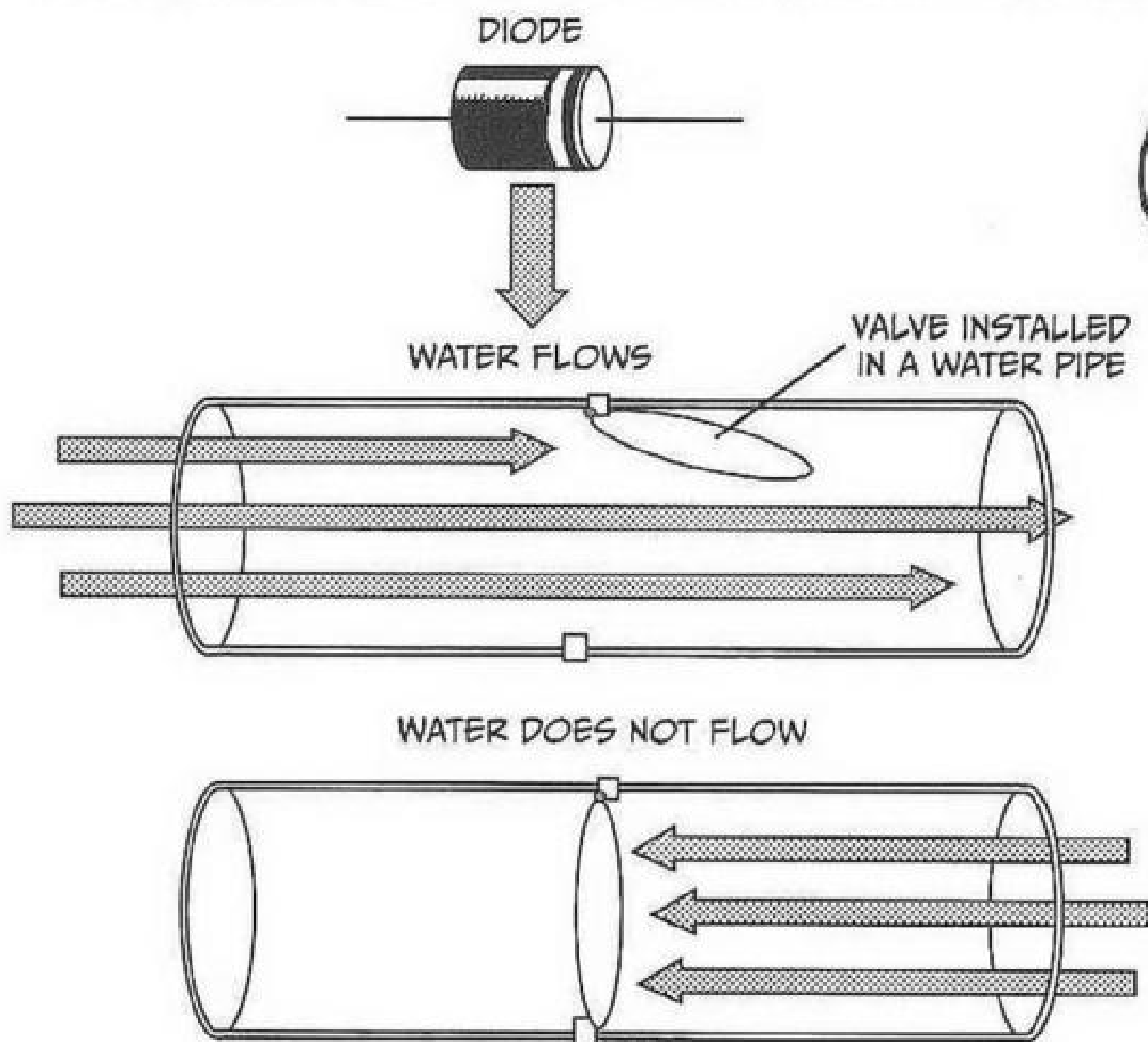
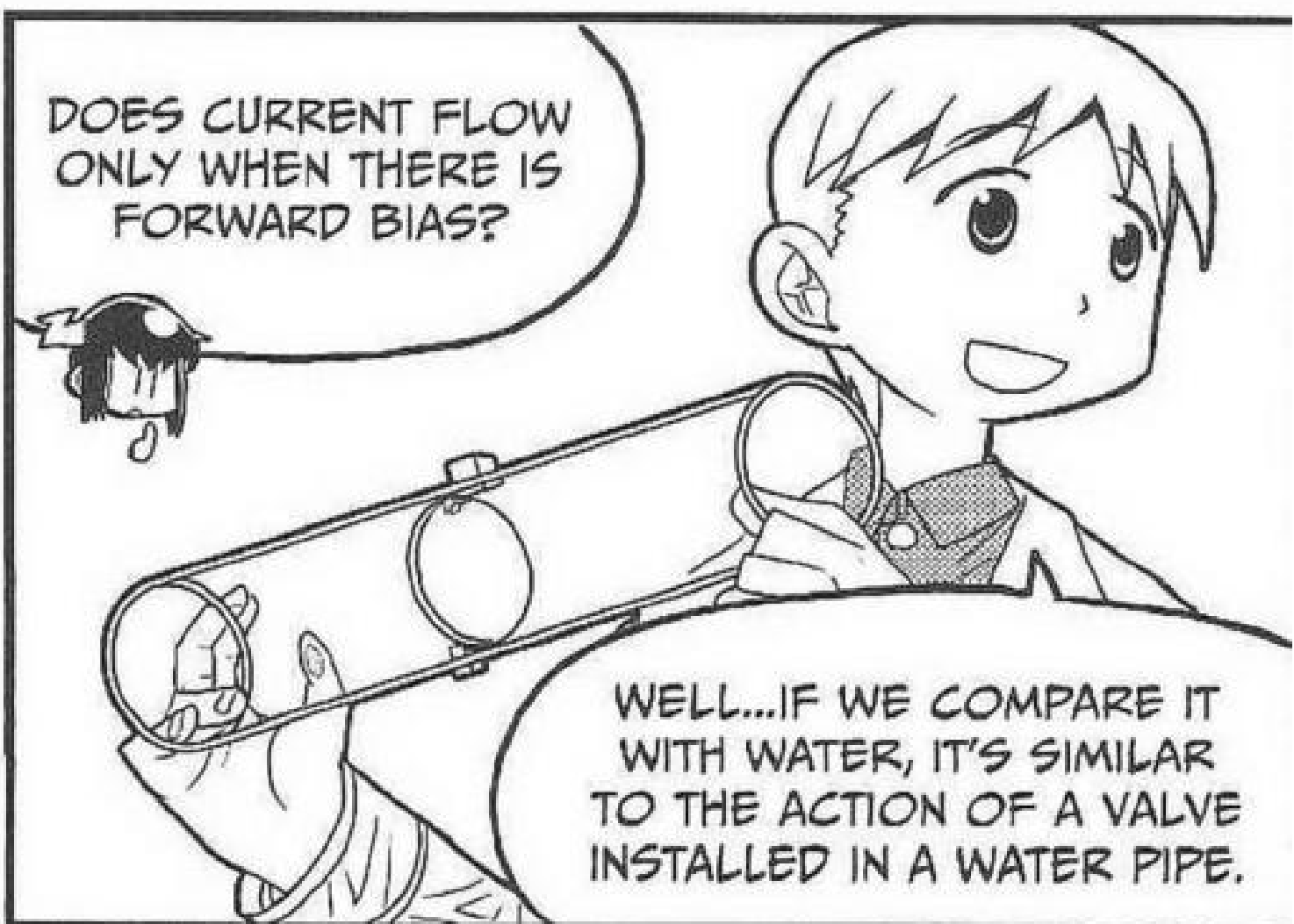
HMMM...

THE HOLES OF THE P-TYPE SEMICONDUCTOR ARE ALSO DRAWN TOWARD THE NEGATIVE POLE AND MOVE TO THE N-TYPE SEMICONDUCTOR.

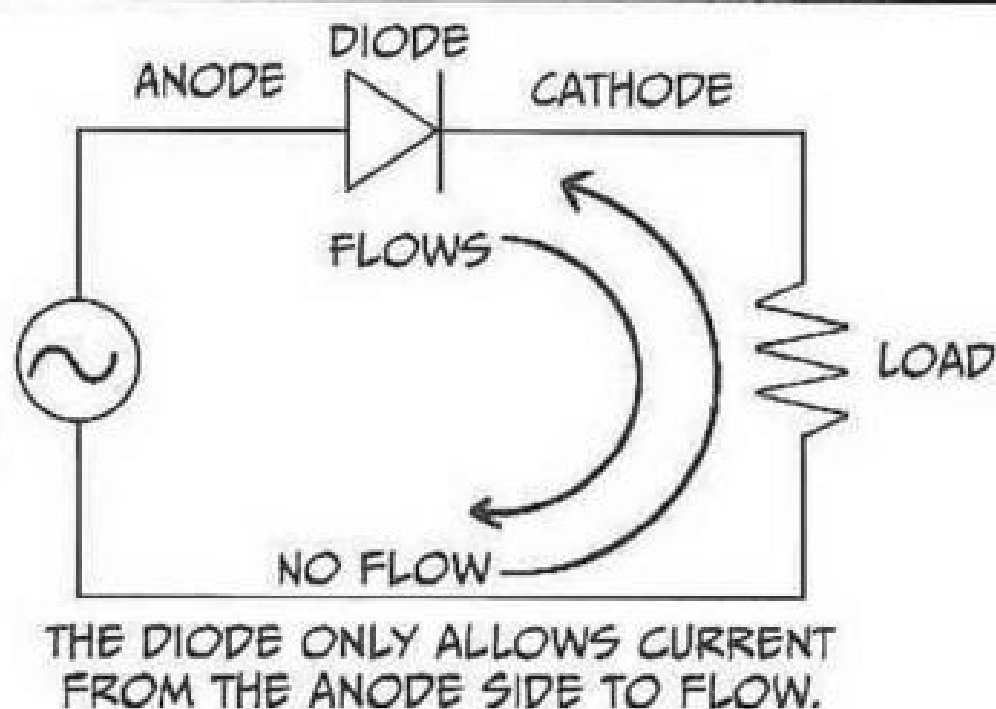


THIS ENABLES ELECTRICITY TO FLOW!



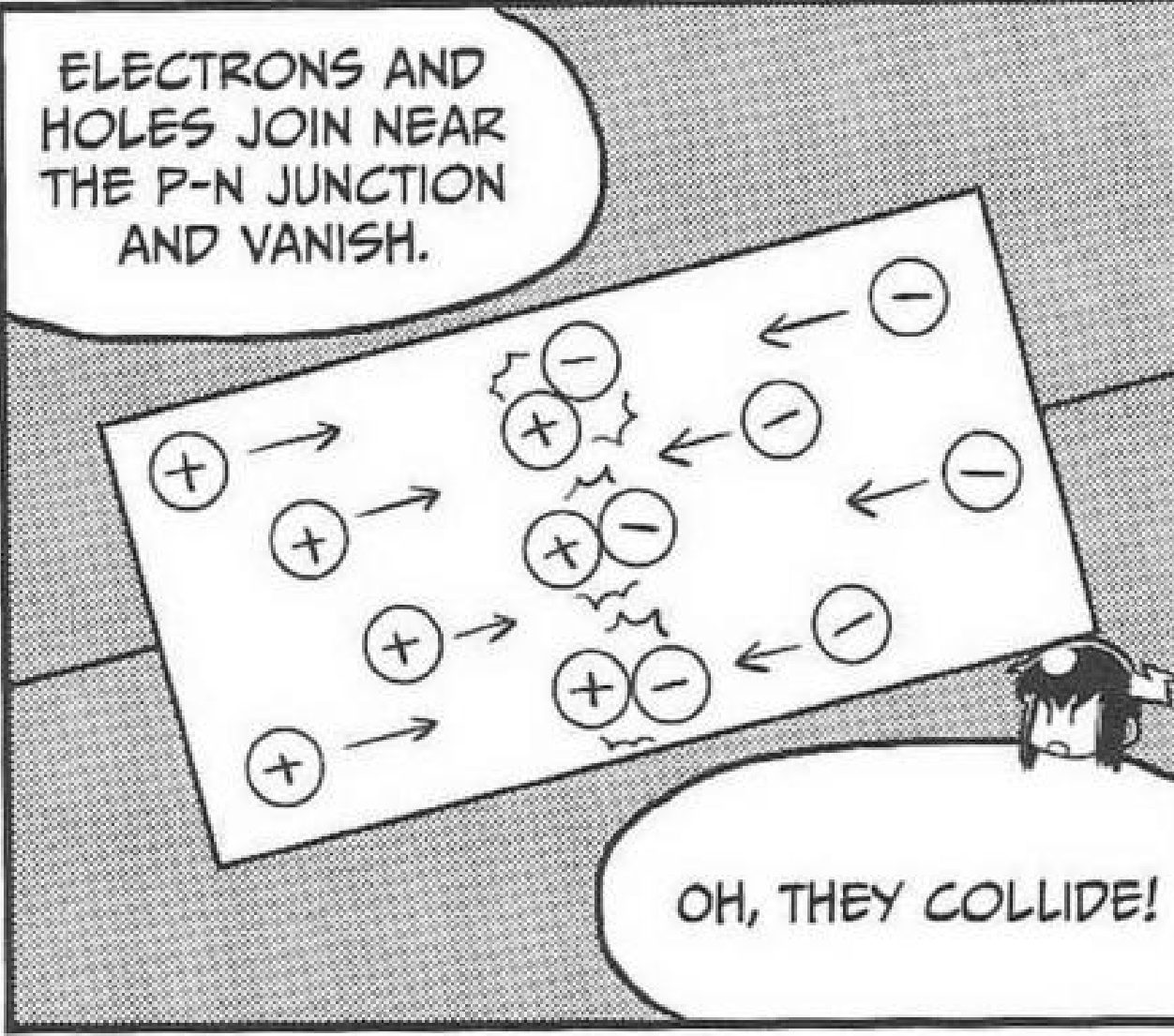
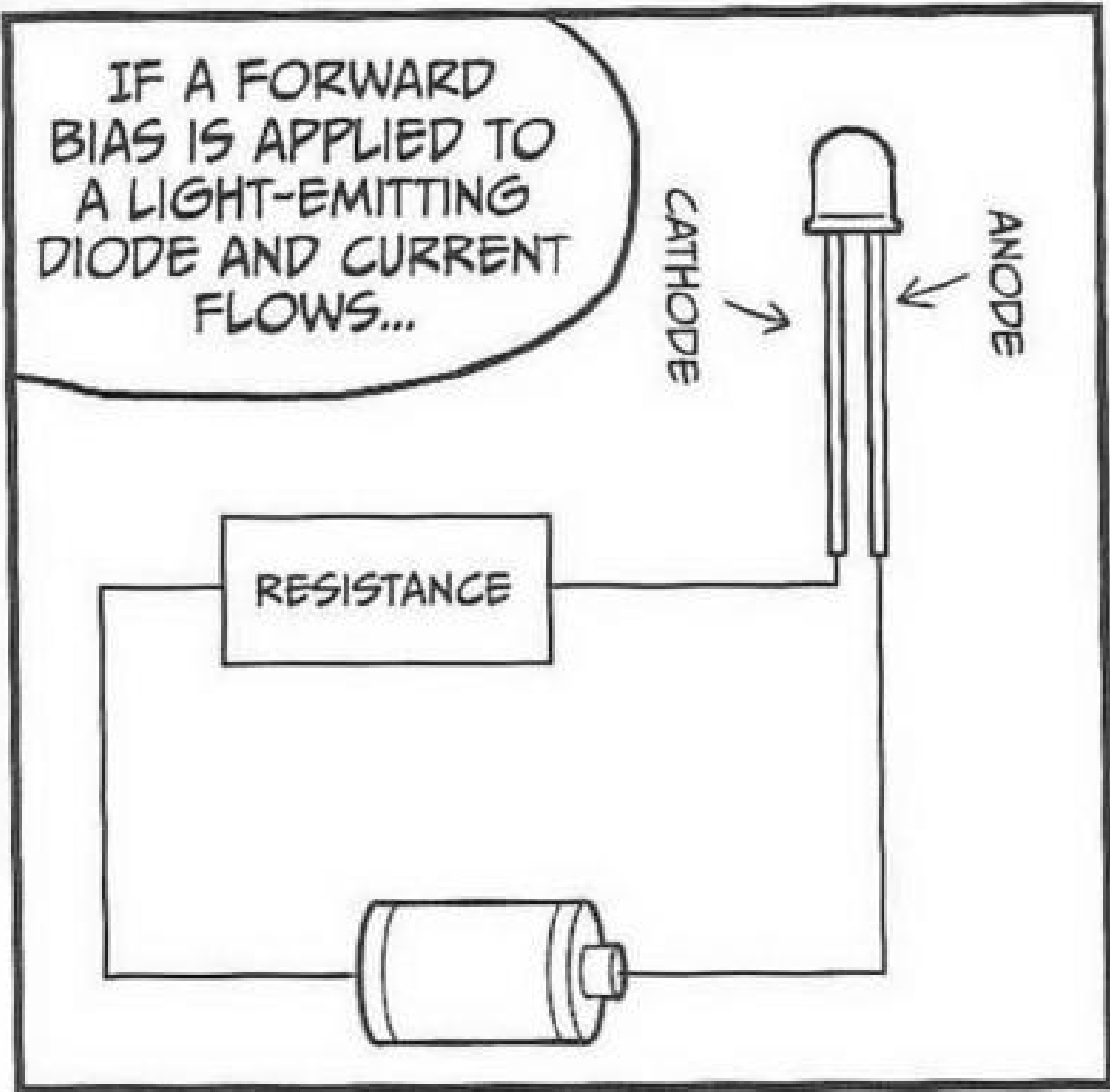
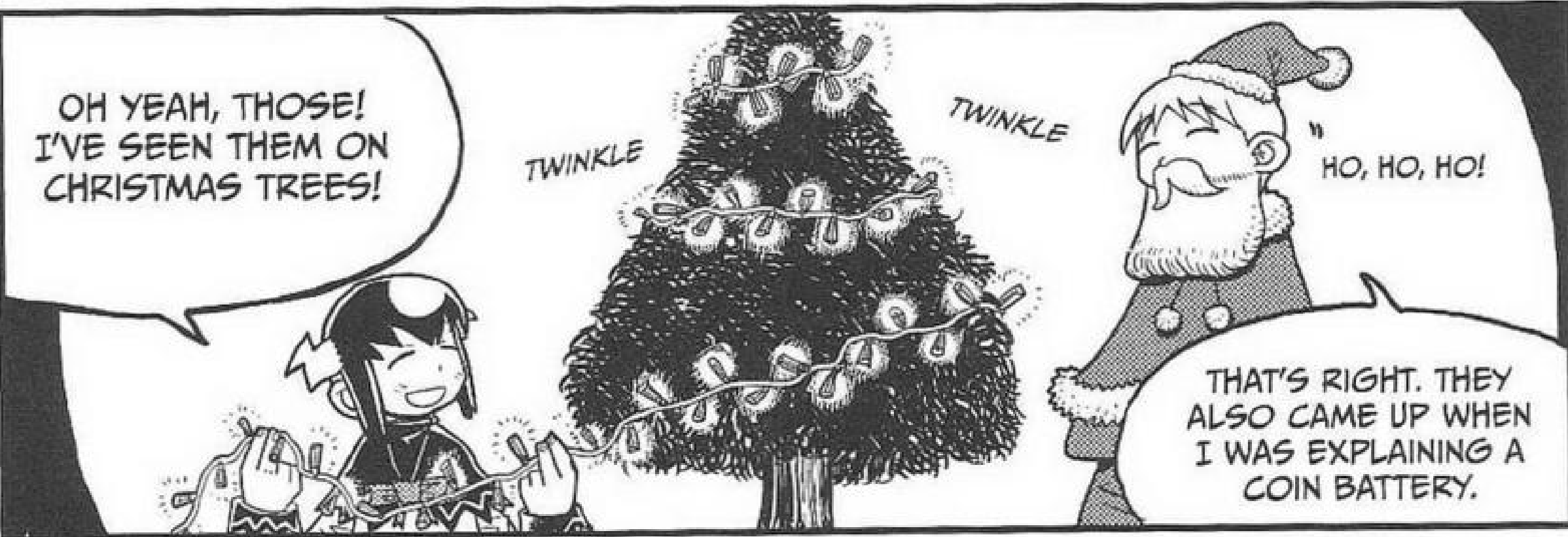


THE PROPERTY THAT ALLOWS CURRENT TO FLOW ONLY IN ONE DIRECTION IN THIS WAY IS CALLED RECTIFICATION.





DIODES THAT EMIT LIGHT



THE ENERGY THAT IS PRODUCED AT THAT TIME IS EMITTED AS LIGHT.

SINCE THE WAVELENGTH OF THE LIGHT EMITTED DEPENDS ON THE RAW MATERIAL OF THE SEMICONDUCTOR, VARIOUS COLORS OF LIGHT CAN BE CREATED.

OOOH, AAAAAH.

TRAFFIC SIGNALS

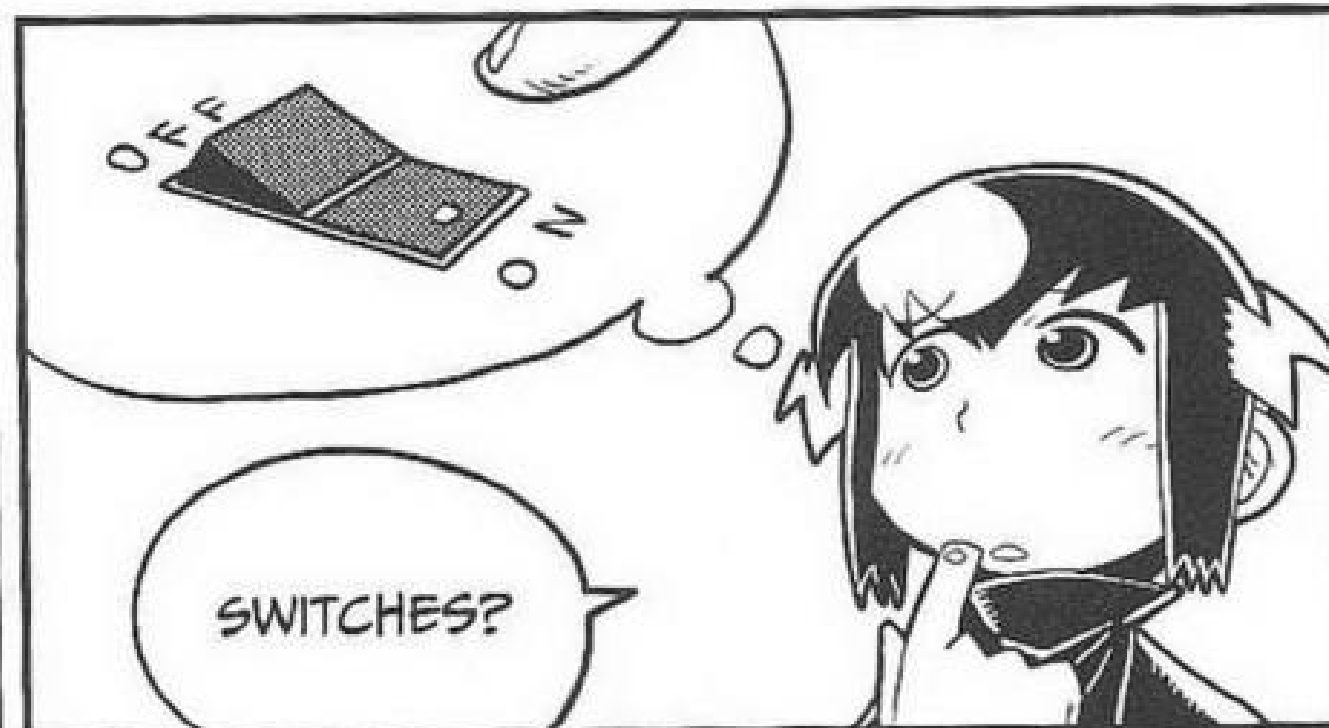
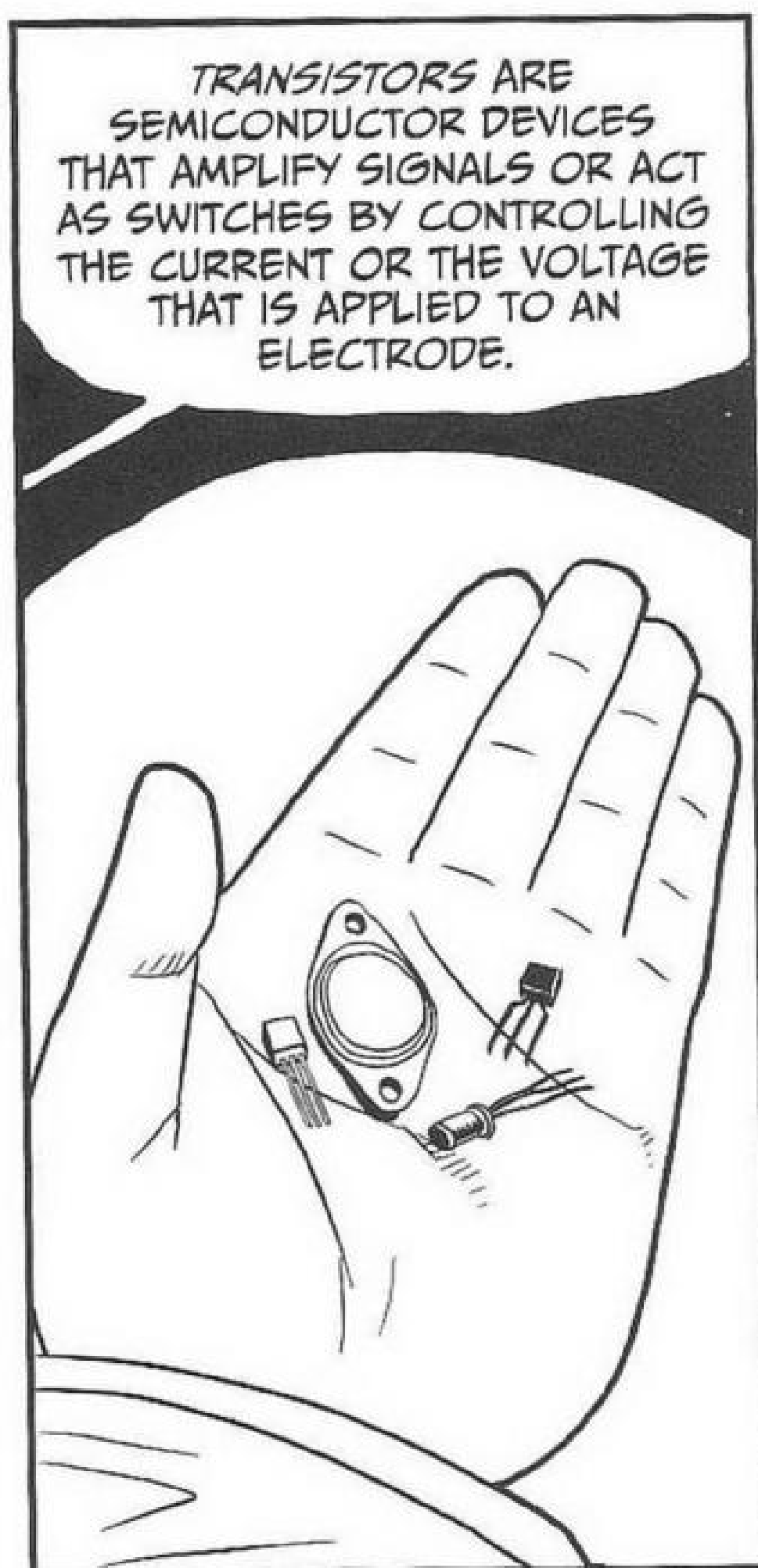
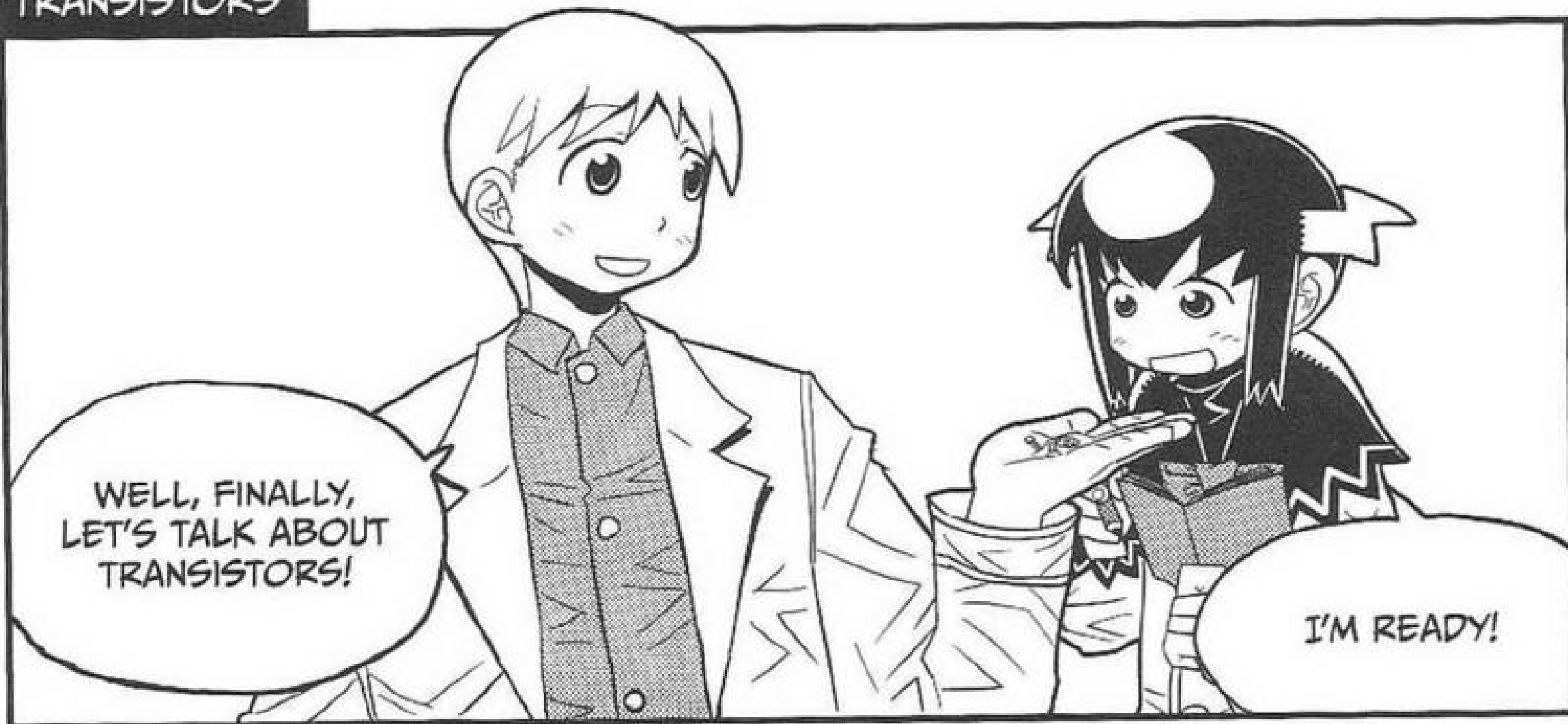
LARGE-SCREEN OUTDOOR DISPLAYS

INTERIOR LIGHTS OF CARS

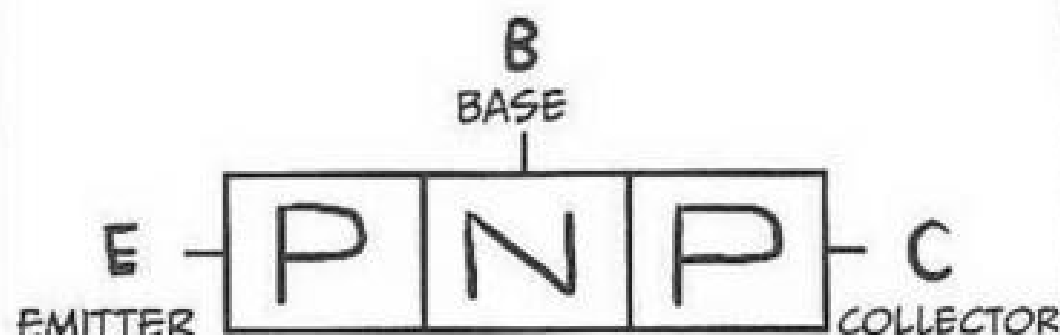
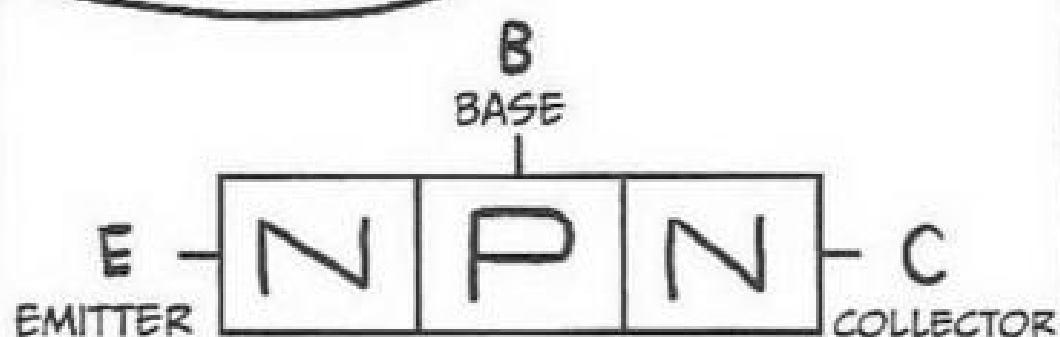
BACKLIGHTING OF MOBILE PHONES OR DIGITAL CAMERAS

SINCE THE LUMINESCENCE OF LIGHT-EMITTING DIODES DOES NOT INVOLVE HEAT, THEY ARE ENERGY EFFICIENT AND HAVE A LONG LIFETIME. THEREFORE, THEY ARE USED IN VARIOUS WAYS.

WE SURE SEE LOTS OF THEM IN OUR EVERYDAY LIVES.



TWO TYPES OF TRANSISTORS ARE NPN AND PNP TRANSISTORS.

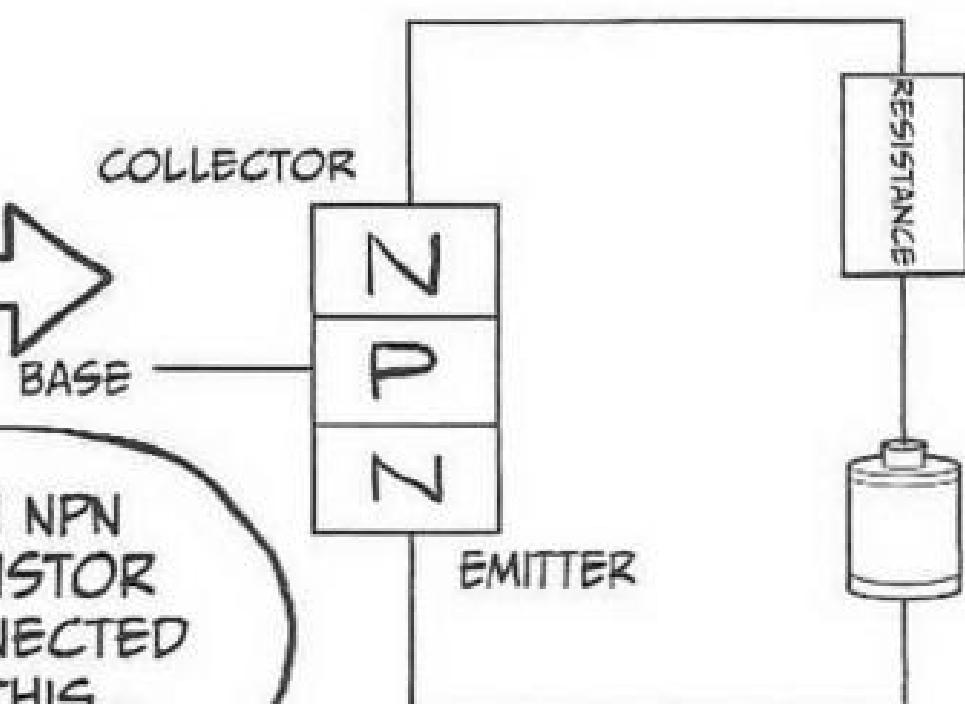


THEY HAVE THREE ELECTRODES REFERRED TO AS B (BASE), C (COLLECTOR), AND E (EMITTER).

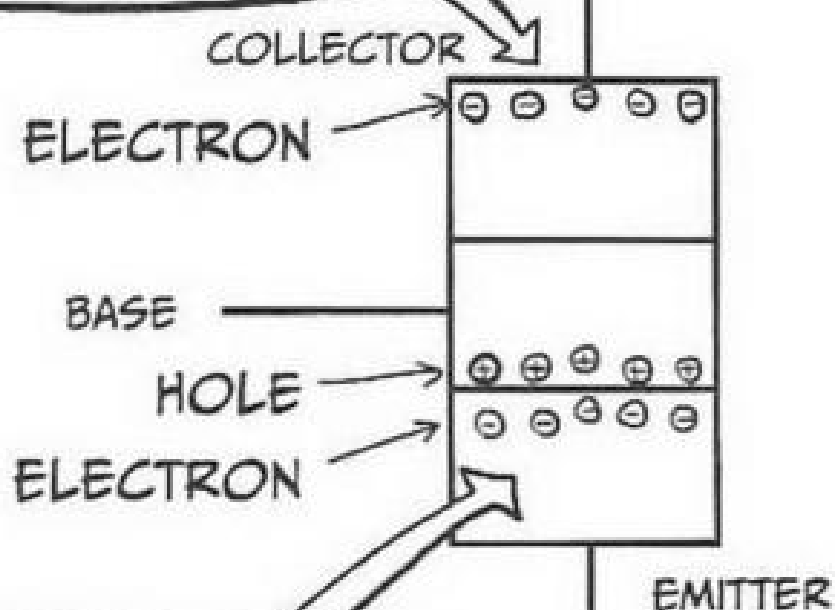
THEY HAVE ONE MORE ELECTRODE THAN A DIODE!



IF AN NPN TRANSISTOR IS CONNECTED LIKE THIS...



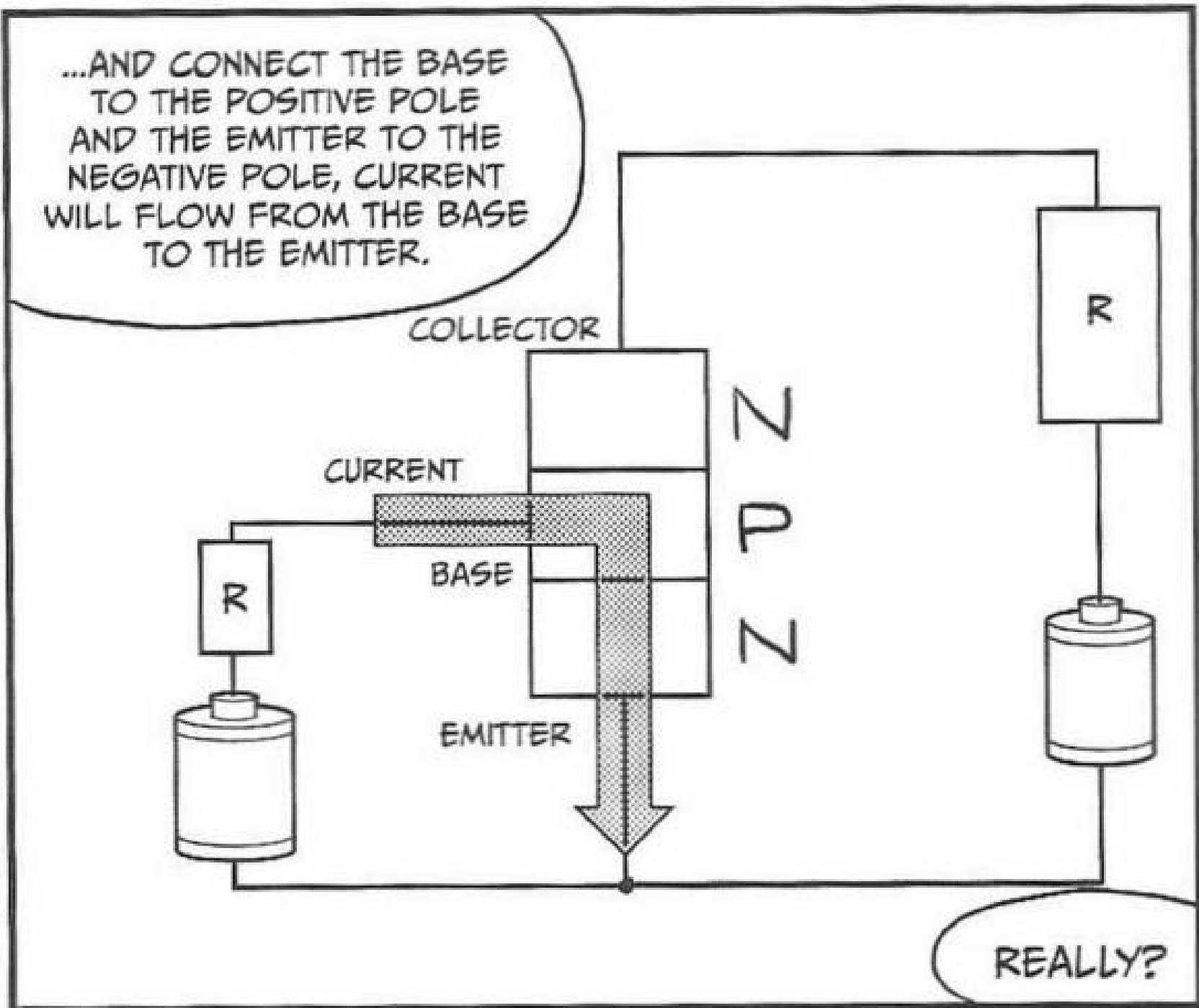
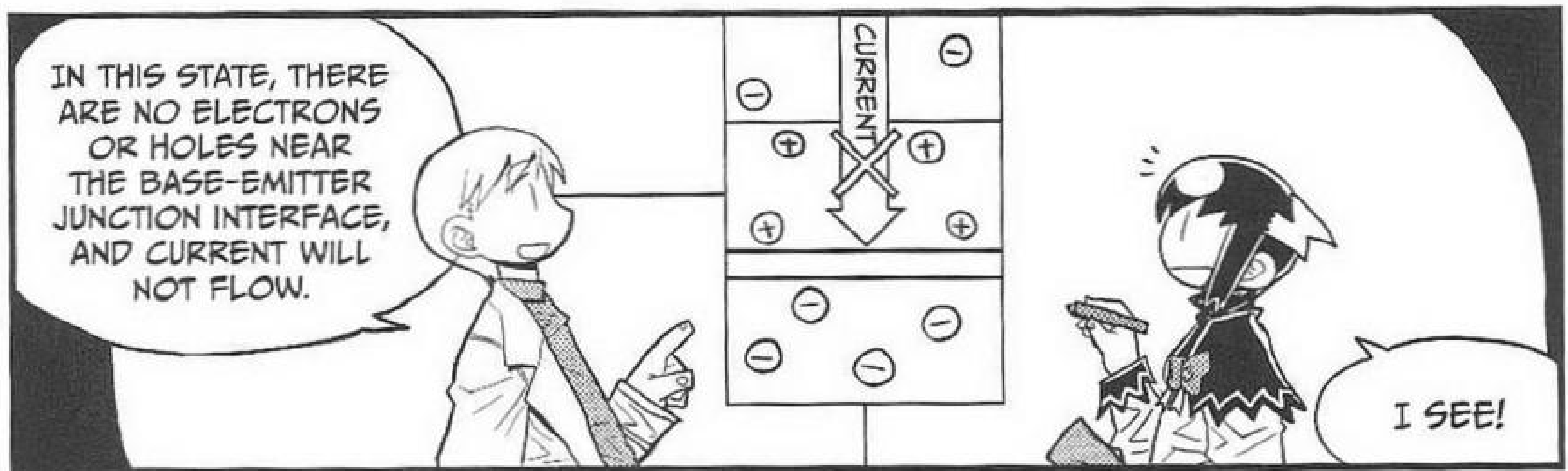
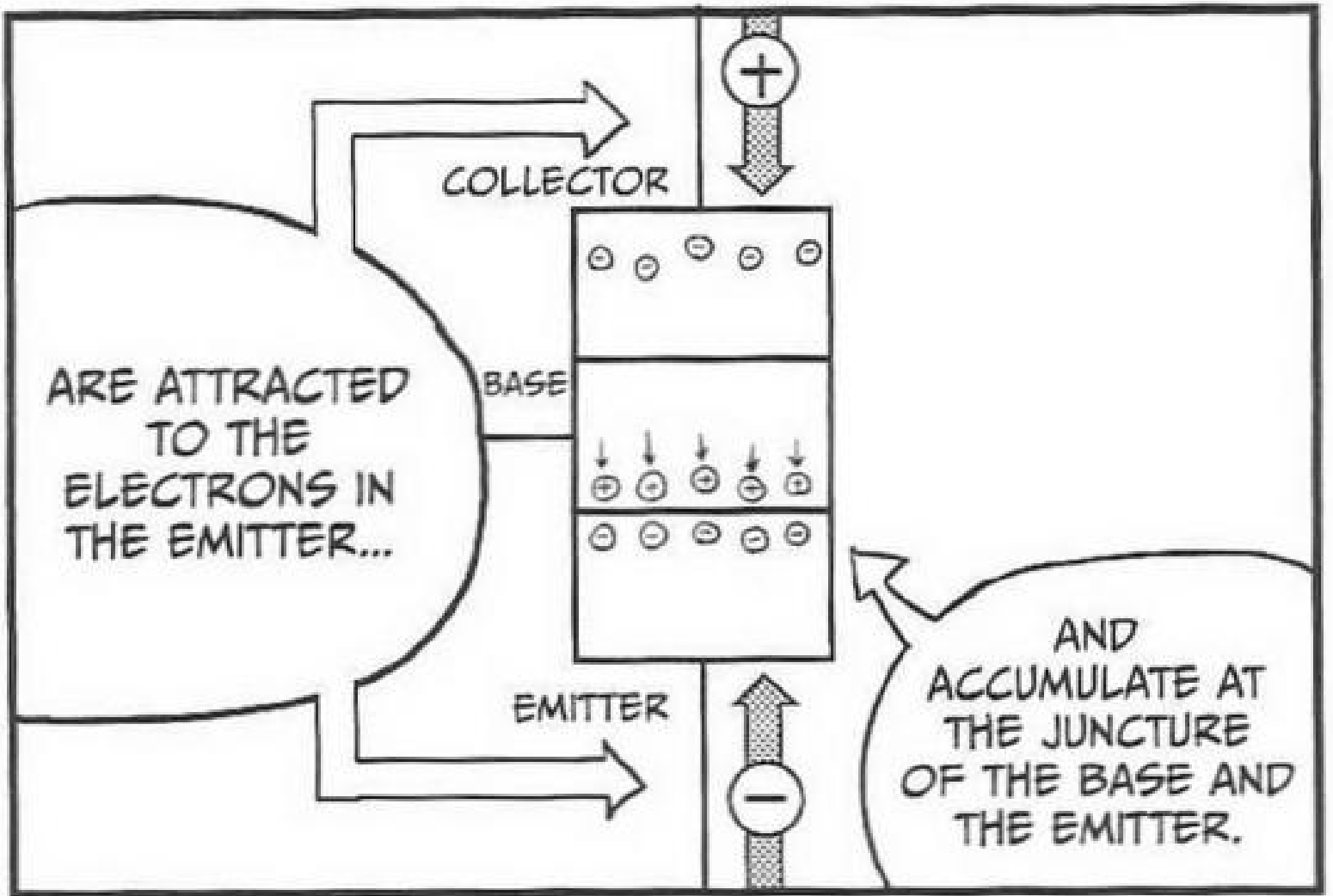
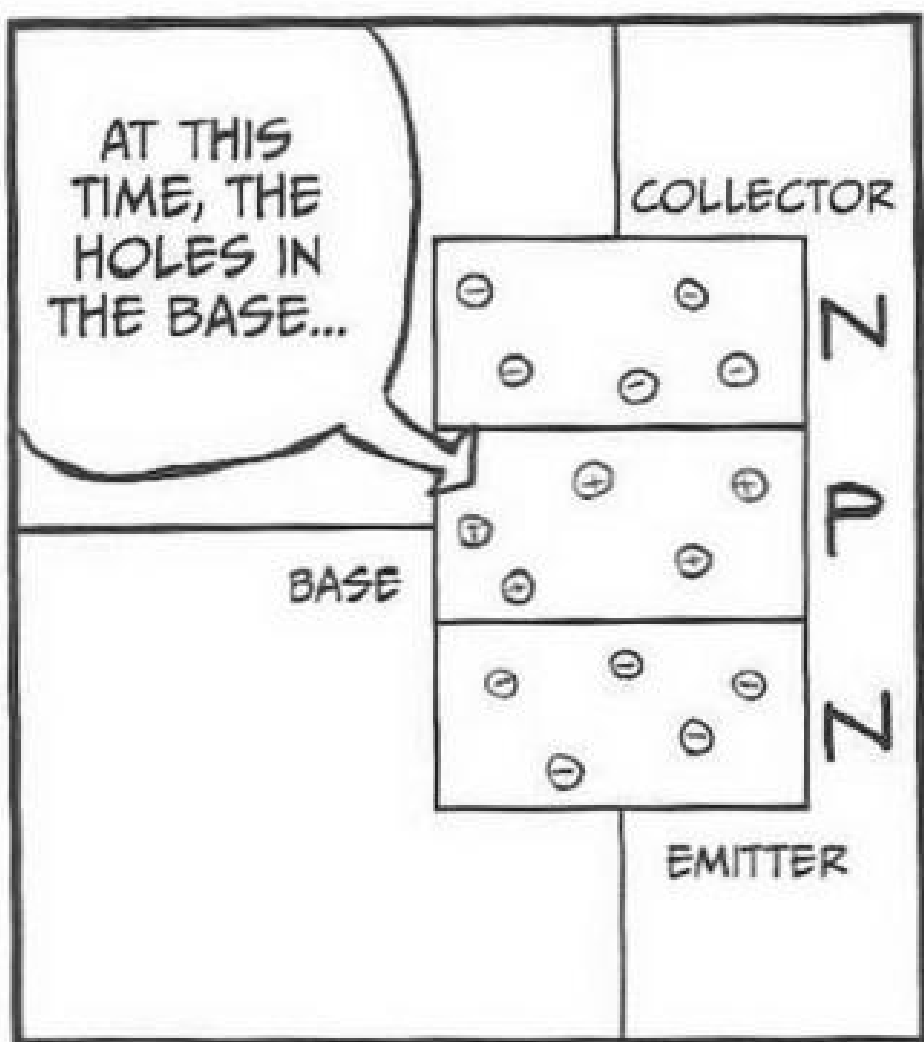
...THE ELECTRONS IN THE COLLECTOR ARE DRAWN TO THE POSITIVE POLE WHERE THEY ACCUMULATE.



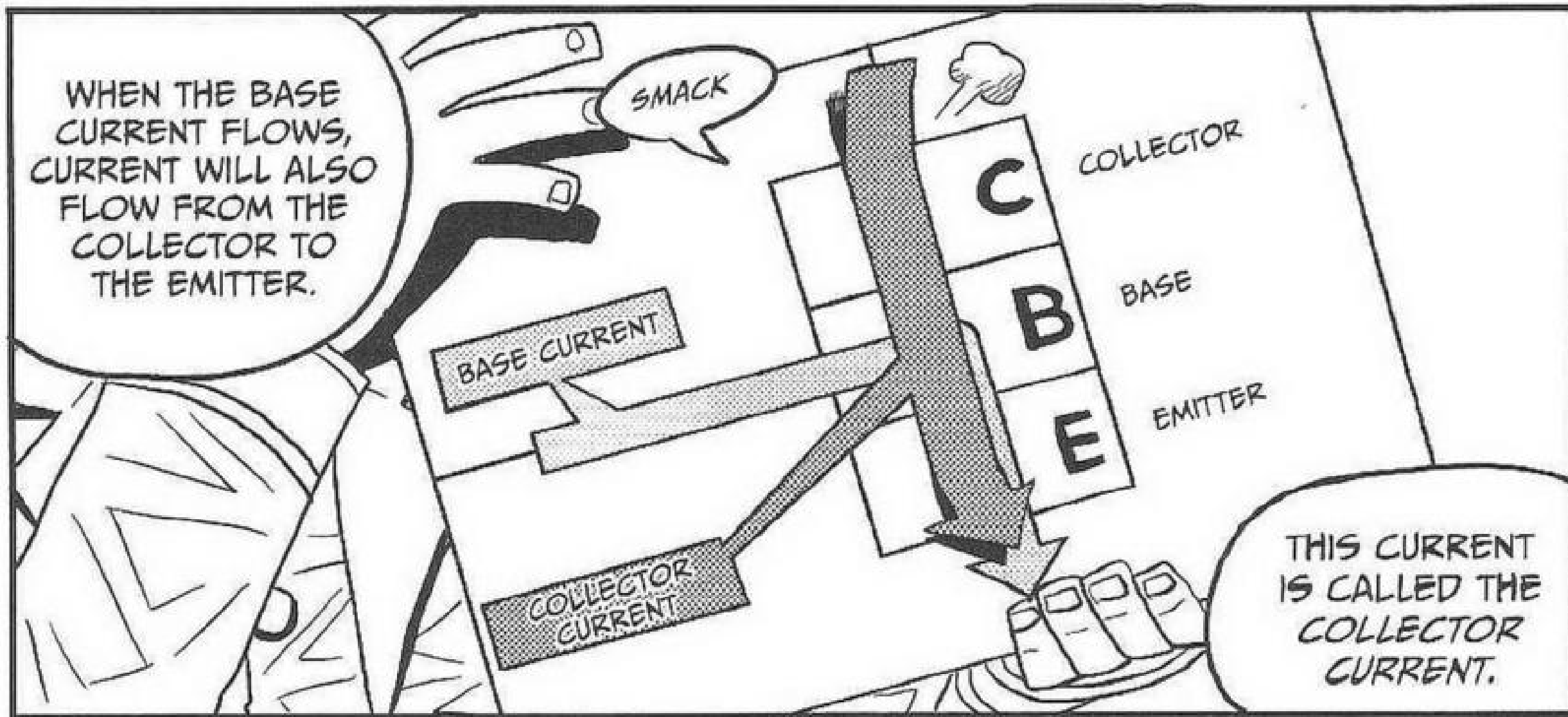
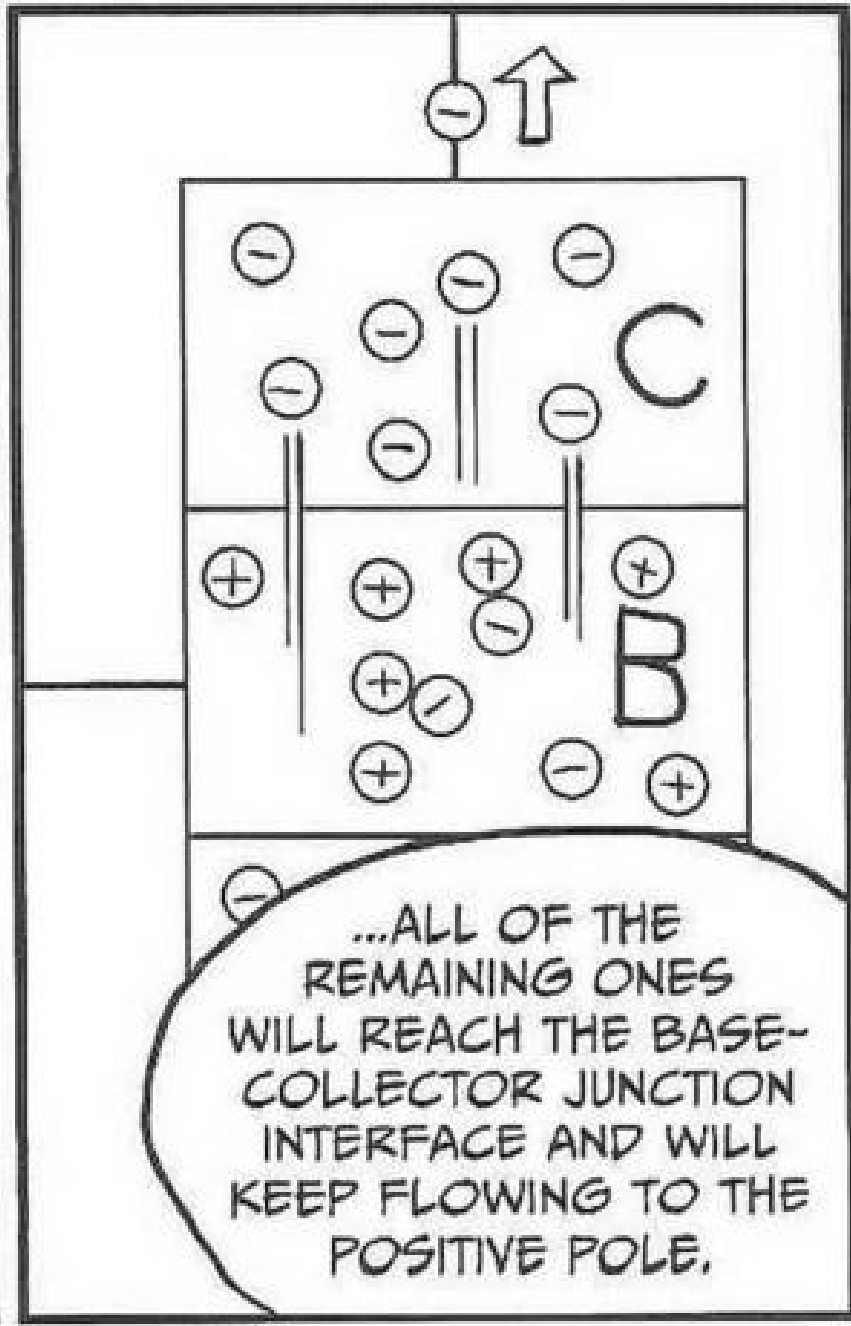
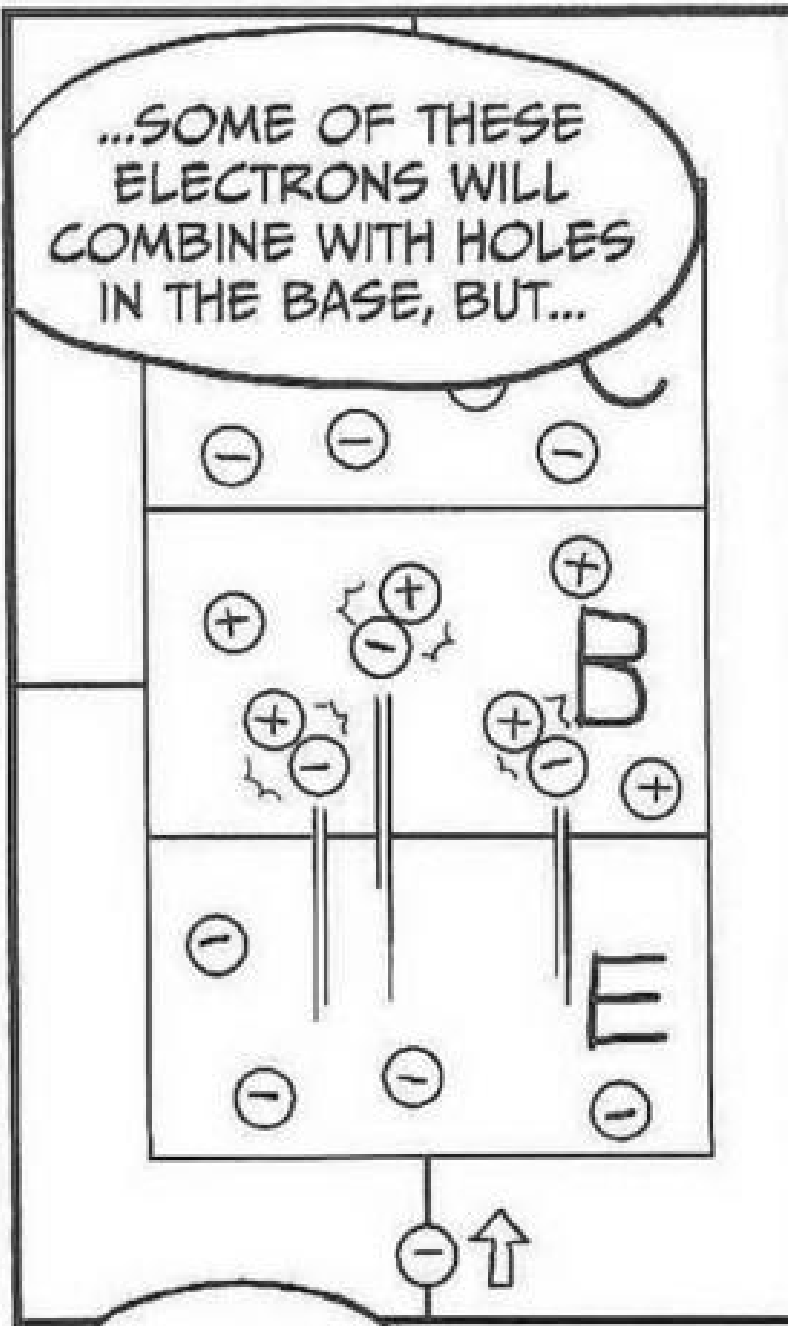
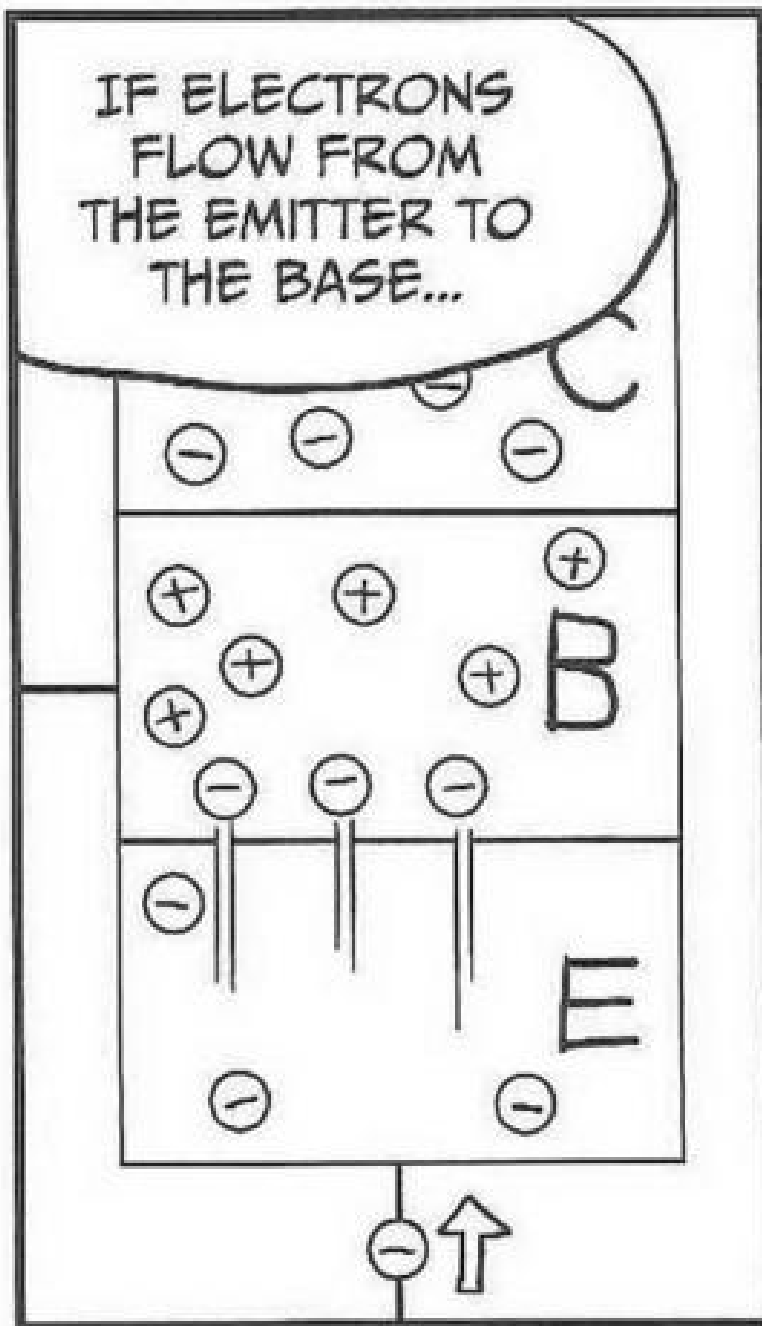
ON THE OTHER HAND, THE ELECTRONS IN THE EMITTER ARE PUSHED TO THE NEGATIVE POLE AND ACCUMULATE NEAR THE BASE-EMITTER JUNCTION INTERFACE.

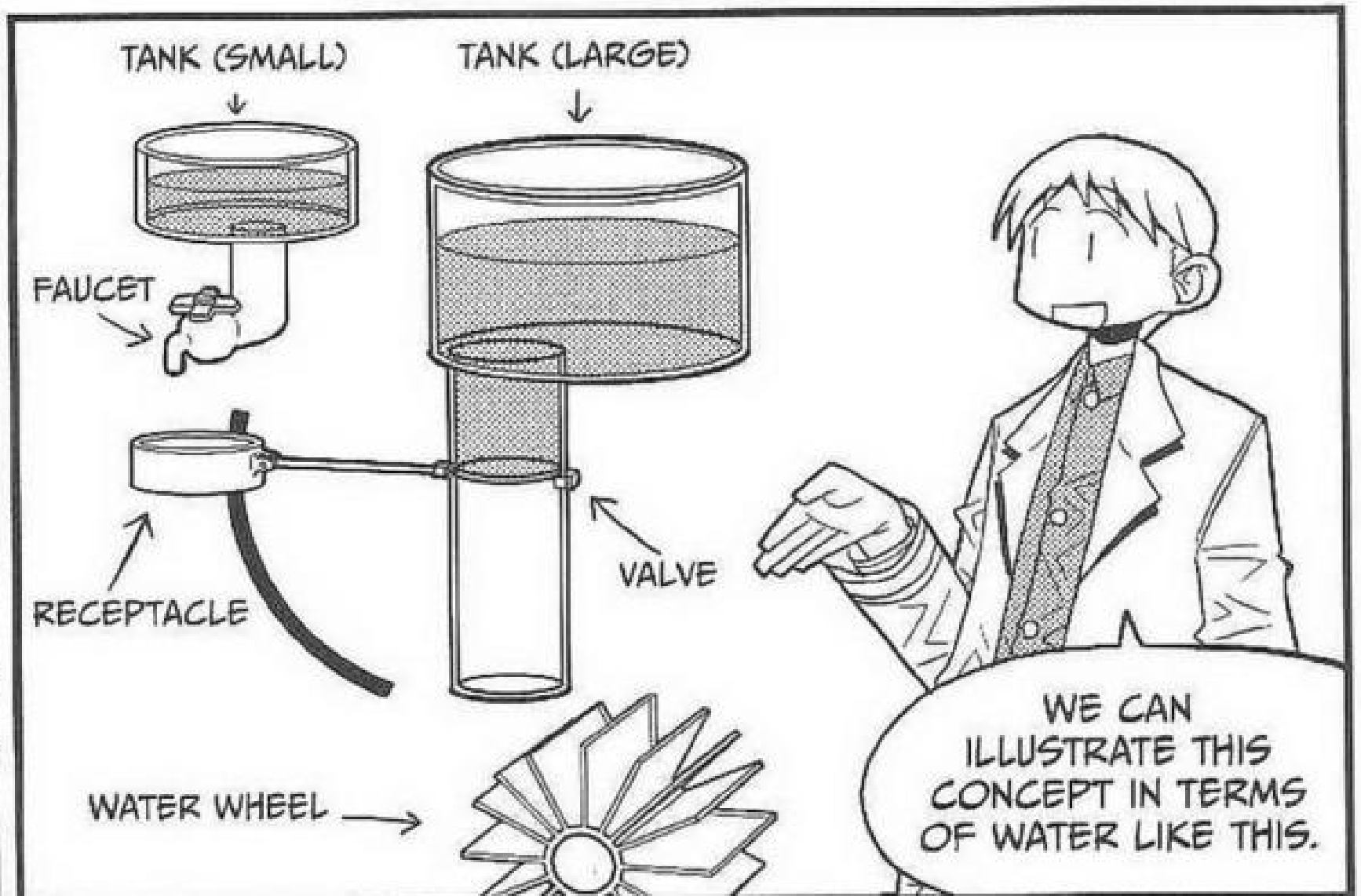
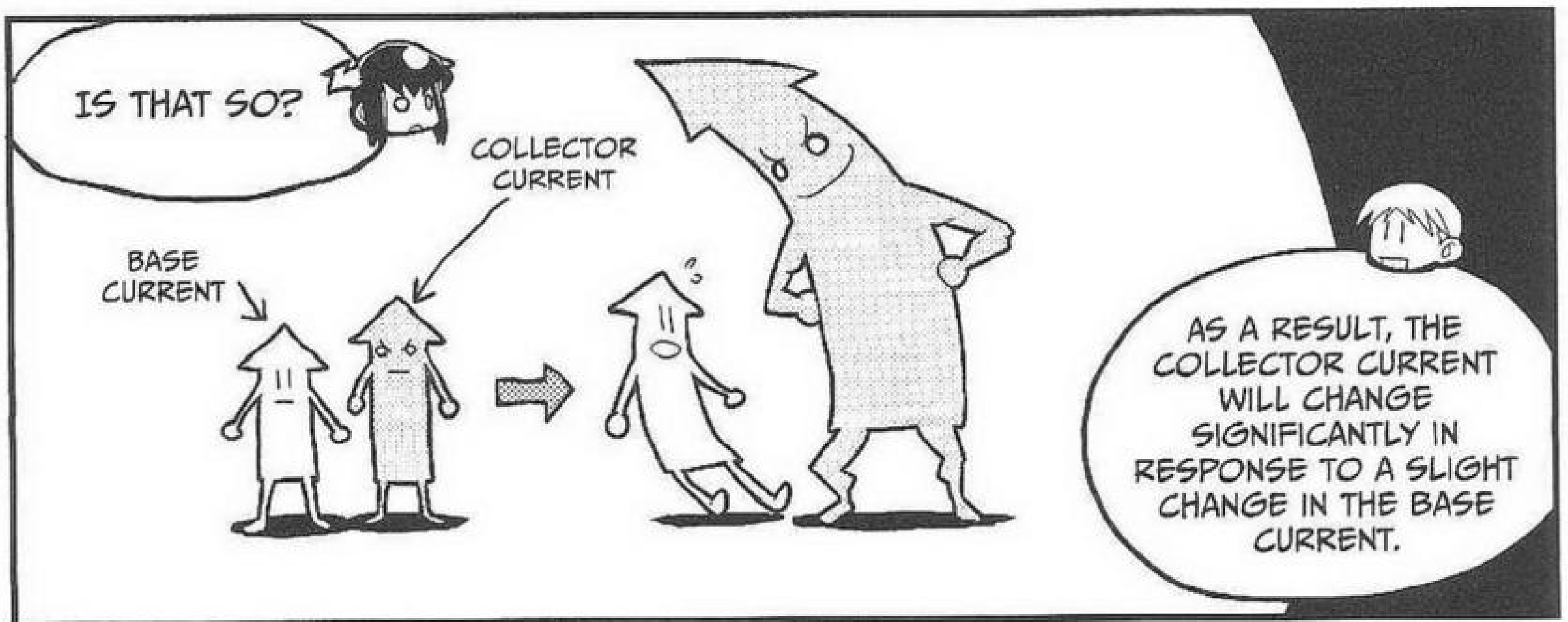
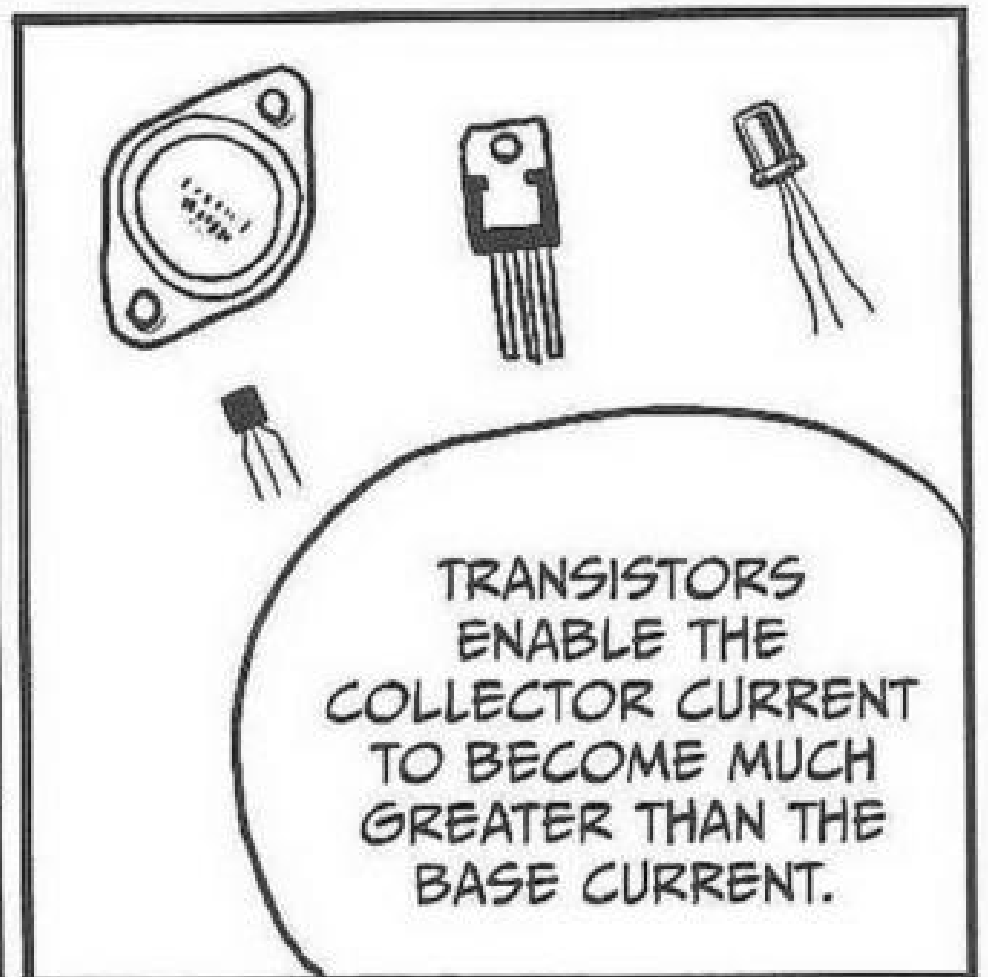
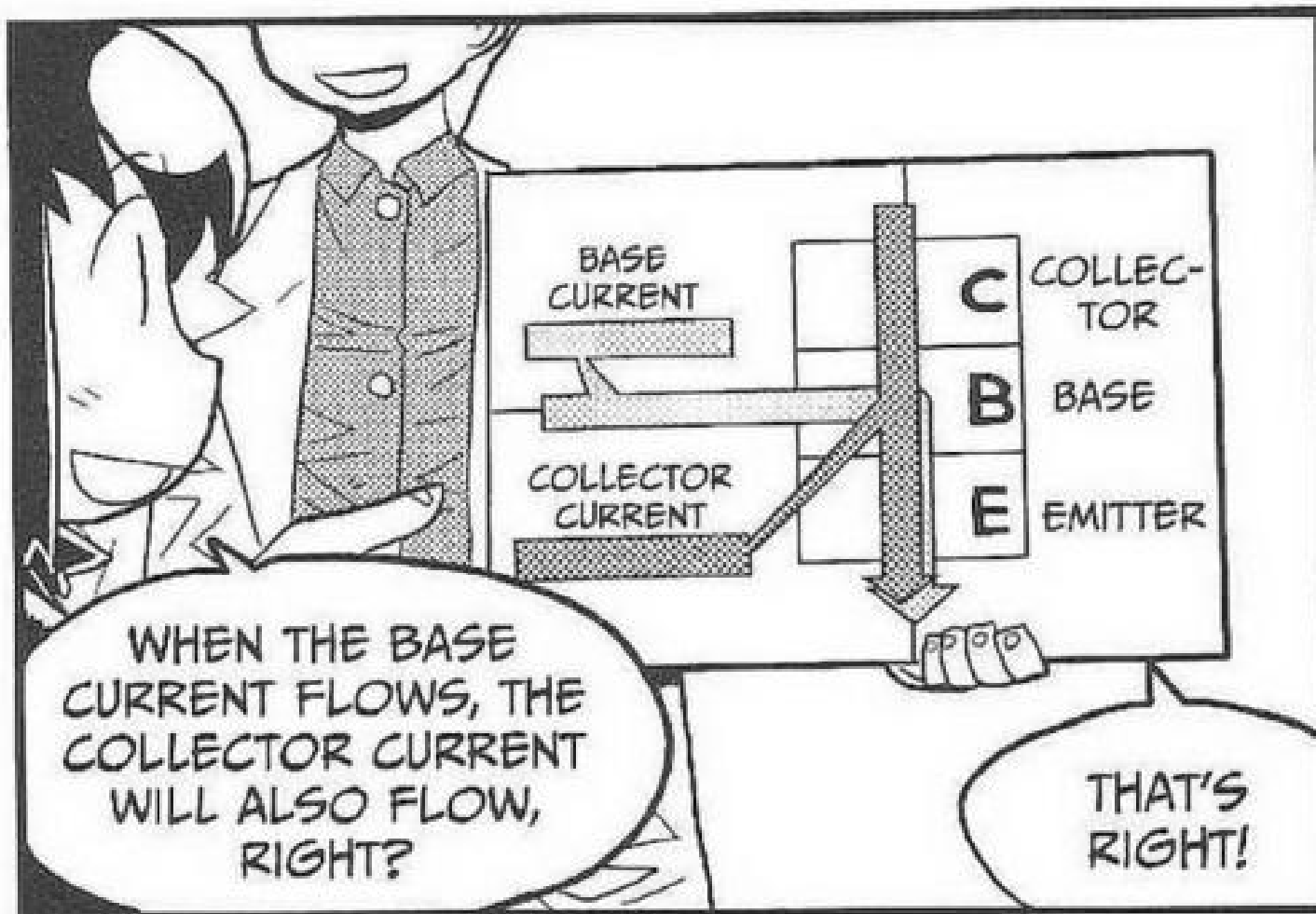
OKAY, GOT IT!

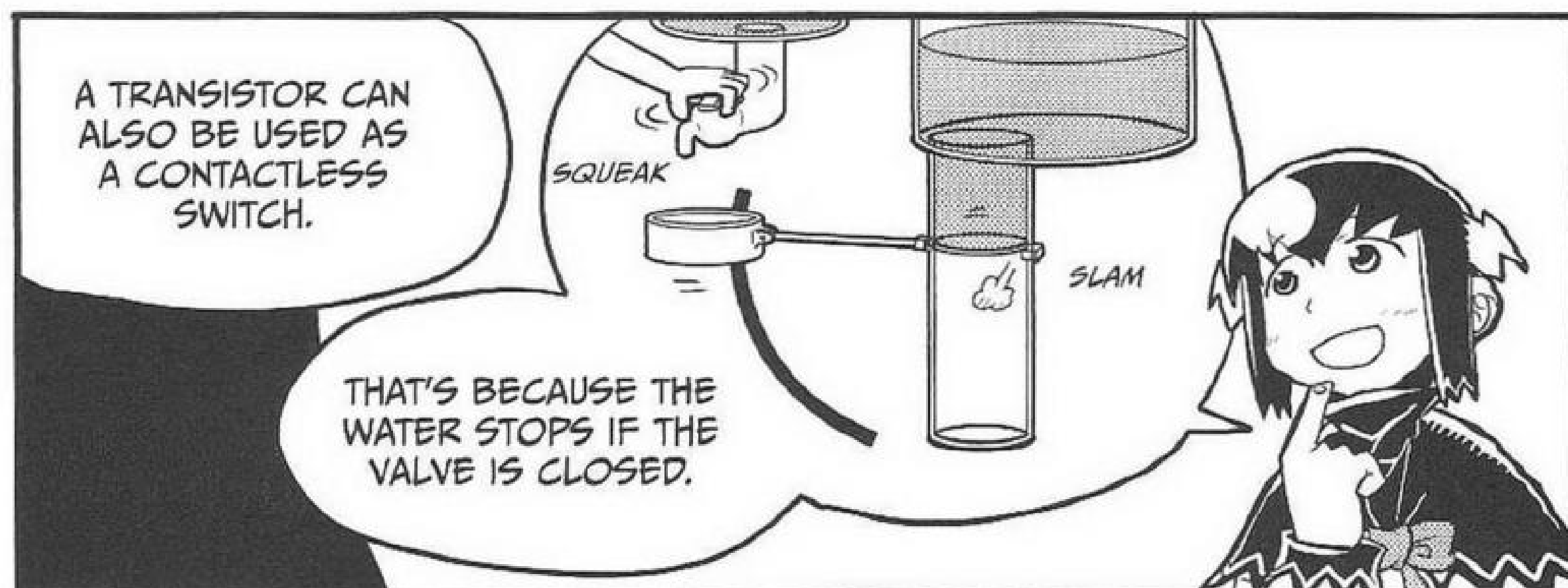
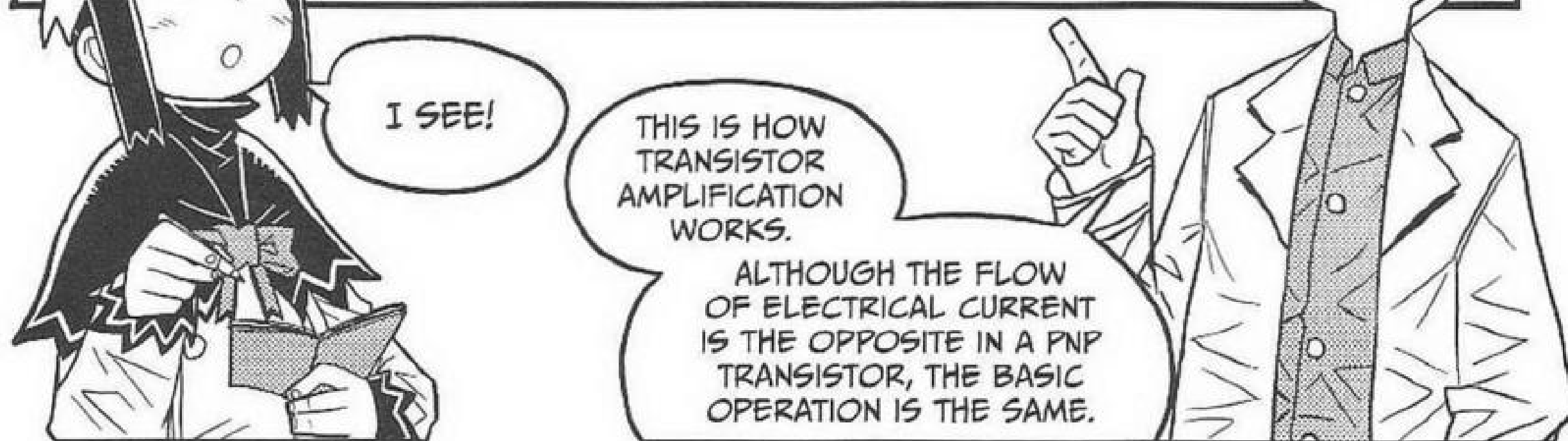
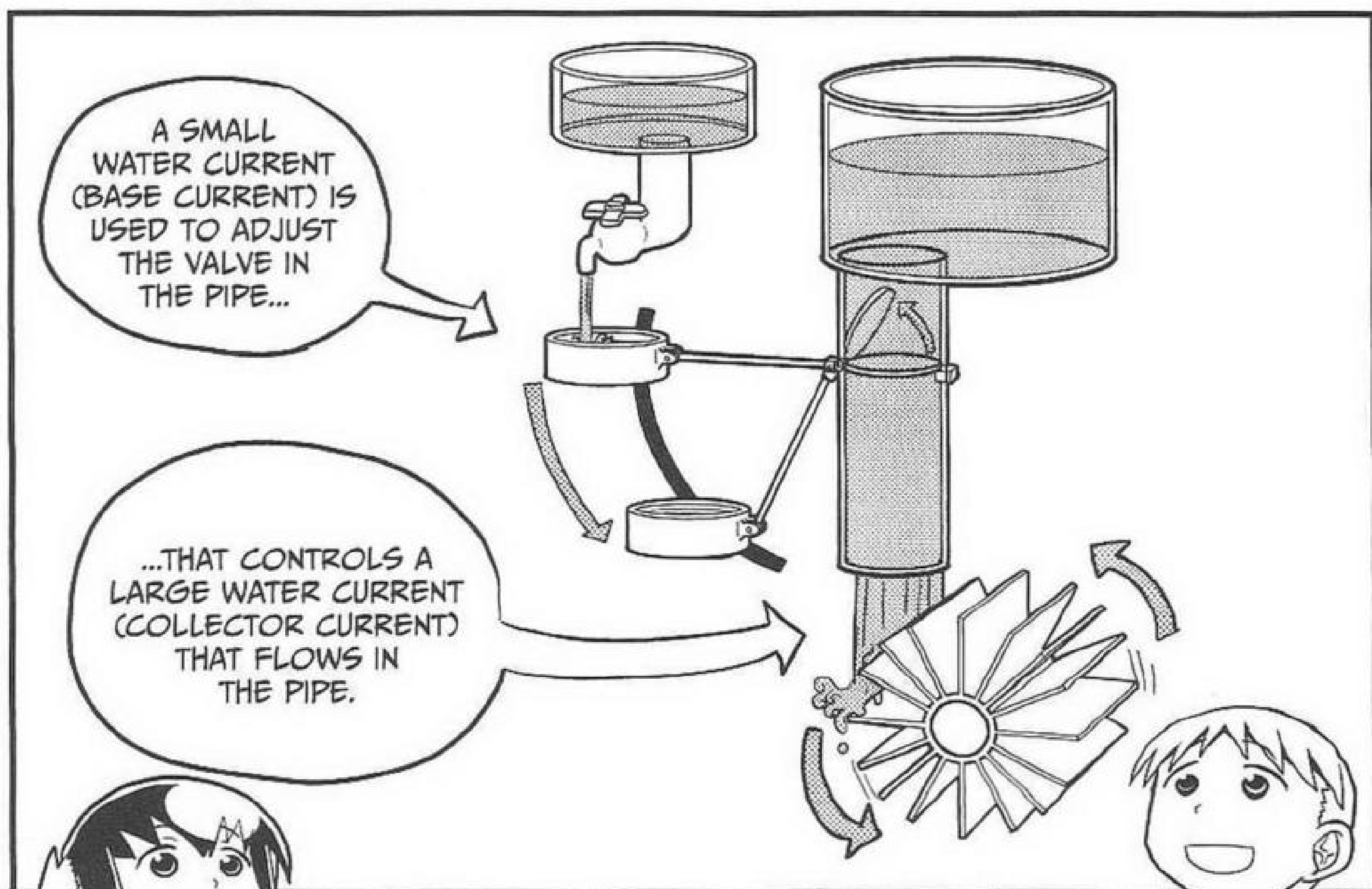


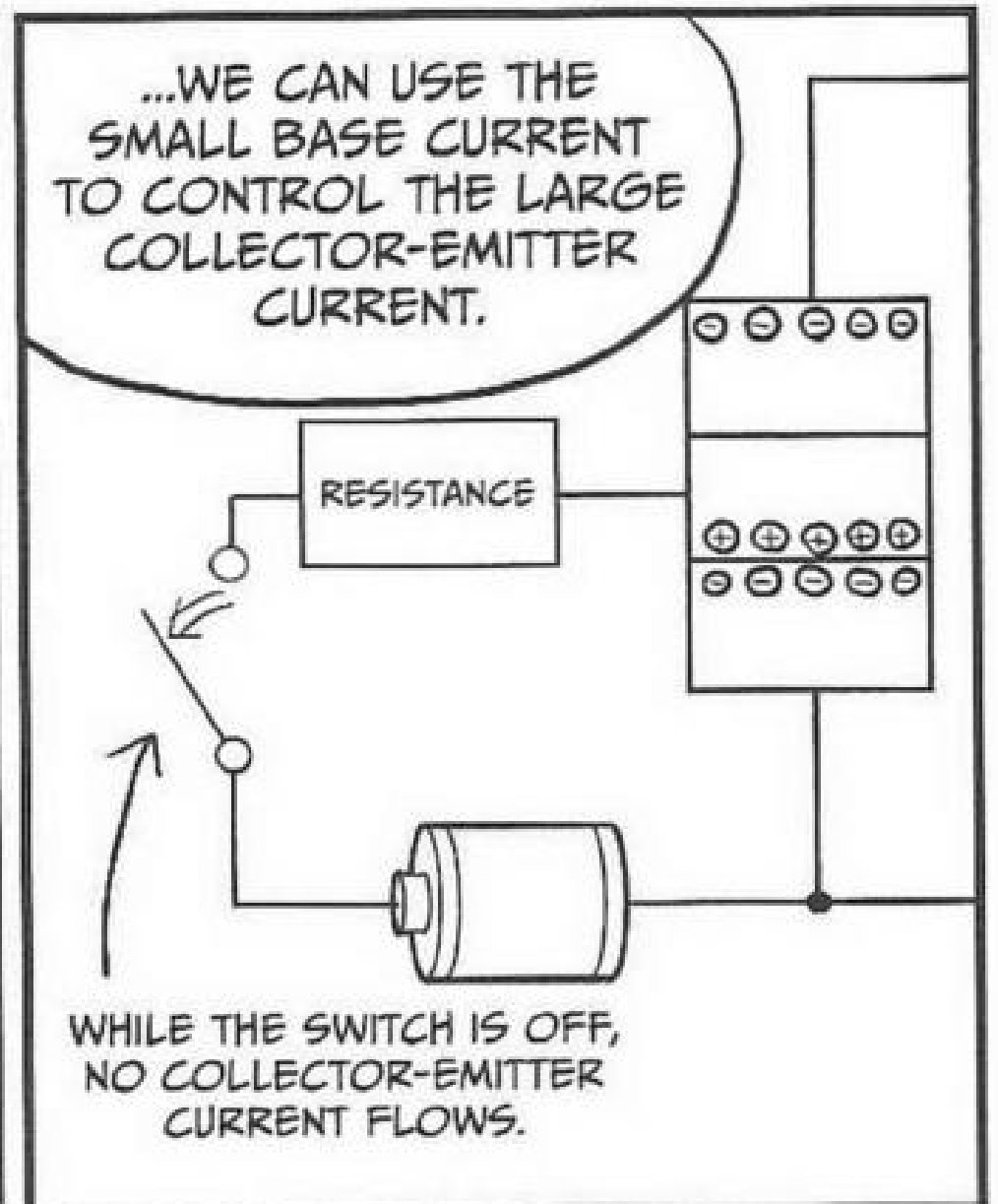
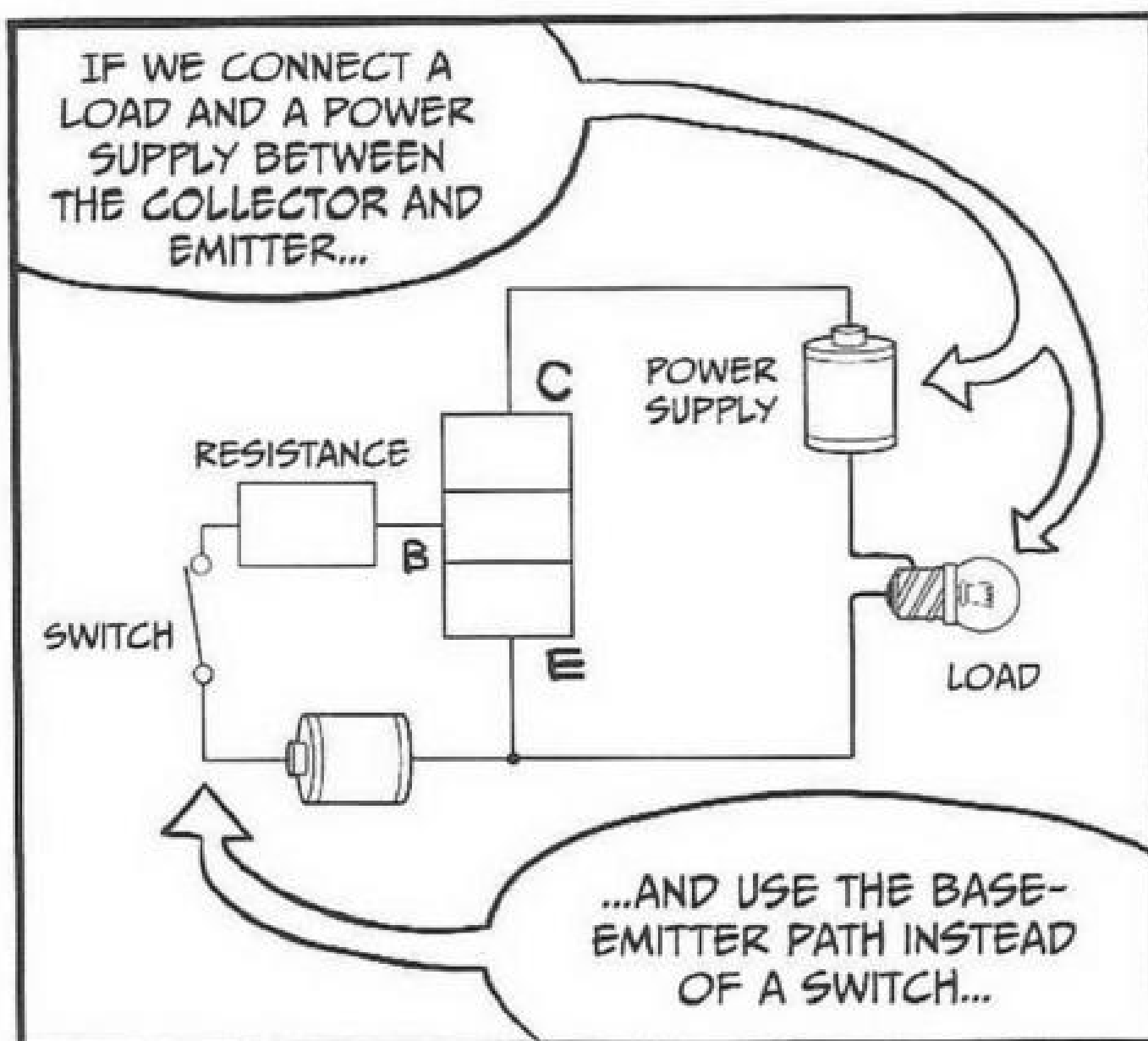






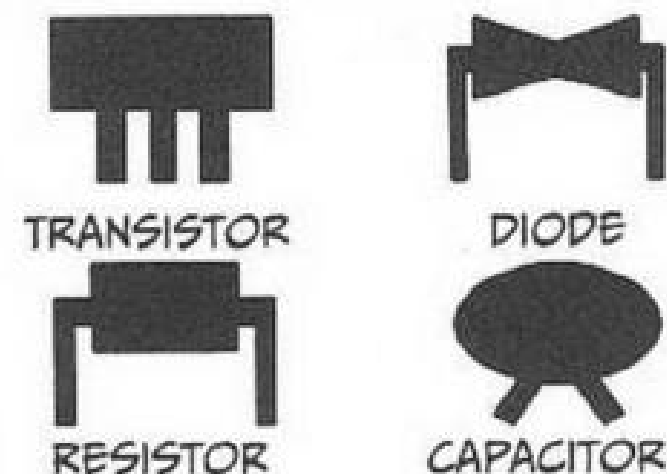






COMPONENTS CALLED  
INTEGRATED CIRCUITS  
(ICs) ARE ALSO  
USED IN ELECTRONIC  
DEVICES SUCH AS TVs  
OR COMPUTERS.

AN IC CONTAINS AN EXTREMELY  
LARGE NUMBER OF ELEMENTS  
SUCH AS TRANSISTORS, DIODES,  
RESISTORS, AND CAPACITORS—  
THESE COMPLICATED CIRCUITS CAN  
PERFORM DIGITAL LOGIC.



HMMMM...

WELL, THIS  
COMPLETES OUR  
DISCUSSION OF  
THE BASICS OF  
SEMICONDUCTOR  
DEVICES...

CLAP  
CLAP

...WHICH MEANS...

YOUR STUDIES ARE  
OVER! THANK YOU FOR  
ALL YOUR HARD WORK!

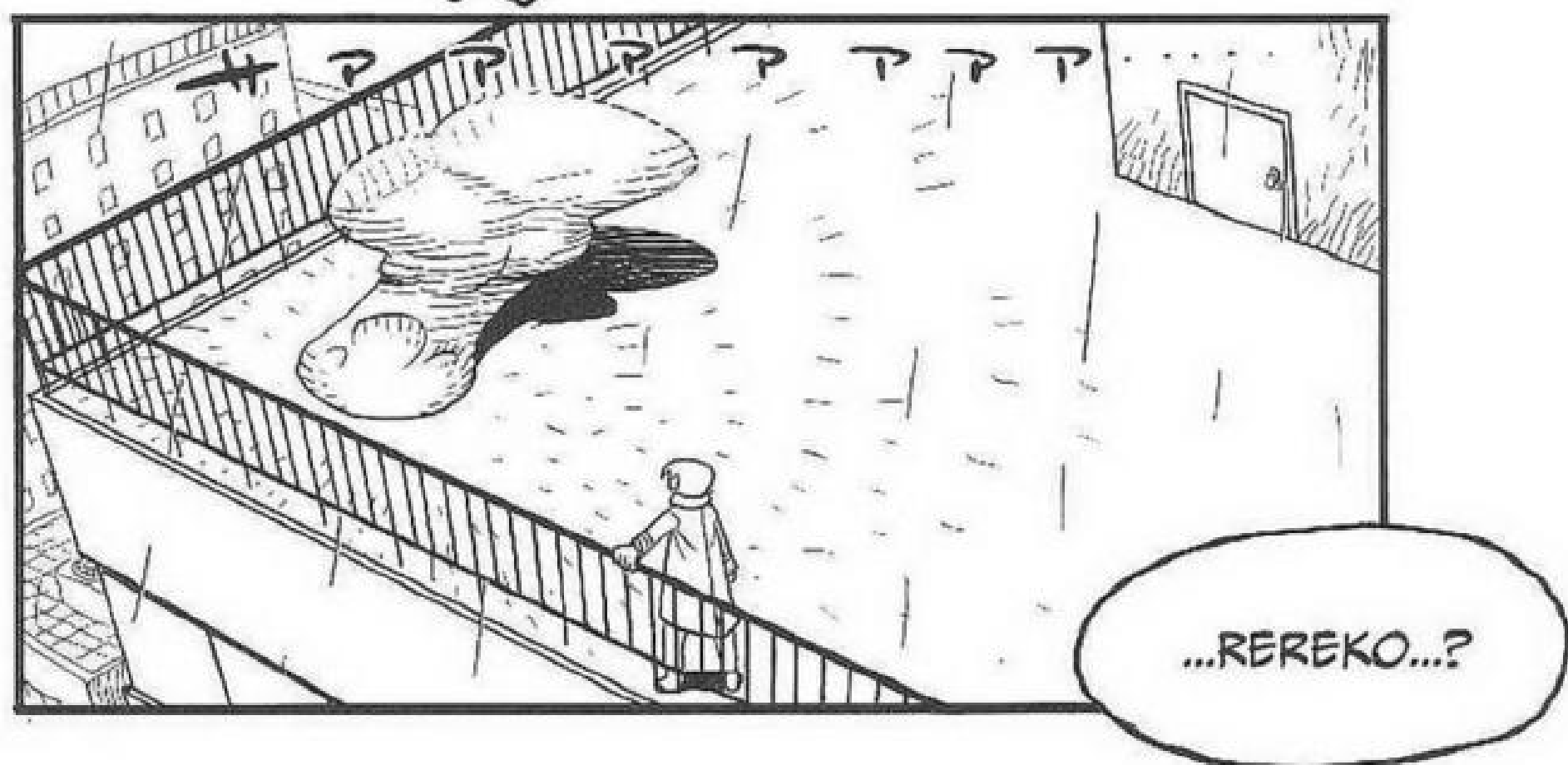
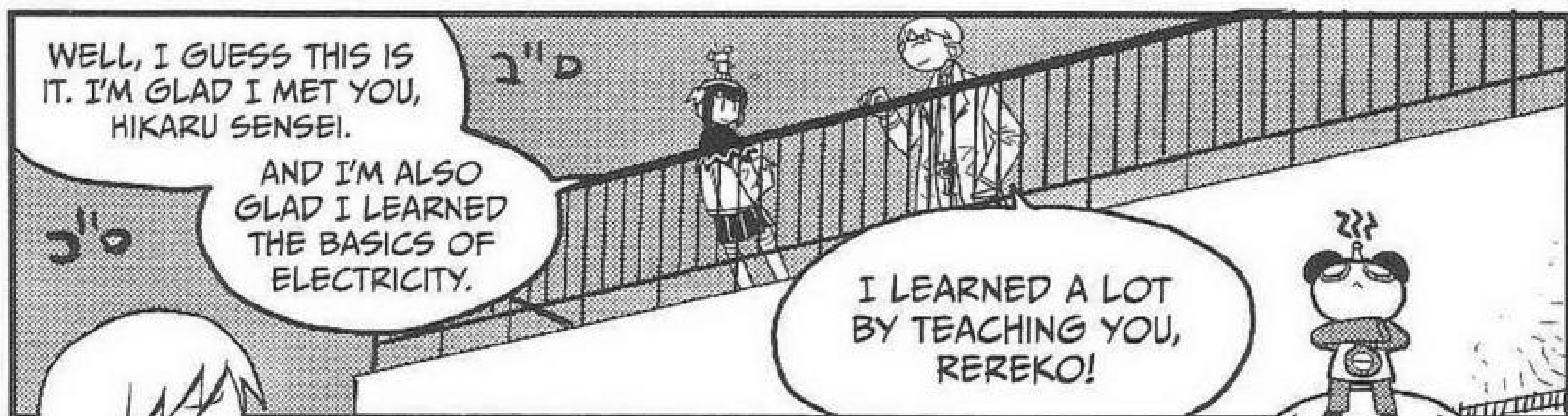
NO WAY!  
IT'S YOU WHO  
DESERVES ALL THE  
THANKS. THANK YOU  
VERY, VERY MUCH!!

SINCE THE CALL  
FOR PICKING YOU UP  
HASN'T COME YET,  
LET'S GO FOR A  
LITTLE STROLL!

REALLY!?  
THAT WOULD BE  
AWESOME!!

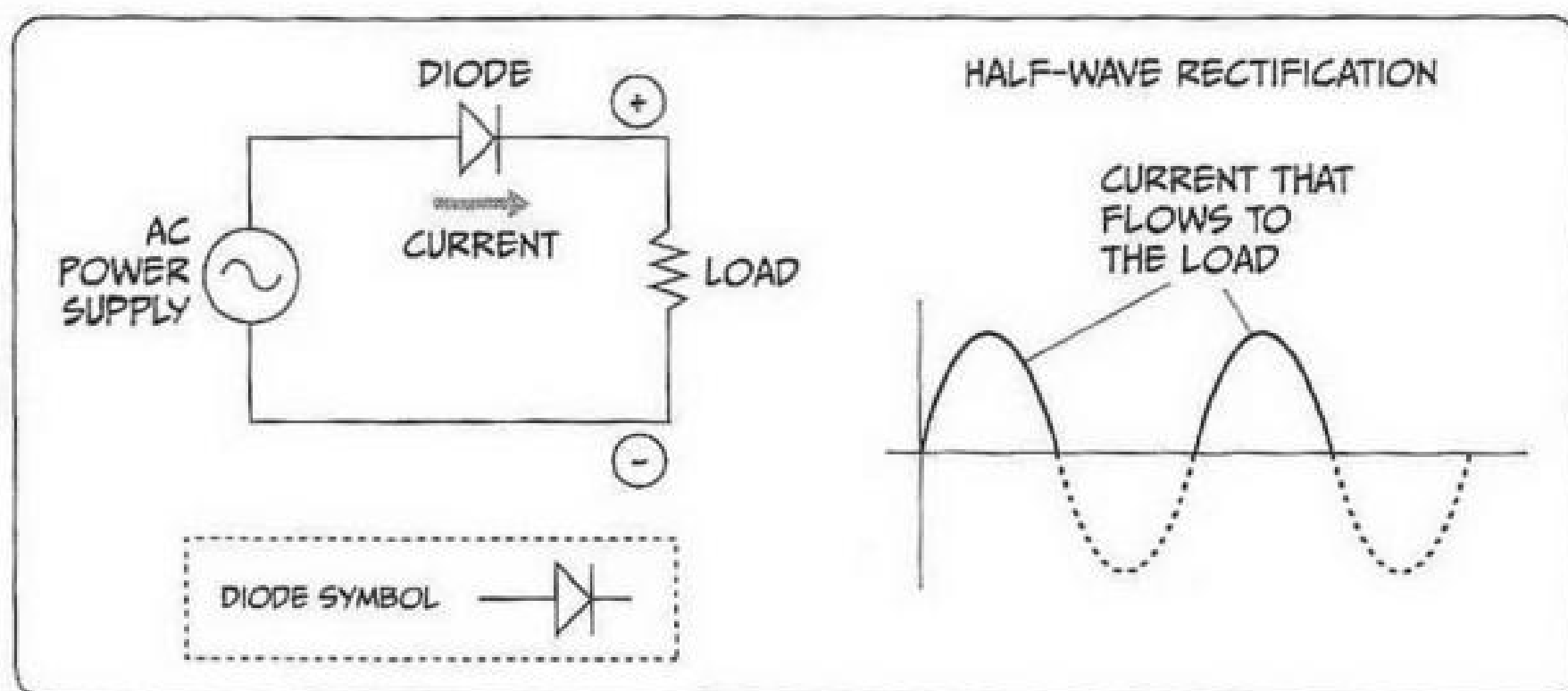






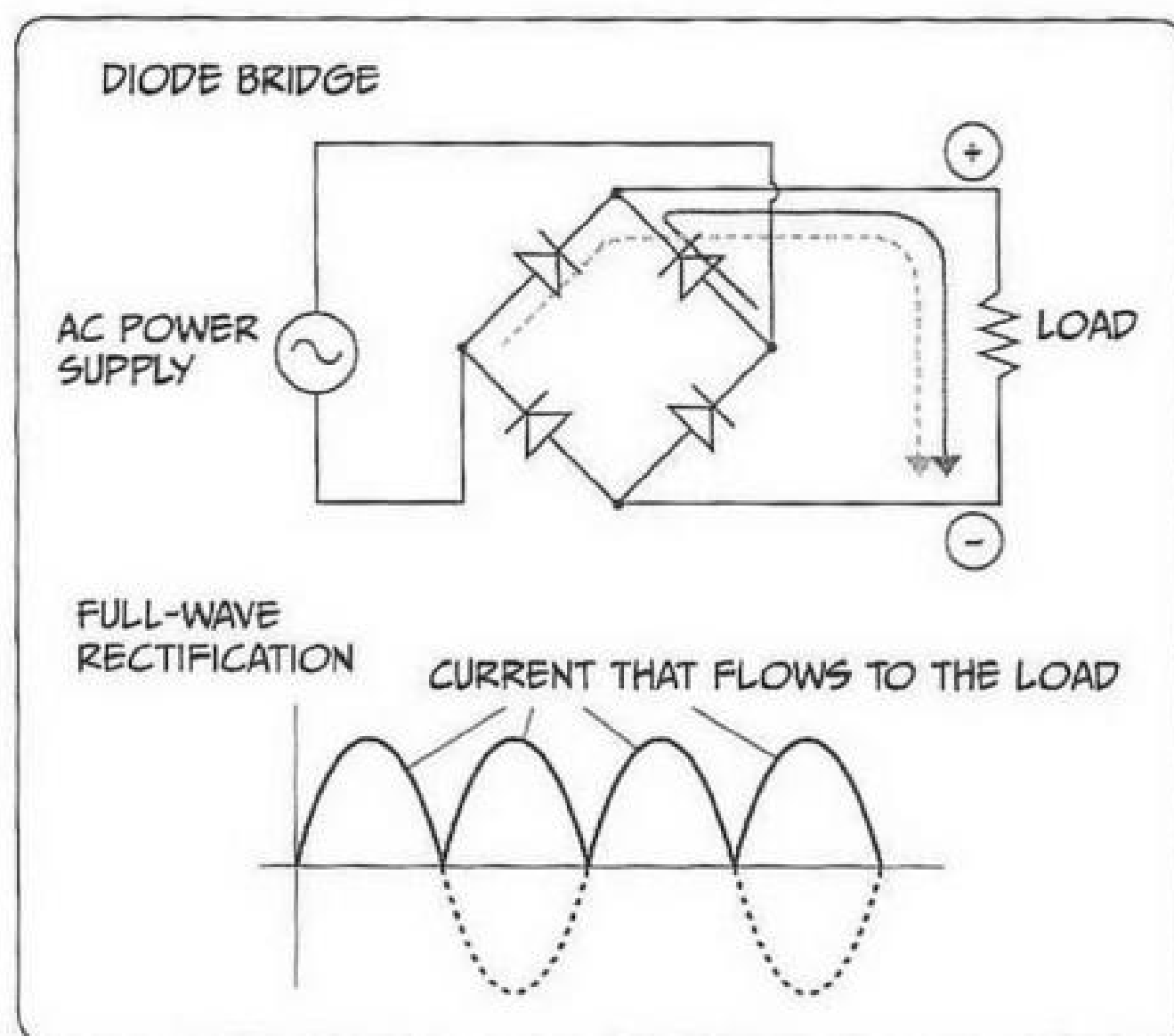
# DIODES

When a single diode is connected to an AC power supply, current flows to the load for only one direction of the AC power supply due to rectification. Rectification that only allows a half-cycle of the alternating current to flow is called *half-wave rectification*, and the current that flows to the load in this process flows in only one direction, just like a direct current power supply. But since only a half-cycle of the AC waveform flows, this kind of rectification is inefficient.



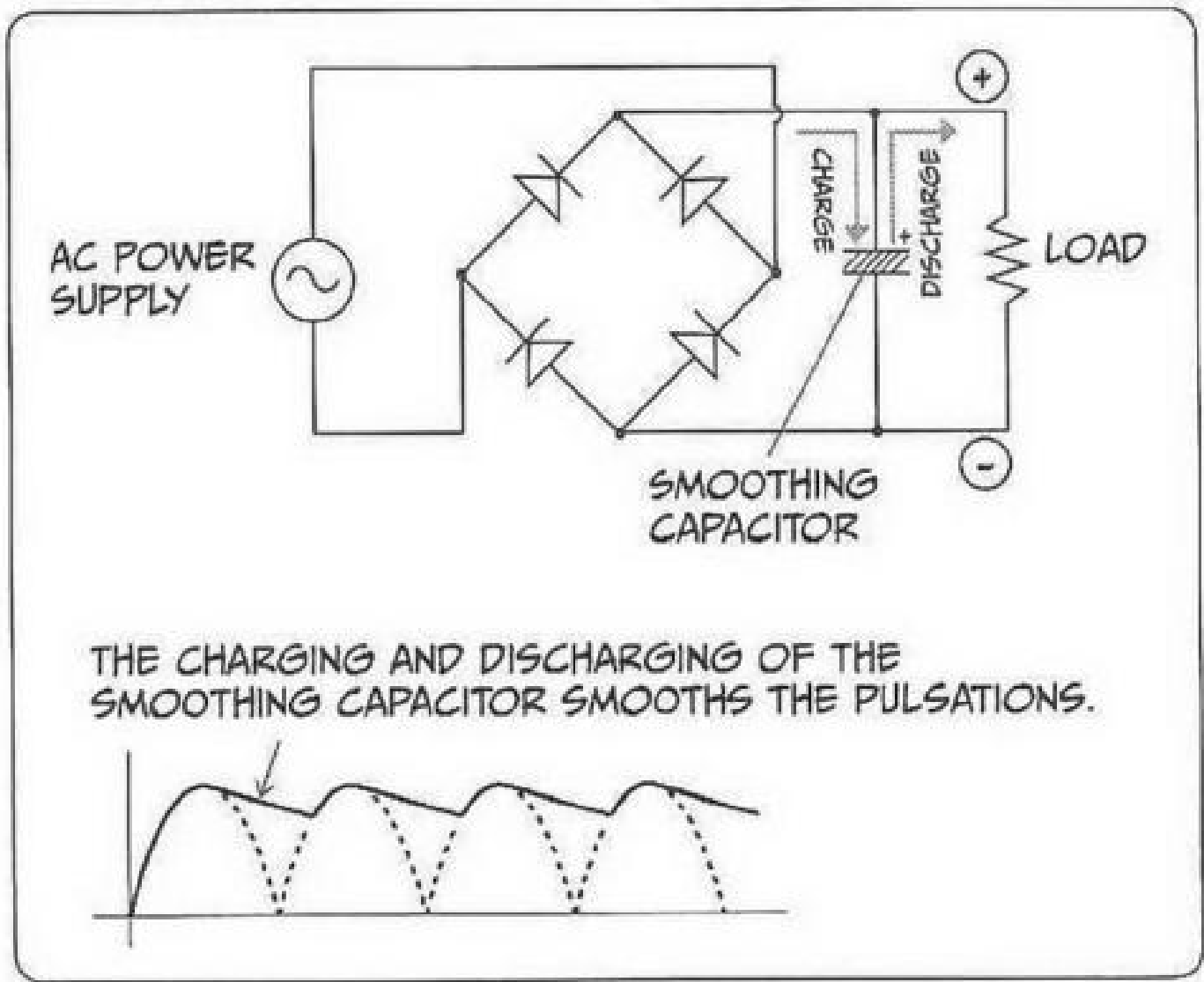
Half-wave rectification

When four diodes are arranged in a bridge configuration and an AC power supply is connected, the current of the entire cycle becomes positive and flows to the load. This kind of rectification is called *full-wave rectification*, and diodes that are connected in this way are called a *diode bridge*. Full-wave rectification enables current from the entire cycle of the AC power supply to be used as direct current.



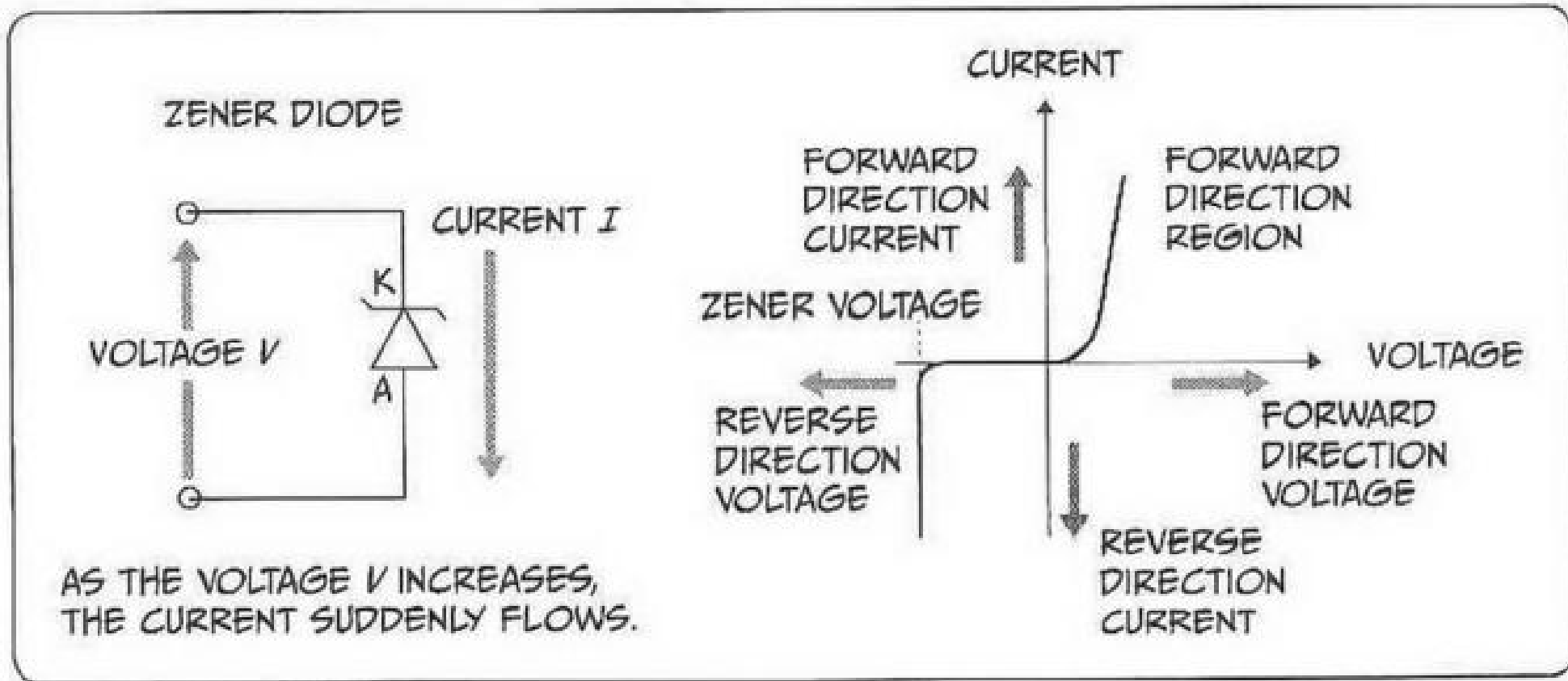
Full-wave rectification

Although this kind of full-wave rectification is more efficient than half-wave rectification, the waveform exhibits large pulsations. However, if an electrolytic capacitor is connected to the output, the charging and discharging of the capacitor can change the pulsations in the waveform into a flat, smooth direct current. A capacitor that is used to change a pulsating flow to a flat waveform in this way is called a *smoothing capacitor*.



Smoothing capacitor

If a reverse-direction voltage is applied to a *Zener diode* (or *constant-voltage diode*) and the value of the voltage is steadily increased, current will flow once a certain voltage is reached. This phenomenon is called *breakdown*, and when the circuit voltage rises more than necessary, current can flow from the cathode to the anode to suppress the rise in voltage. This characteristic of a Zener diode is used in a constant voltage circuit that maintains a fixed voltage.



Characteristics of a Zener diode

If an ordinary diode is used as a Zener diode, it will be damaged because breakdown and the Zener current will be concentrated locally within the diode.

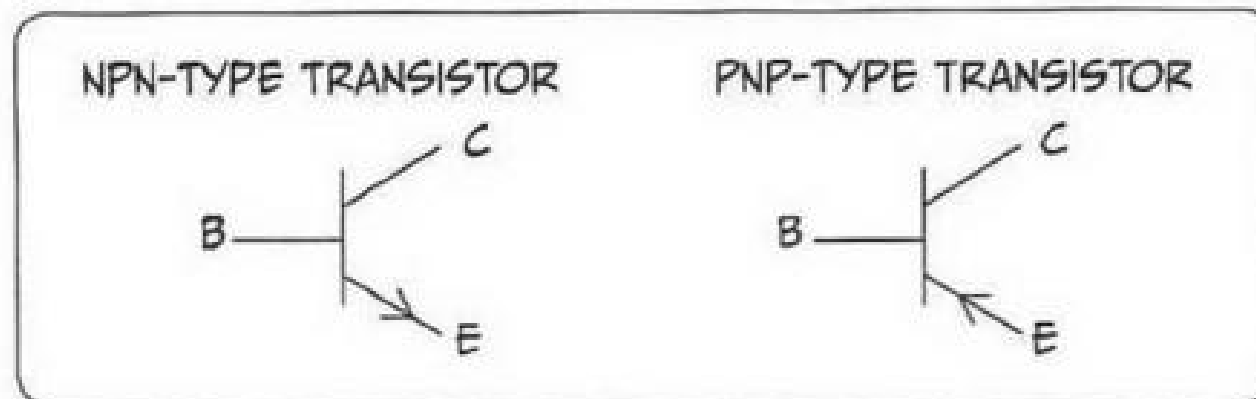
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## TRANSISTORS

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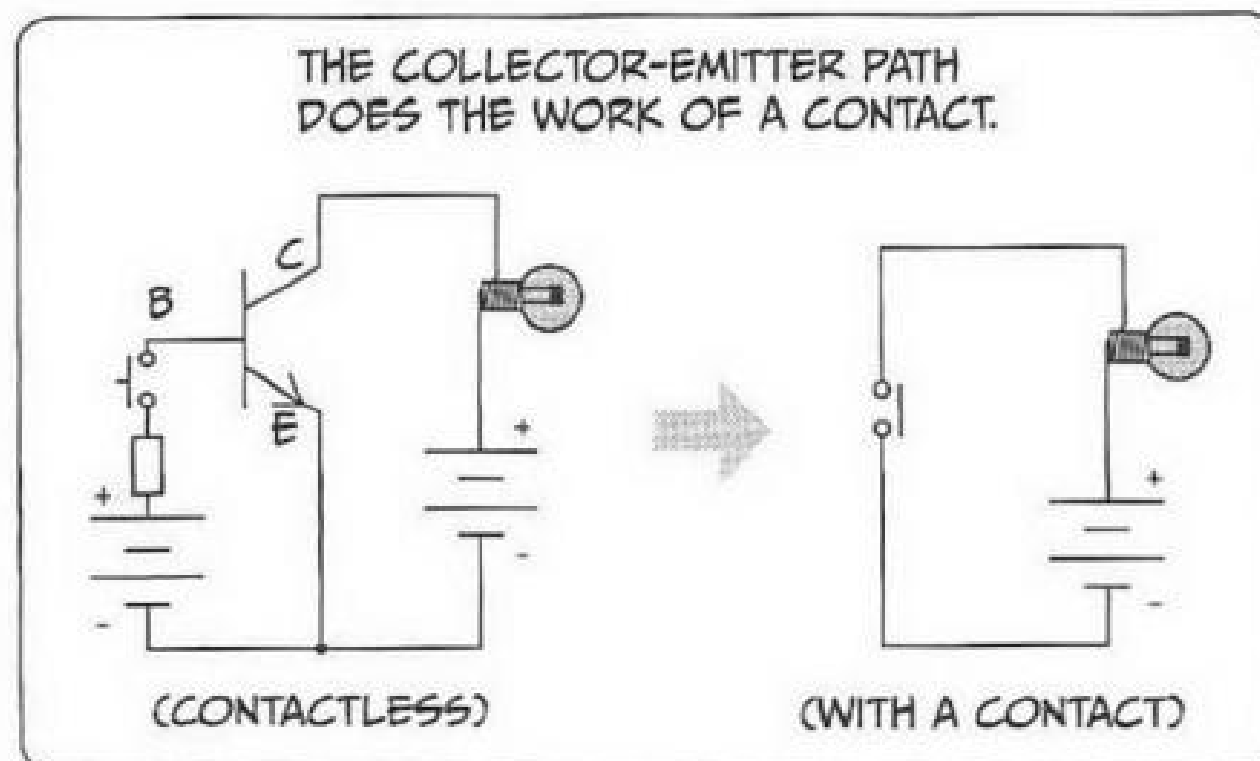
A *transistor* is a semiconductor device that amplifies signals or acts as a switch by controlling the current or the voltage that is applied to an electrode.

When a large amount of electric power is controlled by a transistor that is used as a switch, the transistor is called a *power transistor*. Generally, an NPN-type transistor is used in this way.



Transistor symbols

A switch that uses a transistor has no contact that will wear out, reducing the occurrence of failures, allowing it to be turned on and off rapidly, and allowing users to finely tune control of the device.



Transistor that does the work of a contact

---

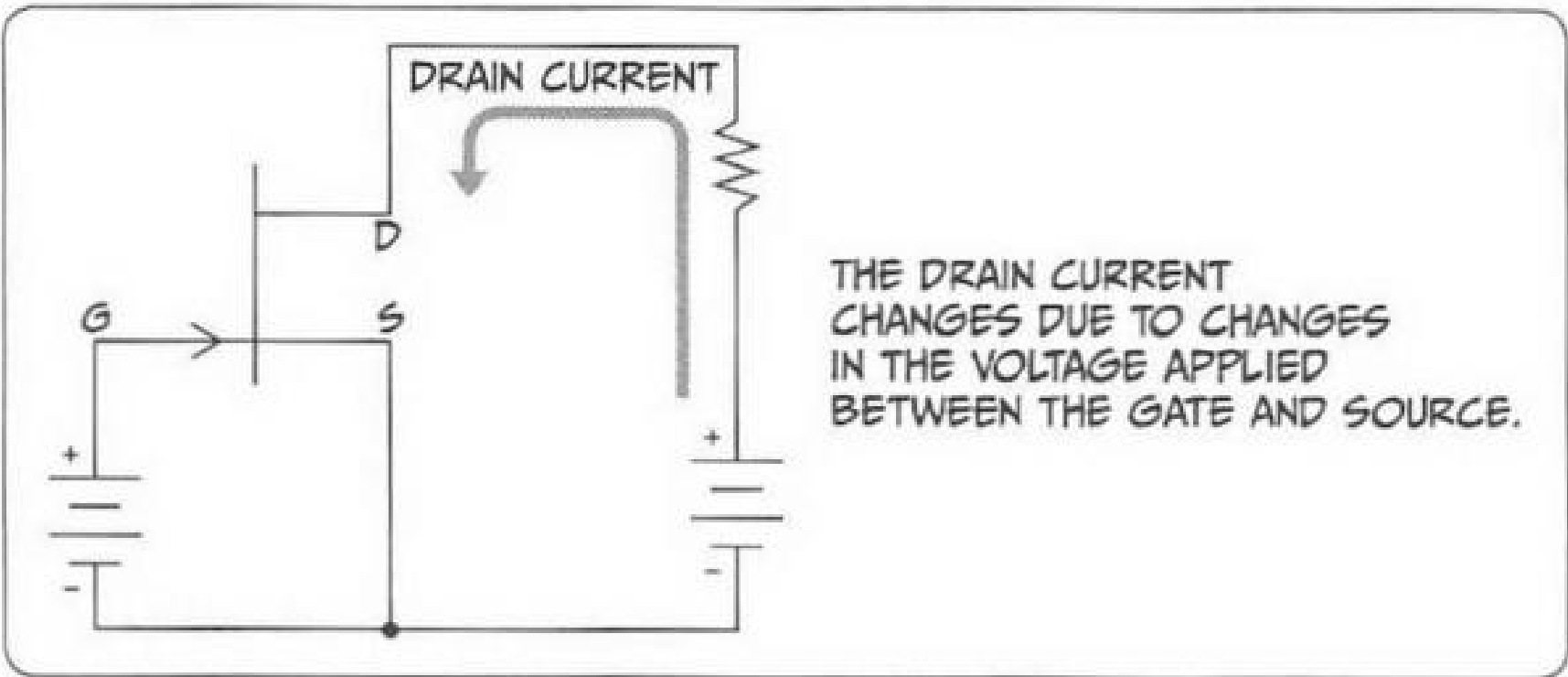
## FIELD-EFFECT TRANSISTOR

---

A transistor in which the collector current is controlled by the change of current that is input to the base is called a *bipolar transistor (junction transistor)*. In contrast, a transistor that is controlled by changing the voltage that is input, rather than the current, is called a *field-effect transistor (FET)*.



The merits of a field-effect transistor are that power consumption is low and response speed is extremely fast because current does not flow to the input. A field-effect transistor has three terminals that are referred to as *G* (*gate*), *D* (*drain*), and *S* (*source*), which correspond to the base, collector, and emitter of a bipolar transistor, respectively. A field-effect transistor controls the drain current according to changes in the voltage that is input to the gate.

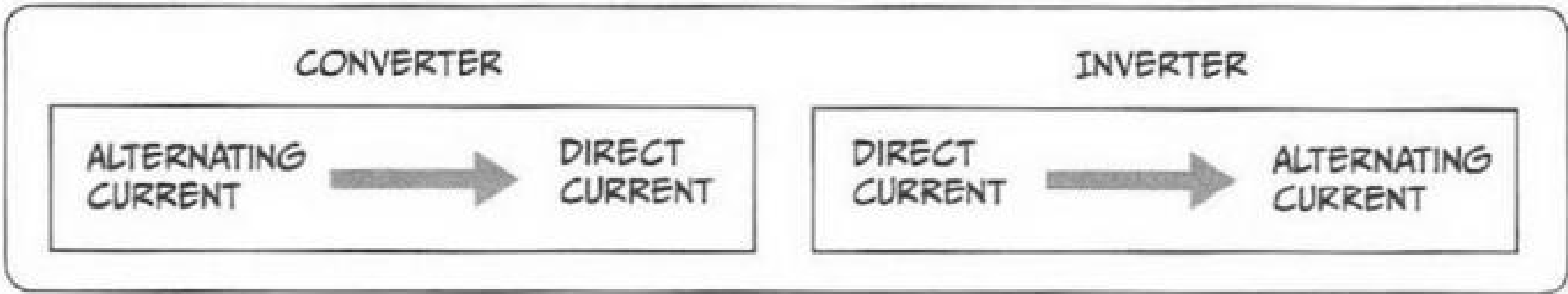


Field-effect transistor (N-channel type)

An *integrated circuit (IC)* is a device in which an extremely large number of elements such as transistors or resistors are placed on one component; ICs are used in more complex electronic devices such as TVs and computers. An amplifier called a *MOSFET* (*metal-oxide semiconductor field-effect transistor*), in which the input gate is insulated by a thin film of silicon dioxide, is used in ICs.

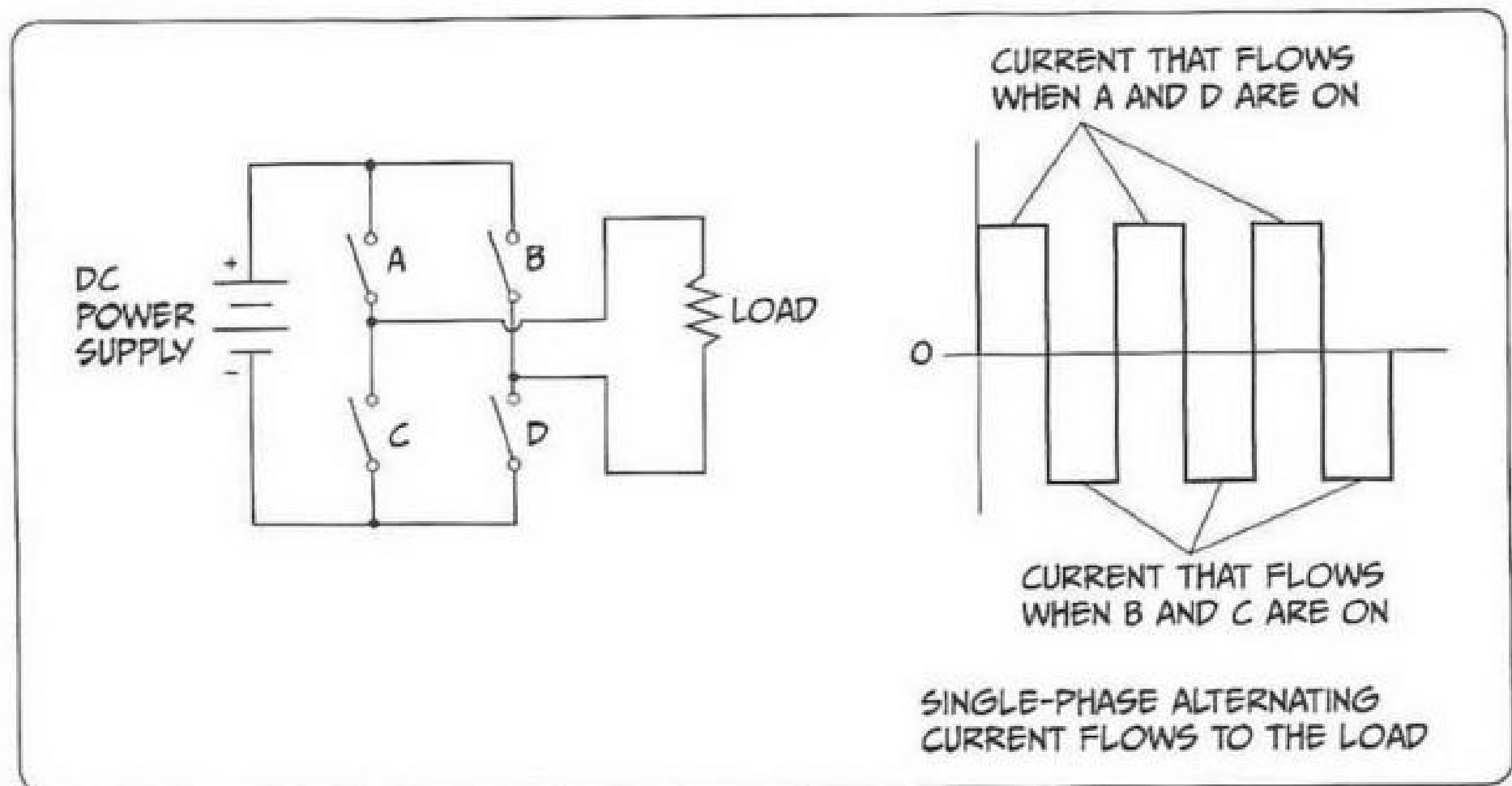
## CONVERTERS AND INVERTERS

A device that uses a diode to convert alternating current to direct current is called a *converter*, and a device that converts direct current to alternating current is called an *inverter*.



Converter and inverter

An inverter uses a semiconductor switching device such as a transistor to do the work of a switch. Single-phase alternating current can be produced by connecting four semiconductor switching devices and alternately turning on and off A, D, B, and C, as shown in the next figure. The frequency of the single-phase alternating current can be changed at will by varying the switching speed of the semiconductor switching devices.



Single-phase alternating current created by an inverter

The rotational speed of an *induction motor* is directly proportional to the power supply frequency. If the supply frequency is constant, the rotational speed will also be constant.

For an air conditioner to cool the air, a motor must turn a compressor to compress the refrigerant gas. If the rotational speed of the motor is constant, a large capacity will be output even when a small capacity is required, and electrical power will be wasted.

Therefore, energy-saving operation with no waste can be achieved by using an inverter to create alternating current with the frequency required to continuously vary the rotational speed of the motor according to the required capacity.

A DC motor that is rotated by a DC power supply is used in the newest inverter air conditioners. In order to vary the rotational speed of the DC motor, the voltage must also vary, so a semiconductor switching device is used for this purpose.

In addition to air conditioners, inverters are also widely used in other familiar electrical appliances such as lighting or refrigerators and even in railroad cars.

## SENSORS

Various sensors are used in electrical appliances in place of the perceptions of our eyes or skin. For example, an electric thermostat uses a temperature sensor to detect the temperature and turn a heater on and off, so we need not repeatedly turn the switch on and off ourselves.

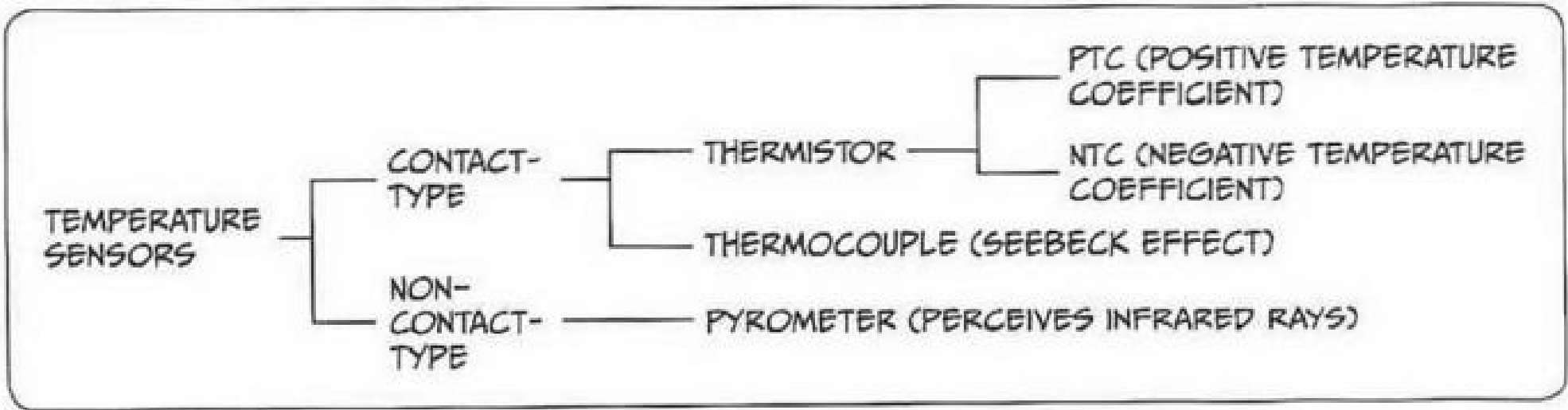
Since sensors convert physical information such as light or heat to electrical information, if they are incorporated into an electric circuit, they can allow an electrical appliance to operate automatically. There are also sensors that can detect magnetism, which cannot be perceived by humans, or infrared rays, which cannot be seen by the naked eye.

### TEMPERATURE SENSORS

A *temperature sensor* is a device that opens or closes a contact or varies electrical resistance according to the temperature it detects. Temperature sensors include contact-type sensors, which perceive the temperature by directly touching the substance whose

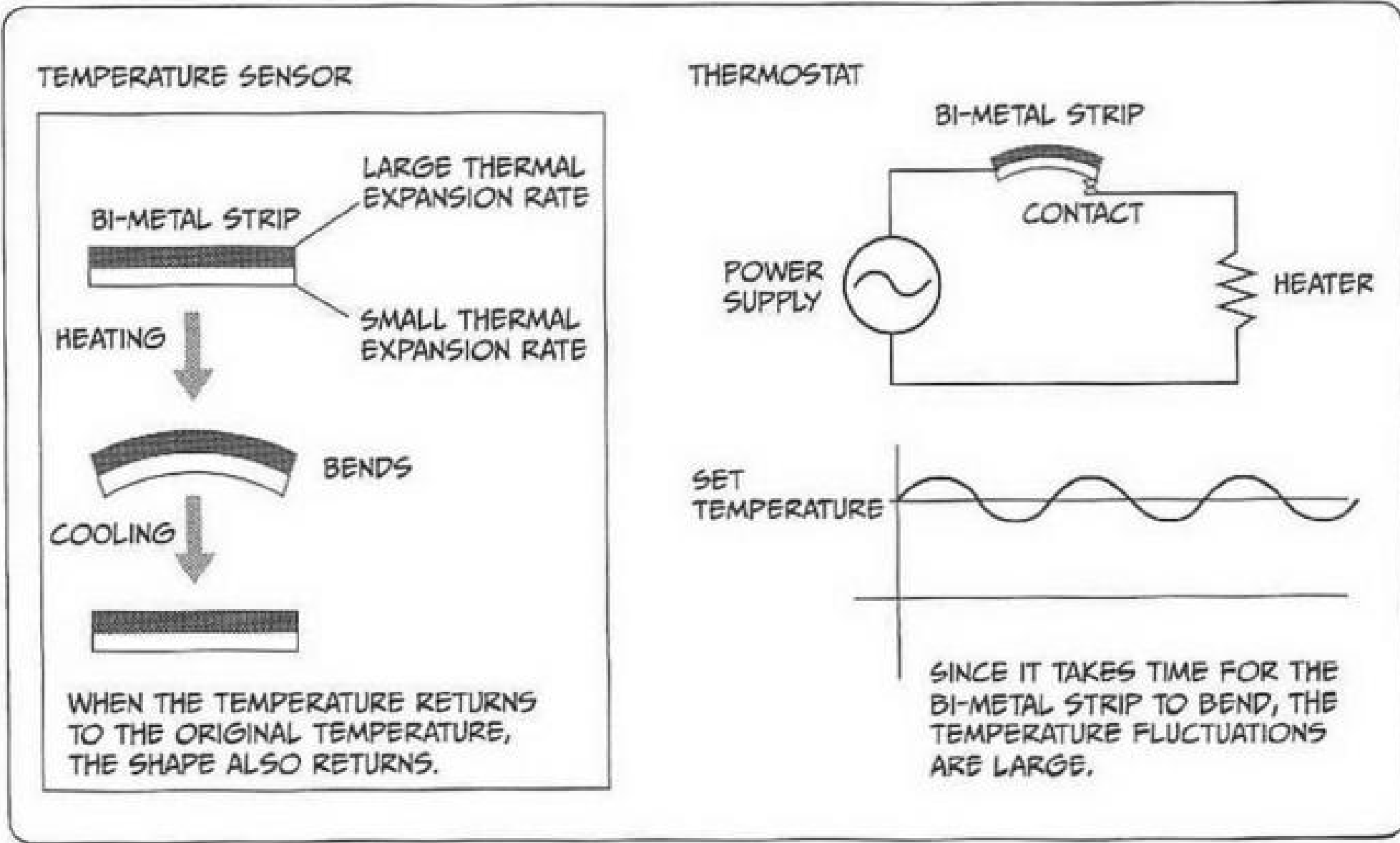
temperature they are trying to measure, and non-contact-type sensors, which perceive emitted thermal energy without directly touching the substance whose temperature they are trying to measure.

There are many types of contact-type temperature sensors such as thermostats, thermistors, and thermocouples. Non-contact-type temperature sensors include infrared sensors.



Classification of temperature sensors

A bi-metal thermostat is the simplest temperature sensor. It uses a bi-metal strip consisting of two types of metal with different thermal expansion rates, which curves in response to a temperature change. Although a thermostat is used in an appliance like an electric blanket, since the heater is turned on and off directly by a contact, the thermostat can only control large temperature fluctuations. A temperature sensor using a bi-metal strip is also used for the overcurrent action of a circuit breaker.



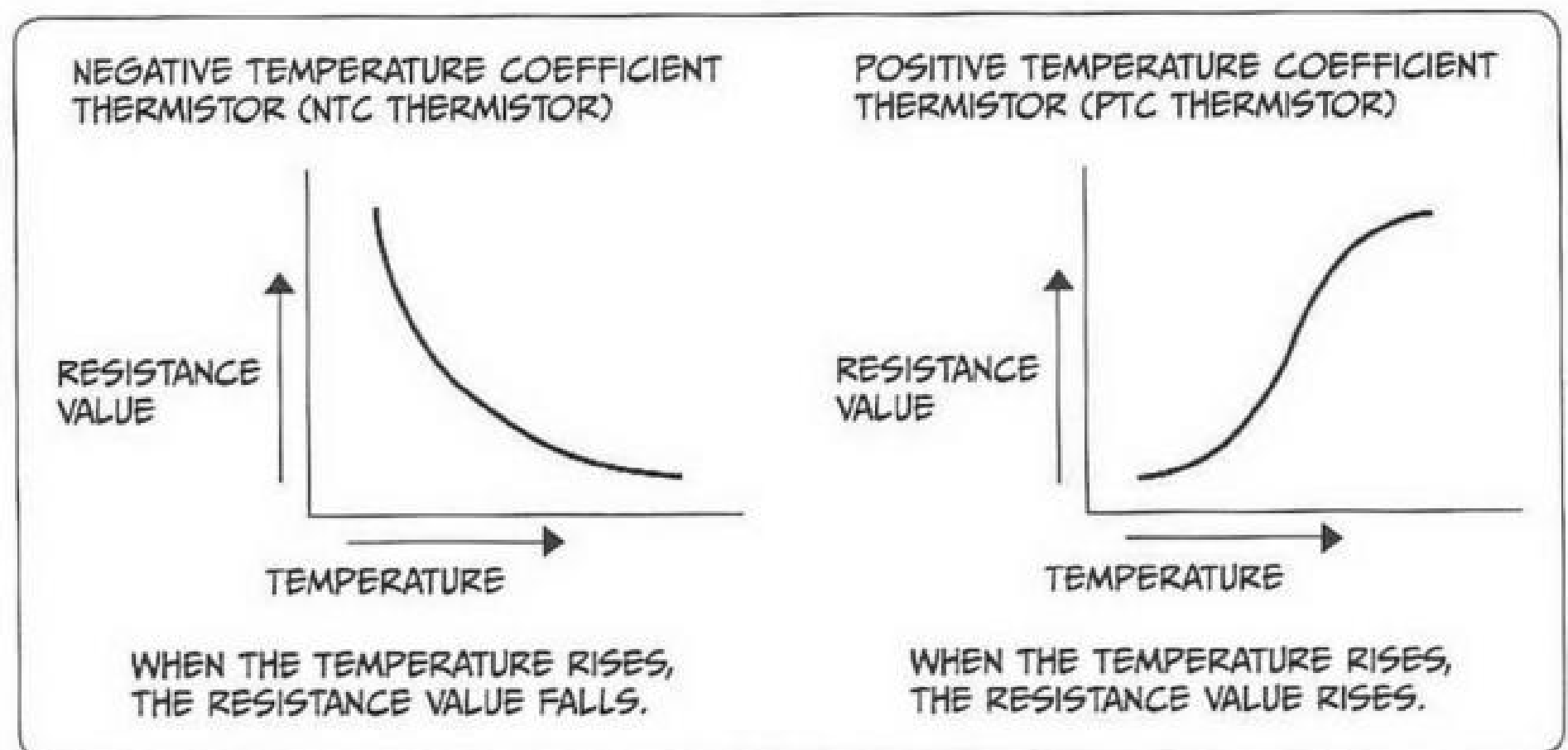
Temperature control by a bi-metal thermostat

A *thermistor* is a temperature sensor whose electrical resistance varies according to a temperature change. Generally speaking, electrical resistance also varies with temperature

for any metal. However, thermistors' resistance changes significantly, even in response to a small temperature change. Since a large current does not flow directly to a thermistor, it is used in combination with an electrical circuit to control temperature.

Thermistors are classified into *positive temperature coefficient (PTC) thermistors*, those whose resistance value rises when the temperature rises, and *negative temperature coefficient (NTC) thermistors*, those whose resistance value falls when the temperature rises.

The newest air conditioners and electric refrigerators use thermistors for temperature sensors, combined with electrical circuits that use semiconductor devices to enable temperature control to be finely tuned.

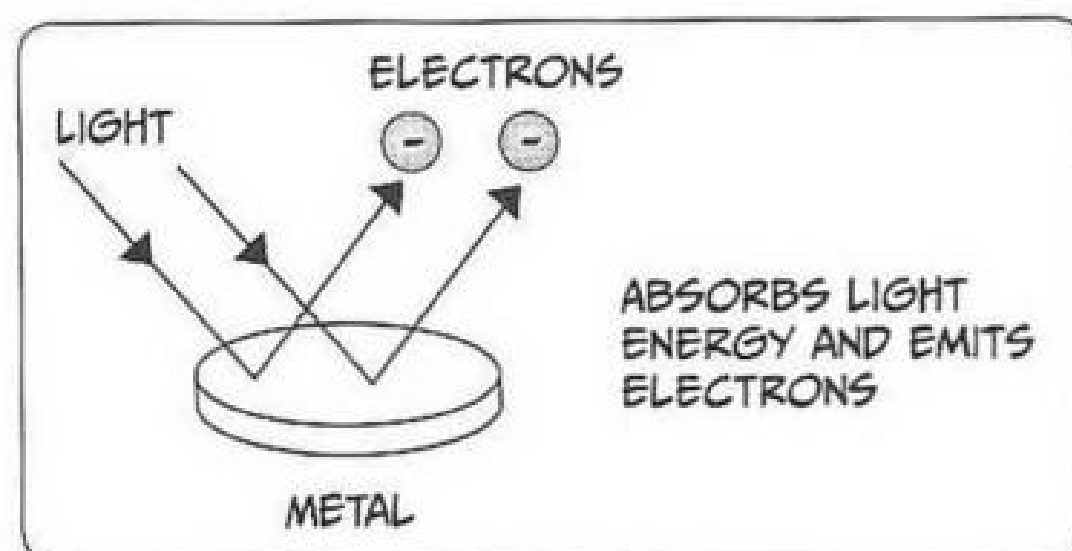


Temperature characteristics of thermistors

## OPTICAL SENSORS

An *optical sensor* perceives light like our eyes do. These sensors are frequently used to automatically turn on street lights when it gets dark, and they function as the receiver of an infrared remote controller on an electrical appliance.

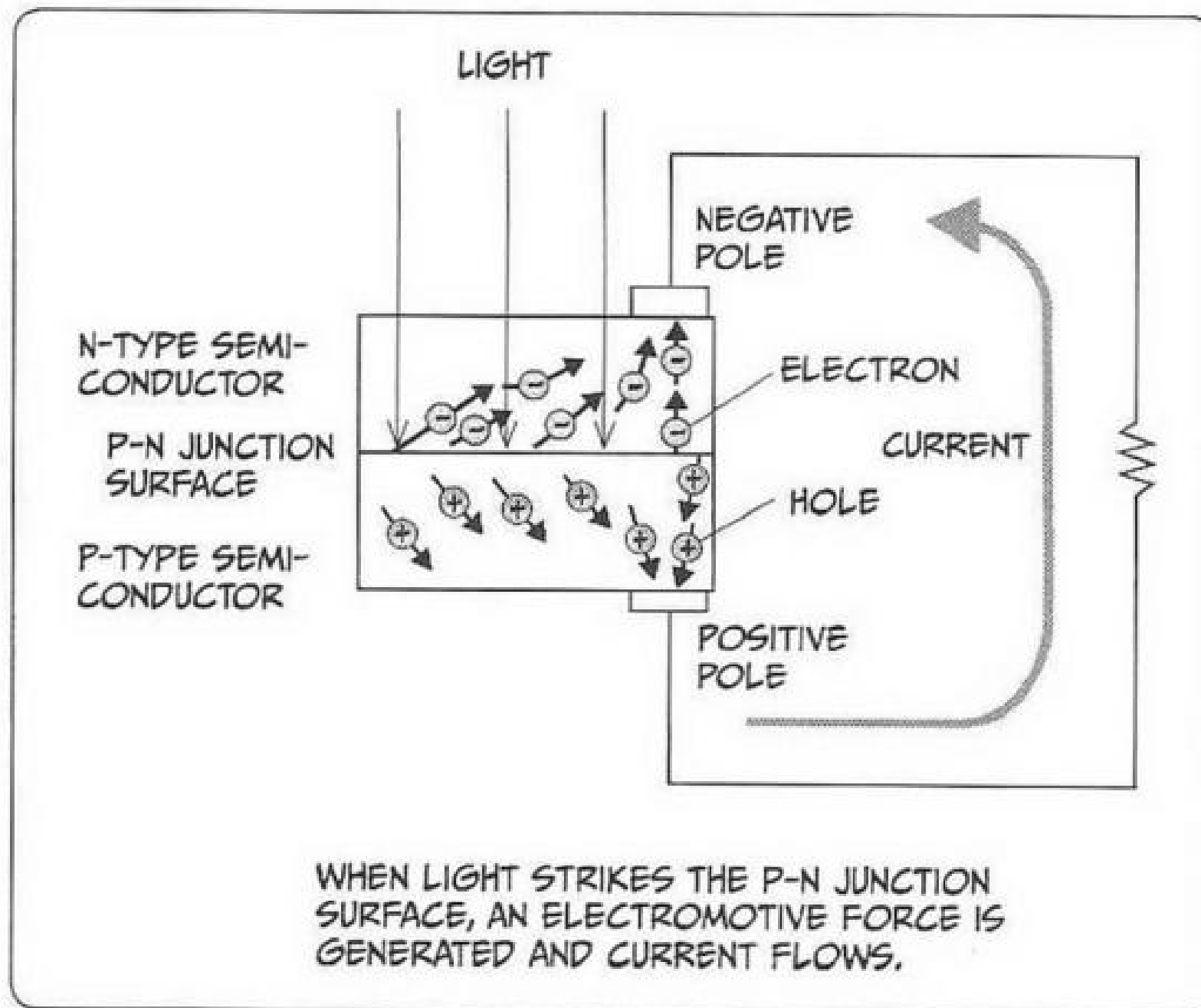
An optical sensor converts light energy to electrical signals. The phenomenon in which a substance such as a metal absorbs light energy and emits electrons as a result is called the *photoelectric effect*.



Photoelectric effect

The phenomenon that describes how voltage appears at the junction of a semiconductor due to the photoelectric effect is called the *photovoltaic effect*. Optical sensors that use the photovoltaic effect include *photodiodes* and *phototransistors*. A solar cell that is used for photovoltaic power generation also uses the photovoltaic effect to create electricity.

A *solar cell* generates an electromotive force when light energy strikes the p-n junction surface, causing the electrons and holes to move to the negative and positive poles, respectively. When a load is connected to a solar cell, current flows.

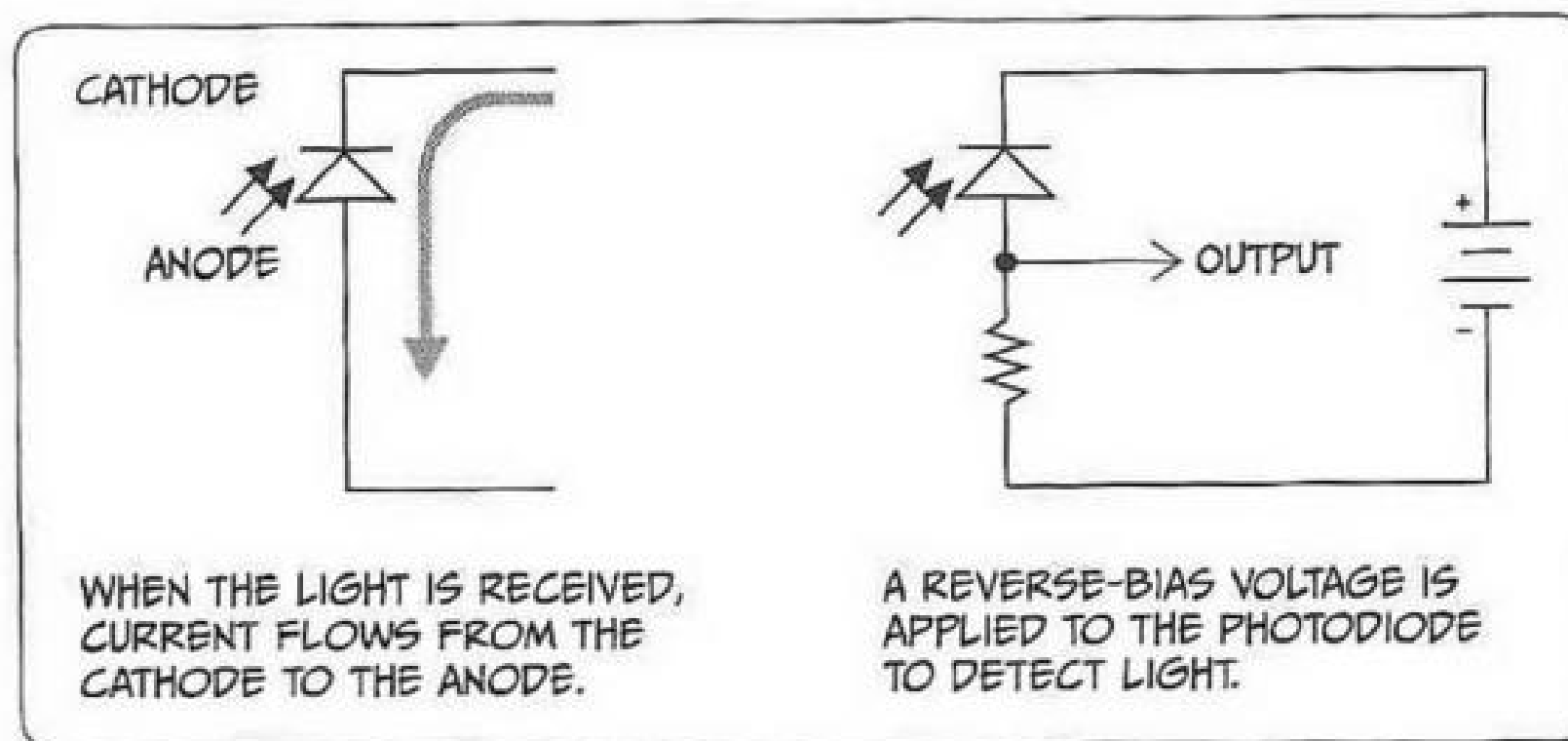


*Photovoltaic effect of a solar cell*

The effect in which a carrier of electricity such as an electron is generated by the photoelectric effect, thus causing the internal resistance value of a substance to change, is called *photoconductivity*. A *cadmium sulphide (CdS) cell* is a solar cell that functions using photoconductivity.

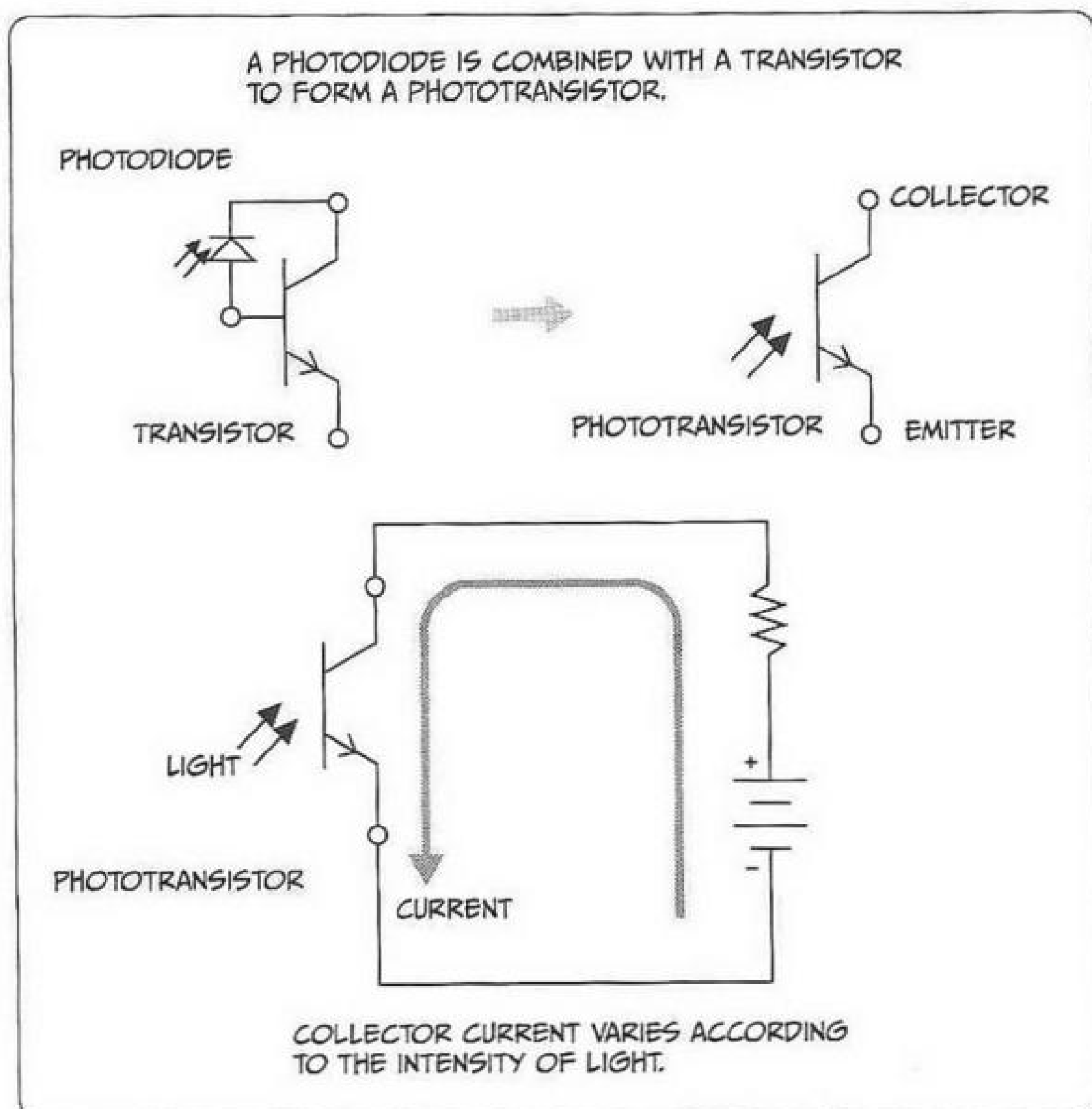
A *photodiode* is a semiconductor device in which current flows from the cathode to the anode due to the photovoltaic effect when light or infrared rays are received. The current that flows at this time varies according to the intensity of the light, and the photodiode measures this current.

The current when the light is received is extremely small. It is generally used by applying a reverse-bias voltage.



Photodiode

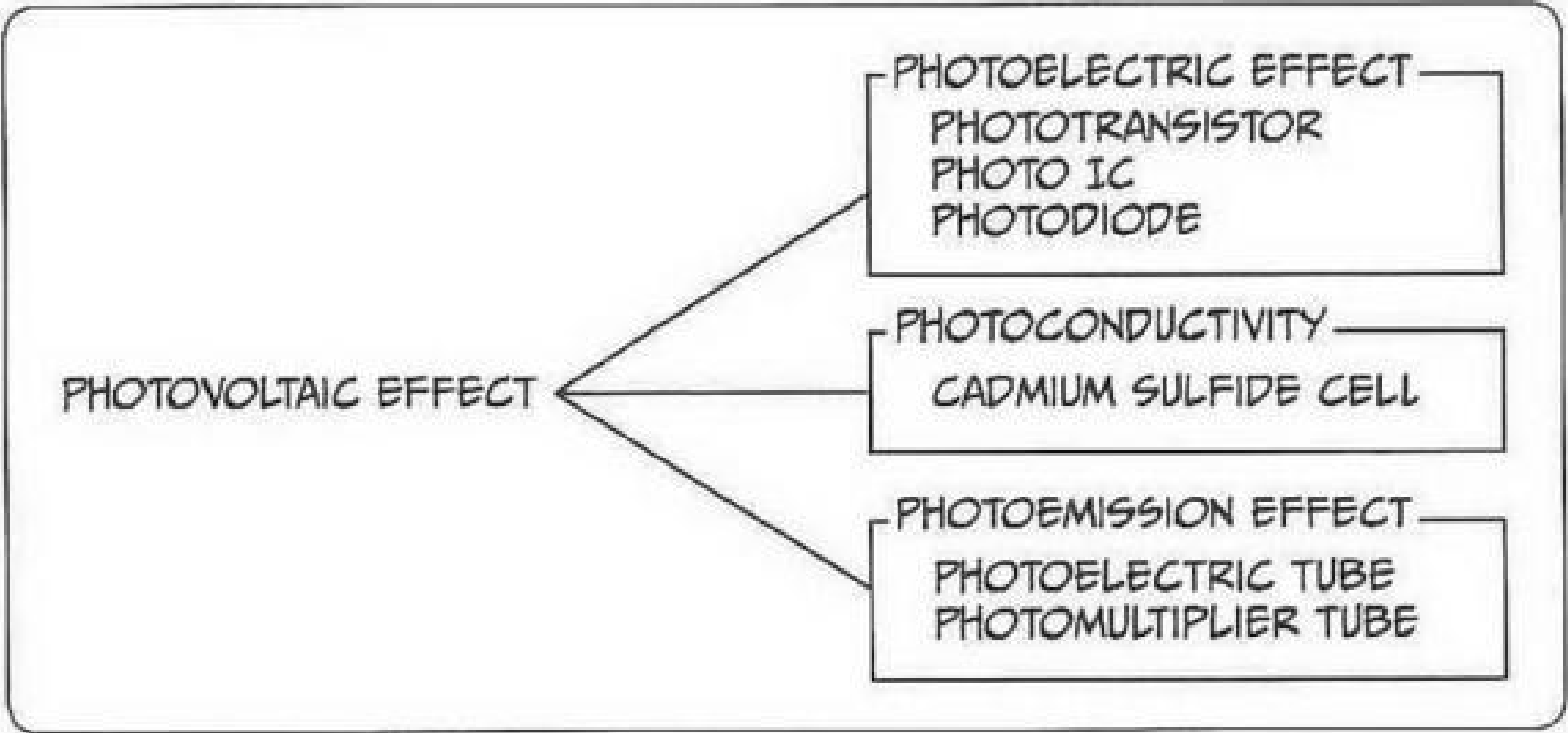
A photodiode combined with a transistor is called a *phototransistor*. Although a phototransistor has no base, a collector current flows when light is received in a manner similar to how base current flows in a transistor. The current in the collector varies according to the intensity of the light.



Phototransistor

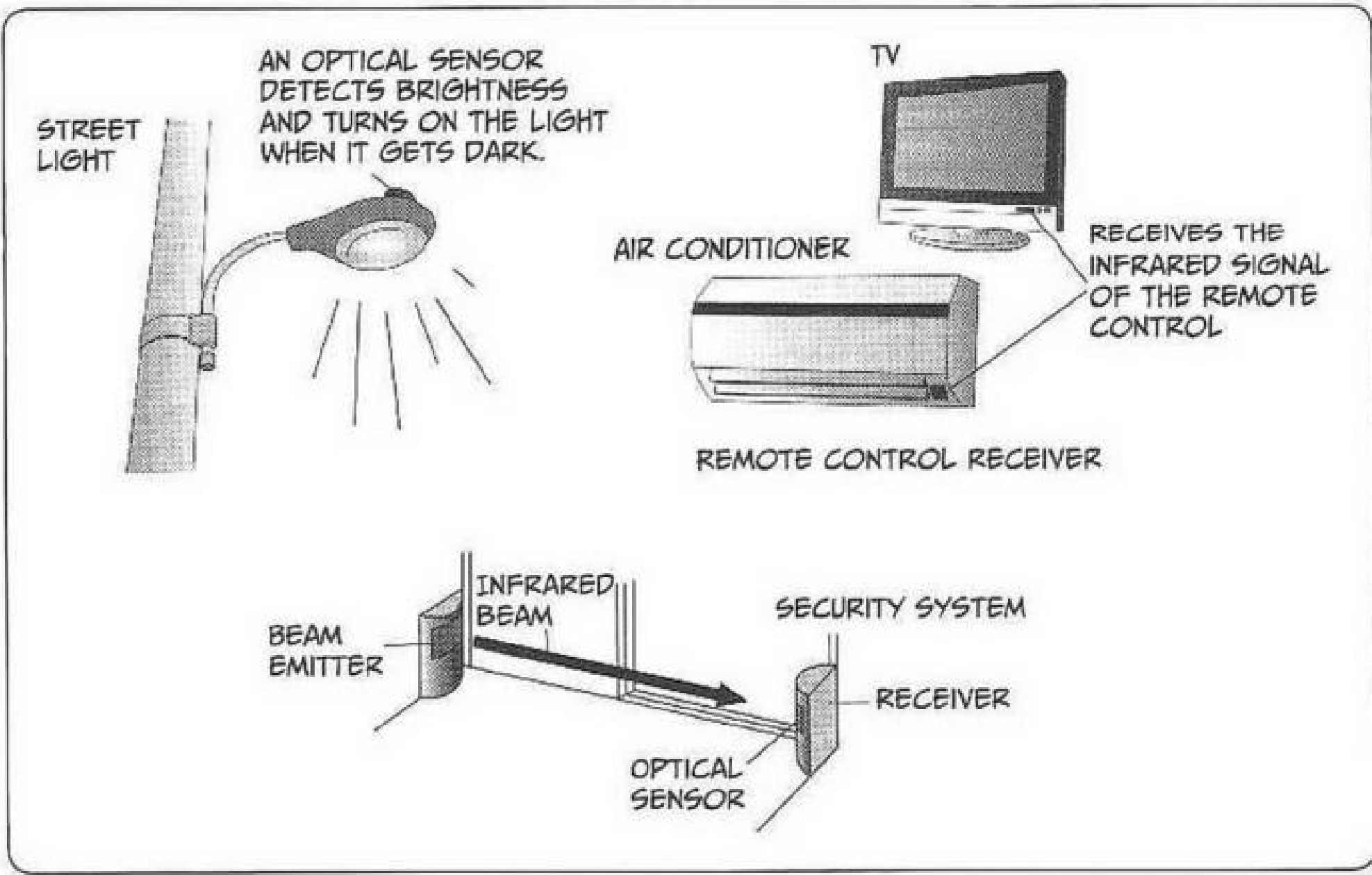


An optical sensor like a phototransistor can be used to determine the position or existence of a target object without touching it.



Photoelectric effect and optical sensors

Optical sensors are widely used for various purposes such as detecting brightness and turning on or dimming lights; an optical sensor can also be used in a security system as a photoelectric eye that detects the changes in light—that is, movement.

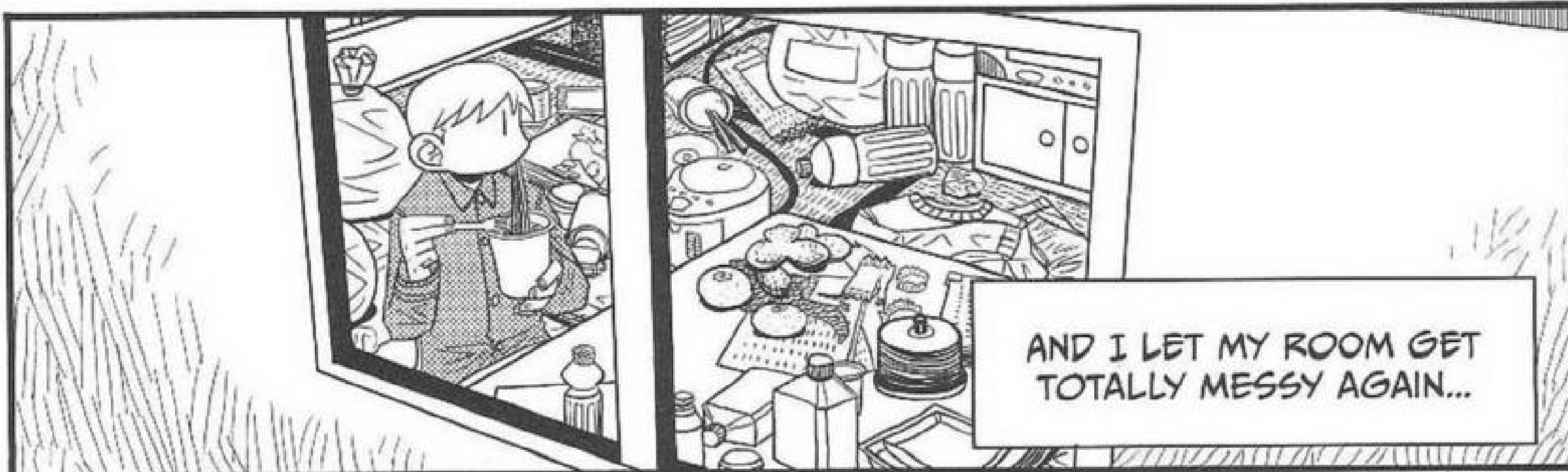


Uses of optical sensor

WITHOUT REREKO AROUND,  
I RETURNED TO REGULAR  
LIFE—SPENDING ALL MY  
TIME IN THE LAB.

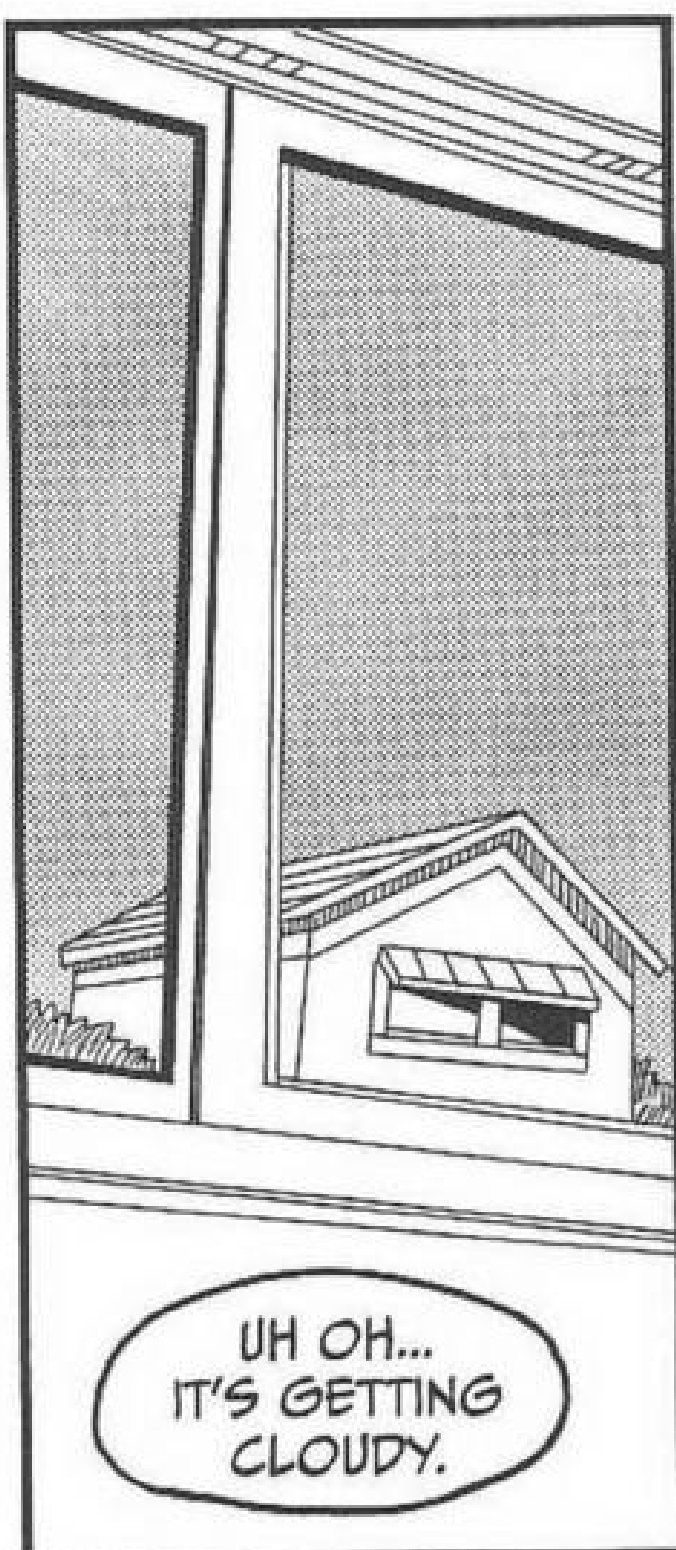


AND I LET MY ROOM GET  
TOTALLY MESSY AGAIN...



I GUESS I'LL  
TRY TO BEAT  
THE RAIN!

UMPH.

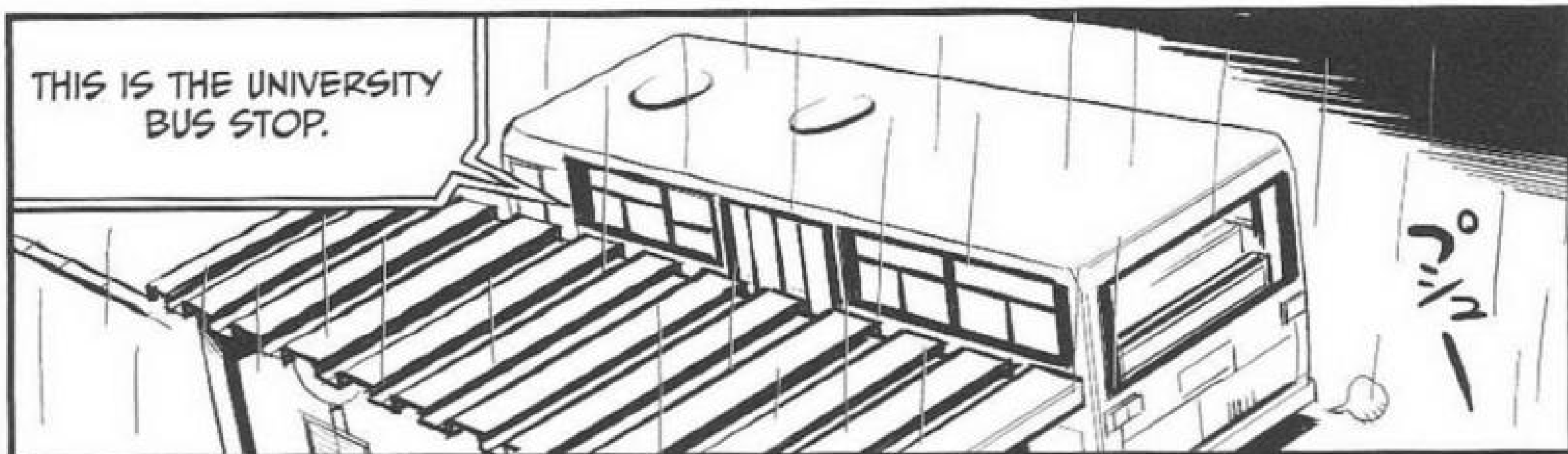


UH OH...  
IT'S GETTING  
CLOUDY.



IT'S BEEN A  
WHOLE YEAR...  
I REMEMBER THE  
WEATHER THAT  
DAY WAS LIKE IT  
IS NOW.





LABORATORY

SWOOSH!

I WONDER IF MY  
DATA IS OKAY...!?

HIKARU  
SENSEI!?

AHHHH!

ZZZUUUH?

RE...REREKO!?

YEP, IT'S ME!!  
IT'S NICE TO SEE  
YOU AGAIN!

WHY ARE YOU BACK?  
MORE MAKEUP  
CLASSES!?

NOPE!  
THANKS TO YOU,  
I HAD NO PROBLEM  
GRADUATING.





# INDEX

## A

absolute zero, 87, 88, 104-105  
AC. See alternating current (AC)  
active material, 132  
air conditioners, 192  
alkaline dry cell batteries, 125, 133-134  
alternating current (AC), 64-66, 75-76, 113-116, 121, 123, 149, 173, 189-190  
  circuits, 75-76  
  power supply, 114, 121, 123, 186  
amber, 25  
ammeter, 143  
Ampère, André Marie, 45  
amperes/amps (A), 16, 45, 68  
Ampère's law, 96, 107-108  
anemometer/anemoscope, 154  
anions, 127  
anodes, 136-139, 169, 171, 193  
appliances, electrical, 19, 24, 45, 46, 56-58, 71-72, 96, 123, 190  
atomic numbers, 34  
atomic structures, 34-35  
atoms, 26-28, 34-35, 47, 127, 165  
attraction, force of, 25, 49-50, 97, 108

## B

base-collector junction, 179  
base current, 178, 179-181, 182  
base-emitter junction, 177-178  
batteries, 45, 59-60  
  AA, 46-47, 74  
  chemical reactions and, 120  
  coils and, 112  
  coin, 140-141, 174  
  creating your own, 140-141  
  dry cell, 125, 130, 131, 132-134, 171-172, 178

  in flashlights, 59, 73  
  lithium, 125  
  as power supplies, 63-64, 124-125  
  solar, 125  
  supply voltage, 46-47  
  types of, 125  
  voltage of stacked, 47  
bi-metal thermostats, 191  
bipolar transistors, 188  
boilers, 147  
boiling water reactors, 151-152  
boron, 167, 168  
breakdowns, 187  
breakers, 19, 21-23  
  circuit, 19, 21

## C

cadmium sulphide (CdS) cells, 193  
calories, 85, 86, 104  
capacitance, 115  
capacitive reactance, 116  
capacitors, 115-116, 187  
cathodes, 136-139, 169, 171, 193  
cations, 127, 128  
CdS (cadmium sulphide cells), 193  
cells, 124-132  
  cadmium sulphide, 193  
  chemical, 124-132  
  fuel, 124-125, 135-138  
  galvanic, 126, 130  
  physical, 124-125  
  solar, 125, 193  
  voltaic, 125  
  water, 135-137  
charges, 29  
  attraction and repulsion, 25, 49-50, 97, 108  
  electrical discharges, 31-33, 51  
  measuring, 49  
  negative/positive, 29, 30-33, 36-39, 42, 47-48, 50-52  
  polarity of, 41  
  stored on capacitors, 115

chemical cells/reactions, 124-132, 137, 138  
circuits  
  alternating current, 75-76  
  in appliances, 56-58  
  breakers, 19, 21  
  closed, 61, 73  
  connection methods used in, 69-72, 78-80  
  creating your own, 141, 142  
  diodes in, 171  
  direct current, 64, 74-75  
  drawings of, 73, 74  
  electrical parts of, 61-66, 73  
  in flashlights, 58-61, 73  
  integrated (ICs), 183  
  parallel, 79  
closed current, 61  
coal (as fuel), 147, 149  
coils, 108, 111-115  
coin batteries, 140-141, 174  
collector current, 179-181  
collector-emitter current, 182, 183  
collectors, 177-180, 182  
combined cycle generation, 149, 150-151  
compasses, 95  
compound semiconductors, 163  
condensers, 149, 151  
conductance (G), 77  
conductivity, 34-35, 77, 135, 166, 168  
  photoconductivity, 193, 195  
  superconductivity, 88, 105  
conductors, 30-31, 98-100, 108-110, 127, 148, 161, 162  
connections, electrical, 69-72, 78-80  
constant-voltage diodes, 187  
consumed power, 17-18  
consumer electric products, 20-24. See also electrical appliances



contactless switches, 181-182  
 contacts, switch, 60, 61, 73, 188  
 contact-type sensors, 191  
 control rods, 151  
 converters, 189-190  
 copper  
   atoms, 35  
   plate, 126, 127, 128, 130, 140  
   wires, 31, 104, 128  
 copy machines, 43  
 cotton, 41-42, 51  
 Coulomb, Charles Augustine, 49  
 Coulomb's force, 29, 43, 49-50  
 coulombs (Q), 45, 49-50, 104  
 counter-electromotive force, 112  
 current (I)  
   alternating, 64-66, 75-76,  
     113-116, 121, 123, 149,  
     173, 189-190  
   base, 178, 179-181, 182  
   closed, 61  
   collector, 179-181  
   collector-emitter, 182, 188  
   defined, 16, 45, 51, 128  
   direct, 64, 66, 74-75, 123,  
     149, 173, 189-190  
   direction of, 33, 51-52, 63-66,  
     75, 96-97, 98-101  
   drain, 189  
   fixed, 63, 74  
   flow of, 15-17, 20-24, 58,  
     61, 63-68, 73-78, 96,  
     108-109, 128  
   forward direction, 187  
   induced, 111  
   lagging, 113  
   leading, 116  
   limiters, 21  
   measuring, 16, 143  
   rated, 23  
   size of, 52  
   speed of, 53  
   temperature differences,  
     142-143  
   water, 181

## D

dam-type power generation,  
   152-153  
 DC. *See* direct current (DC)  
 depolarizers, 131  
 digital cameras, 175  
 diodes, 163, 169-171, 173, 177,  
   183, 186-188, 189  
   bridges, 186  
   constant-voltage, 187  
   light-emitting, 141, 174-175  
   photodiodes, 193-194  
   Zener, 187-188  
 direct current (DC), 64, 66, 74-75,  
   123, 149, 173, 189-190  
   circuits, 64, 74-75  
   power supply, 74  
 direction, current, 33, 51-52,  
   63-66, 75, 96-97, 98-101  
 discharges, electrical, 31-33, 51  
 doping, 164  
 drain, 189  
   current, 189  
 dry cell batteries, 125, 130, 131,  
   132-134, 171-172, 178

## E

effective resistance, 69-72, 78-80  
 effective voltage, 75-76, 123, 149  
 electric  
   current. *See* current  
   generators, 101, 110,  
     120-123, 147-149,  
     152-154  
   heaters, 62, 74  
   outlets, 23-24, 63-64,  
     123, 149  
   power, 17-18, 19, 45, 46  
   resistance. *See* resistance (R)  
   shocks, 40, 66  
   wires, 74, 77, 88, 96, 107,  
     108, 148. *See also* coils  
 electrical  
   appliances, 19, 24, 45, 46,  
     56-58, 71-72, 96, 123, 190

  charges. *See* charges  
   connections, 69-72, 78-80  
   discharges, 31-33, 51  
   potential, 46-47  
 electricity, nature of, 25-29  
 electrochemical reactions, 132  
 electrodes, 127, 136, 169, 177  
 electrolytes, 126, 130, 132, 140  
 electromagnetic  
   force, 109, 111  
   induction, 111-112  
   waves, 91, 106-107  
 electromotive force, 61, 73,  
   100, 110, 111, 112,  
   122, 130  
 electrons, 26-29, 34-35, 47-48  
   in chemical reactions, 128-129,  
     137, 138  
   collisions of, 89-90, 93, 105  
   free, 27-28, 35, 47-48, 166,  
     167, 170, 171  
   holes, 167, 170, 174, 177-178  
   movement and electric charges,  
     49, 51-53  
   single, 48  
   speed of, 53  
   valence, 34-35, 48,  
     165-166, 167  
 electron shells, 34-35, 47-48, 165  
 electrostatic force, 29, 43, 49-50  
 electrostatic induction, 40, 50  
 emitter, 177-180, 182  
 energy  
   defined, 46  
   heat, 61, 62  
   light, 61, 62  
   measuring, 46  
   solar, 124-125  
   thermal, 106, 124  
 environmentally friendly  
   power, 154  
 escaped electrons. *See* free  
   electrons  
 Europe, voltage in, 45  
 extrinsic semiconductors, 164, 168

## F

farads, 115  
field-effect transistor (FET), 188-189  
fixed current, 63, 74  
flashlights, 58-61, 73  
Fleming, John Ambrose, 109  
Fleming's left-hand rule, 98-99, 109  
Fleming's right-hand rule, 100-101, 110, 121, 148  
flow, current, 15-17, 20-24, 58, 61, 67-68, 73-78, 96, 108-109, 128  
fluorescent lights, 92-93, 106-107  
force of attraction, 25, 49-50, 97, 108  
force of repulsion, 49-50, 97  
forward bias voltage, 173, 174  
forward direction current, 187  
Francis turbine, 153  
free electrons, 27-28, 35, 47-48, 166, 167, 170, 171  
frequency, 65, 75, 122  
frictional electricity, 38, 49. *See also* static electricity  
fuel (oil, coal, and gas), 147, 149, 150  
fuel cells, 124-125, 135-138  
fuel reformers, 139  
full-wave rectification, 186-187  
fuses, 19

## G

gallium arsenide, 163  
galvanic cells, 126, 130  
gamma rays, 91  
gas (as fuel), 147, 149, 150  
gas turbine generation, 149, 150  
gate, 189  
generators, 101, 110, 120-123, 147-149, 152-154  
geomagnetism, 95  
germanium, 163-164  
giga-, 46  
glass, 41-42, 51  
graphical symbols, 73-74

## H

hair, 41-42, 51  
half-wave rectification, 186-187  
heat energy, 61, 62  
heaters, electric, 62, 74  
heat generation, 85-93, 104-105, 123, 143-144  
heat rays. *See* infrared rays  
hertz (Hz), 65, 75, 122, 149  
high potential electricity flow, 16, 46-47  
high-temperature resistance, 89  
high-temperature superconductors, 105  
holes, 167, 170, 174, 177-178  
home distribution boards, 20-21  
hydroelectric generator, 110, 152-154  
power generation, 120, 147  
hydrogen gas, 129, 130, 131  
ions, 129, 137, 138, 139  
Hz (hertz), 65, 75, 122, 149

## I

ICs (integrated circuits), 183  
impedance, 116  
induced current, 111  
induced electromotive force, 111, 114  
inductance, 112  
induction electromagnetic, 111-112  
electrostatic, 40, 50  
motors, 190  
mutual, 114  
inductive reactance, 113  
infrared rays, 90-91, 106  
innermost shells, 47  
instantaneous voltage, 75-76  
insulators, 30, 32, 161, 162  
integrated circuits (ICs), 183  
intensity of electricity, 45  
internal combustion generation, 149, 150  
International System of Units (SI units), 46

intrinsic semiconductors, 164  
inverse ohms, 77  
inverters, 189-190  
ionization, 129  
ions, 127, 129

## J

Japan, 45, 65, 153, 154  
Joule, James Prescott, 104  
joule heat, 86, 104  
joules (J), 45, 46, 104  
junction transistors, 188

## K

Kaplan turbine, 154  
kilo-, 46  
kilowatt hours (kWh), 18-19, 46

## L

lagging current, 113  
leading current, 116  
LED (light-emitting diode), 141, 174-175  
Lenz, Heinrich Freidrich Emil, 111  
Lenz's law, 111  
light bulbs, 59, 60-62, 71-72, 73  
light emission, 92-93, 106-107  
series connection of, 79, 80  
light emission, 91-93, 106-107, 174-175  
light-emitting diode (LED), 141, 174-175  
light energy, 61, 62  
light water reactors, 151  
lighting, electric, 175, 190  
lightning, 32-33, 51, 198  
lights, fluorescent, 92-93, 106-107  
liquefied natural gas (LNG), 149  
lithium batteries, 125  
LNG (liquefied natural gas), 149  
loads, 61, 62, 73, 136, 182, 187  
loops, 99, 121, 122, 148  
low potential electricity flow, 16, 46-47  
low power factor, 113

low-temperature resistance,  
89, 104

luminescence, 90-93,  
106-107, 175

## M

magnetic fields, 94-98, 100,  
107-109, 111, 114,  
121, 148

magnetism, 94-97, 107-108,  
110, 111

magnets, 94, 107, 110, 111

manganese dioxide, 132, 134

manganese dry cell batteries, 125,  
131, 132, 134

mega-, 46

metal-oxide semiconductor  
field-effect transistors  
(MOSFETs), 189

metals

aluminum, 88-89, 140

bi-metal thermostats, 191

copper, 34-35, 41-42,  
47-48, 51

properties of, 35

steel, 41-42, 51

mho. See siemens per meter (S/m)

micro-, 46

microwaves, 91

milli-, 46

mobile phones, 175

moderators, 151

MOSFETs (metal-oxide semi-  
conductor field-effect  
transistors), 189

motion, 73

motors, 98-99, 101, 109,  
110, 190

mutual induction, 114

## N

negative electrical properties,  
27-28, 31, 166

negative ions, 127

negative poles, 46-47, 73, 132,  
140, 171, 177-178

negative temperature coefficient  
(NTC) thermistors, 192

neutrons, 27, 47-48

newtons (N), 49

non-contact type sensors, 191

north magnetic pole, 94-95, 99,  
100-101, 107, 110, 111,  
121-122

NPN-type transistors,  
177-178, 188

NTC (negative temperature  
coefficient) thermistors, 192

N-type semiconductors, 166,  
169-171, 172

nuclear

fission, 147, 151

power generation, 120, 147,  
151-152

reactors, 147, 151

nucleus, 26-27, 34-35, 47-48

nylon, 41-42, 51

## O

Ohm, Georg Simon, 73

ohms ( $\Omega$ ), 62, 73, 77, 162

Ohm's law, 67-68, 76

oil (as fuel), 147, 149, 150

optical sensors, 192-195

outermost shells, 35, 47, 48, 165

outlets, 23-24, 63-64, 123, 149

oxidizing agents, 131

## P

paper, 41-42, 51

parallel circuits, 79

parallel connections, 69-72, 79-80

peak voltage, 75-76, 123, 149

Peltier device/effect, 144

Pelton wheel, 153

phase difference, 113

phosphorus, 168

photoconductivity, 193, 195

photodiodes, 193-194

photoelectric effect, 192, 195

photoemission effect, 195

phototransistors, 193, 195-196

photovoltaic effect, 193

physical cells, 124-125

pico-, 46

plugs, 24, 63-64

P-N junction, 169, 170, 174, 193

PNP-type transistors, 177-178,  
181, 188

polarization, 41, 131

polyester, 41-42, 51

polyethylene, 41-42, 51

positive electrical properties,  
27-28, 168

positive ions, 127

positive poles, 46-47, 61, 73, 132,  
171, 177-178, 179

positive temperature coefficient  
(PTC) thermistors, 192

potential barriers, 170-171

potential difference, 15-16

power generation

dam-type, 152-153

hydroelectric, 120, 147

nuclear, 120, 147, 151-152

thermal, 120, 147, 149-152

wind, 154

power lines, 20

power ( $P$ ), 17-18, 19, 45, 46

power plants, 20, 120, 147-154

power supplies, 63-64, 72, 182  
alternating current, 114, 121,  
123, 186

batteries, 63-64, 124-125

direct current, 74

voltage, 60-61, 62, 73-74,  
78, 115

power transistors, 188

pressurized water reactors,  
151-152

primary cells, 124-125

primary sides, 114

primary voltage, 115

propeller wind turbine, 154

protons, 27, 29, 34, 47-48

PTC (positive temperature  
coefficient) thermistors, 192

P-type semiconductors, 168,  
169-171, 172

PVC (vinyl), 37, 39, 41-42, 51

## R

radio waves, 91, 106

rated current, 23

reactors  
 boiling water, 151-152  
 light water, 151  
 nuclear, 147, 151  
 pressurized water, 151-152  
 rectification, 170, 173  
 red light, 91, 106  
 reduction-oxidation (redox), 132  
 refrigerators, 190, 192  
 repulsion, force of, 49-50, 97  
 resistance ( $R$ ), 61-62, 67-74, 76, 77, 79-80, 85, 88-89, 104, 105, 182  
 resistancies, connecting, 69-72, 78-80  
 resistivity ( $\rho$ ), 77, 162  
 resistors, 183  
 reverse-bias voltage, 171, 193  
 reverse-direction voltage, 187  
 reverse electromotive force, 130  
 rice cookers, 22  
 rubber, 41-42, 51

## S

safety breakers, 21-23  
 secondary cells, 124-125  
 secondary sides, 114  
 Seebeck effect, 142-144  
 self-inductance, 112  
 semiconductors, 30, 163, 166-171, 172  
 devices, 160-164, 161, 163, 169, 176, 183, 188-189  
 sensors  
 contact-type, 191  
 defined, 190  
 non-contact-type, 191  
 optical, 192-195  
 temperature, 190-192  
 series connections, 69-72, 78-80  
 shocks, electric, 40, 66  
 Siemens, Ernst Werner von, 77  
 siemens per meter (S/m), 77  
 silicon, 163-166, 167  
 crystals, 165, 168  
 dioxide, 164  
 silk, 41-42, 51  
 single electrons, 48

single-phase alternating current, 189-190  
 SI prefixes and units, 46  
 size, current, 52  
 smoothing capacitors, 187  
 sodium hydroxide, 135-136  
 solar  
 batteries, 125  
 cells, 125, 193  
 energy, 124-125  
 sound, 73  
 source, 189  
 south magnetic pole, 94-95, 99, 100-101, 107, 110, 121-122  
 speed, current/electron, 53  
 static electricity, 25, 29, 32, 36-40, 49-53  
 electrostatic force, 29, 43, 49-50  
 triboelectric series, 51-53  
 uses of, 43-44  
 steam engines, 45  
 steam generation, 149, 150  
 steel, 41-42, 51  
 sulfuric acid, 127, 129  
 sum of reciprocals, 70-71  
 superconductivity, 88, 105  
 supply voltage, 46-47  
 switches, 59, 60-61, 73, 74, 176, 181-182  
 symbols  
 amperes/amps (A), 16, 45, 68  
 charges (Q), 49  
 conductance (G), 77  
 coulombs (C), 45, 49-50, 104  
 current ( $I$ ), 16, 143  
 farads (F), 115  
 giga- (G), 46  
 hertz (Hz), 65, 75, 122, 149  
 joules (J), 45, 46, 104  
 kilo- (k), 46  
 kilowatt hours (kWh), 18-19, 46  
 micro- ( $\mu$ ), 46  
 milli- (m), 46  
 mega- (M), 46  
 newtons (N), 49

ohms ( $\Omega$ ), 68, 73, 77, 162  
 pico- (p), 46  
 power ( $P$ ), 17-18, 19, 45, 46  
 resistance ( $R$ ).  
 See resistance ( $R$ )  
 resistivity ( $\rho$ ), 77, 162  
 siemens per meter (S/m), 77  
 tera- (T), 46  
 time ( $t$ ), 52  
 units and SI prefixes, 46  
 voltage (V). See voltage (V)  
 volts (V), 15, 17-18, 45, 68  
 watt seconds (Ws), 46, 104  
 watts (W), 17, 45

## T

tags, consumer electronic, 45  
 tea kettles, 14, 18, 22  
 temperature sensors, 190-192  
 tera-, 46  
 Thales (philosopher), 25  
 thermal  
 emission, 90-93, 106  
 energy, 106, 124  
 power generation, 120, 147, 149-152, 149-154  
 vibration, 87-90, 104-105  
 thermistors, 191-192  
 thermocouples, 143  
 thermoelectric phenomena, 144  
 thermopiles, 125, 141-143  
 thermostats, 191  
 time ( $t$ ), 52  
 toasters, 74  
 traffic signals, 175  
 transformation ratio, 115  
 transformers, 20, 114-115  
 stations, 20  
 transistors, 163, 176-183, 183, 188-189  
 amplification, 181  
 bipolar, 188  
 field-effect, 188-189  
 junction, 188  
 MOSFET, 189  
 phototransistors, 193, 195-196  
 PNP-type, 177-178, 181, 188  
 power, 188

triboelectricity, 38  
triboelectric series, 40-43, 51-53  
turbine engines, 147, 149,  
152, 153

## U

UHF waves, 91  
ultraviolet rays, 91, 93, 106, 107  
United States, voltage in, 45  
utility pole transformers, 20

## V

valence electrons, 34-35, 48,  
165-166, 167  
valence shells, 48  
VHF waves, 91  
vinyl (PVC), 37, 39, 41-42, 51  
violet light, 91, 106  
visible light, 91, 93, 106  
Volta, Alessandro, 45, 126  
voltage (V)  
100V, 14, 45  
120V, 22, 45, 72, 75, 76, 80,  
123, 149  
170V, 75, 76, 149  
240V, 45  
changes in, 20  
defined, 15, 45, 46-47  
effective, 75-76, 123, 149  
in electrical appliances, 19,  
24, 45, 46, 71-72, 96,  
123, 190  
forward bias, 173, 174  
instantaneous, 75-76  
international differences, 45  
peak, 75-76, 123, 149  
positive and negative poles,  
46-47, 61, 73, 132, 171,  
177-178, 179  
potential and, 46-47  
power supply, 60-61, 62,  
73-74, 78, 115  
reverse-bias, 171, 193

reverse-direction, 187

supply, 46-47

voltaic cells, 125

volts (V), 15, 17-18, 45, 68

## W

water  
cells, 135-137  
current, 181  
levels, 15-16  
turbine, 147, 152, 153-154  
wheels, 17, 59-60  
Watt, James, 45  
watt seconds (Ws), 46, 104  
watts (W), 14, 17, 19, 45  
waveforms, 187  
wavelength, 91, 106  
waves  
electromagnetic, 91, 106-107  
radio, 91, 106  
UHF, 91  
VHF, 91  
wind power generation, 154  
wires  
coils, 108, 111-115  
copper, 31, 104, 128  
electric, 74, 77, 88, 96, 107,  
108, 148  
wood, 41-42, 51  
wool, 41-42, 51

## X

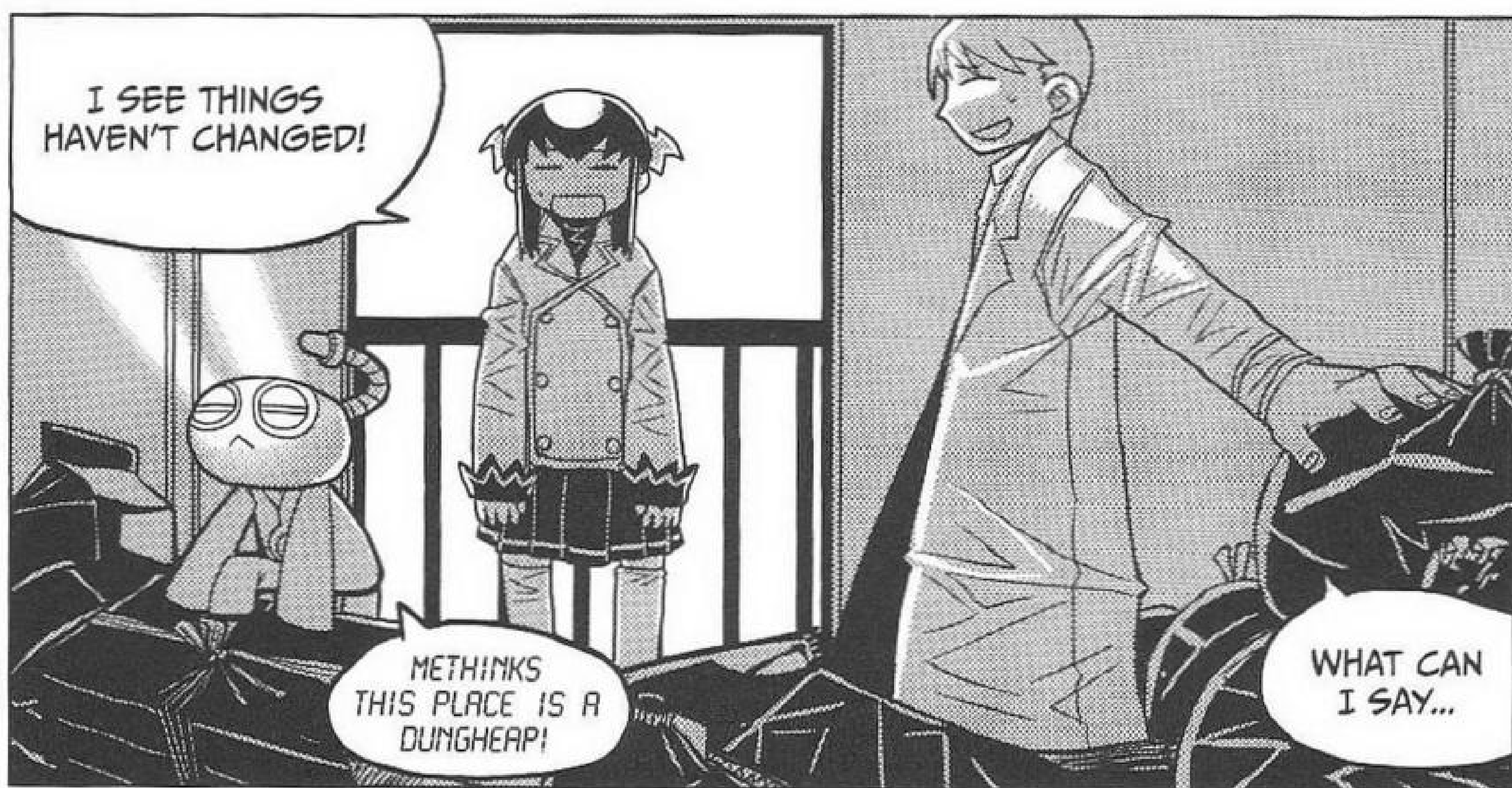
X rays, 91

## Z

Zener diodes, 187-188

zinc

chloride, 132  
ions, 129  
plate, 126, 127, 128  
powder, 133



I SEE THINGS  
HAVEN'T CHANGED!

METHINKS  
THIS PLACE IS A  
DUNGHEAP!

WHAT CAN  
I SAY...