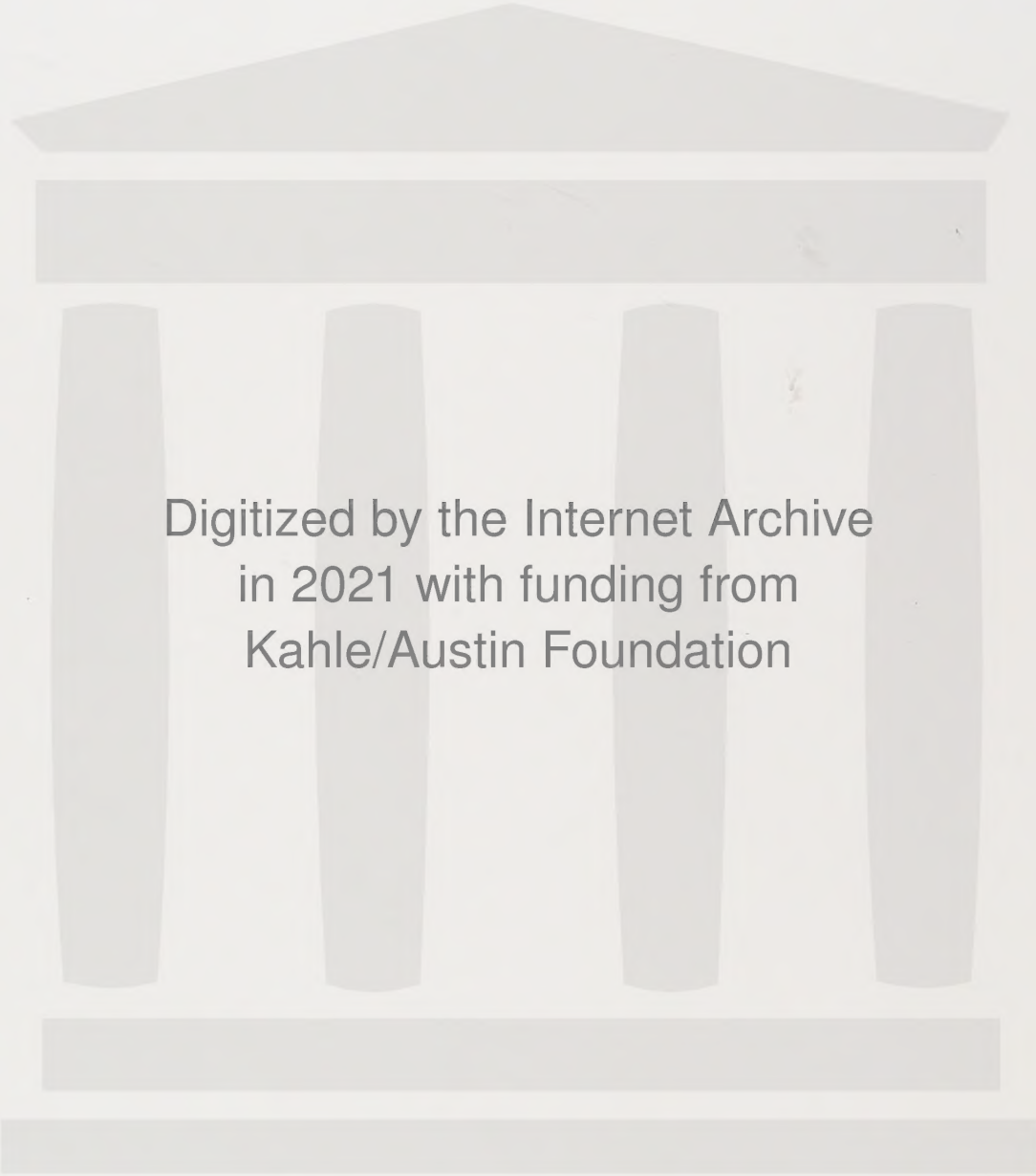


MAX ^{THE} DEMON VS ENTROPY OF DOOM

Assa Auerbach Richard Codor

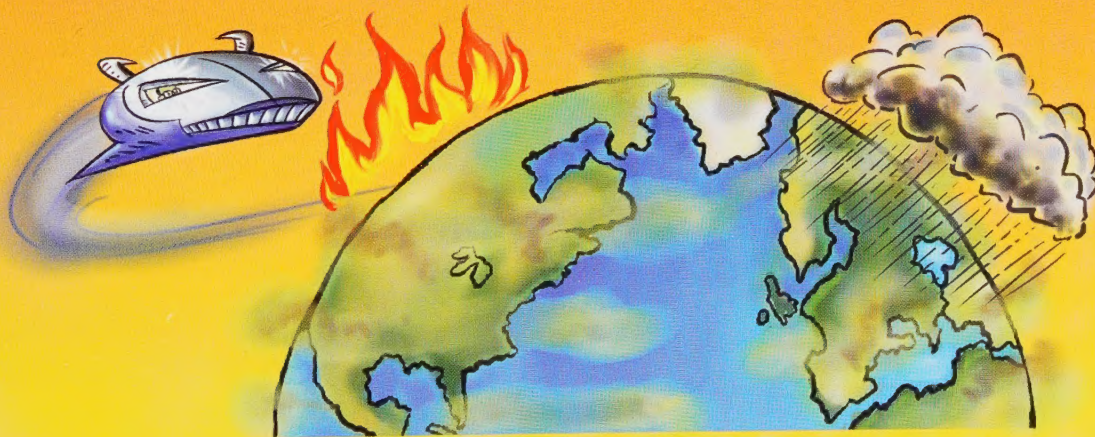




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MAX ^{THE} DEMON VS ENTROPY OF DOOM

The Epic Mission of Maxwell's Demon to
Face the 2nd Law of Thermodynamics and
Save Earth from Environmental Disaster



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Colored By
Prentis Rollins

Loose Line Productions, Inc.

To our children:
Tamara, Carmel, Ronen, Nadav, Sivan, Ethan, and Avigail

Max the Demon vs Entropy of Doom

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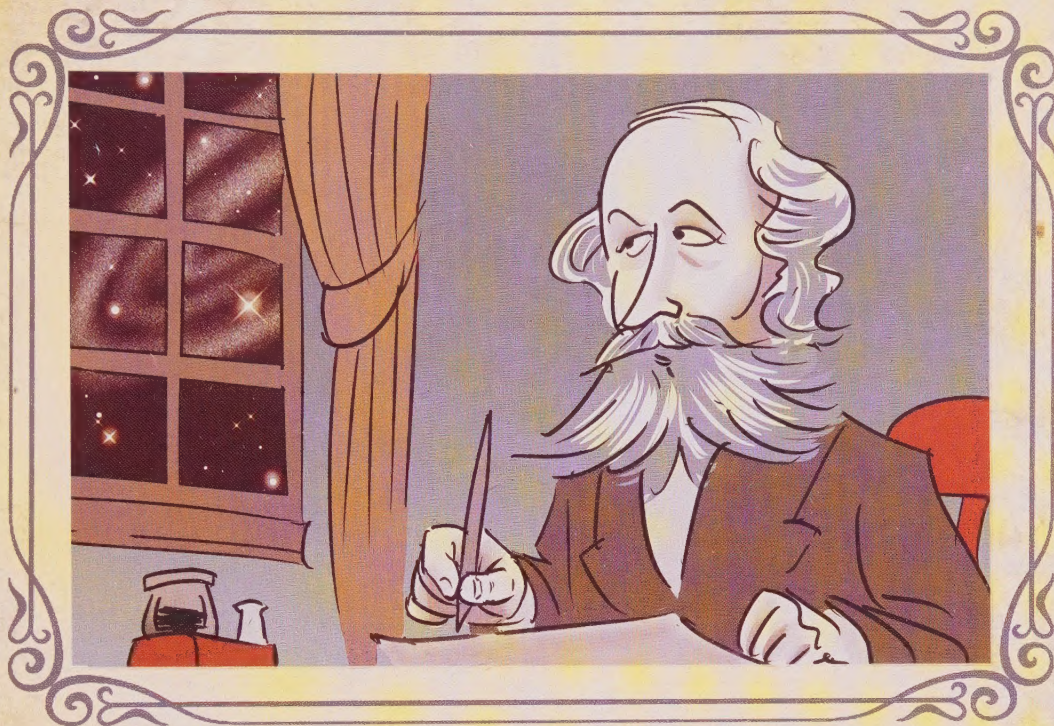
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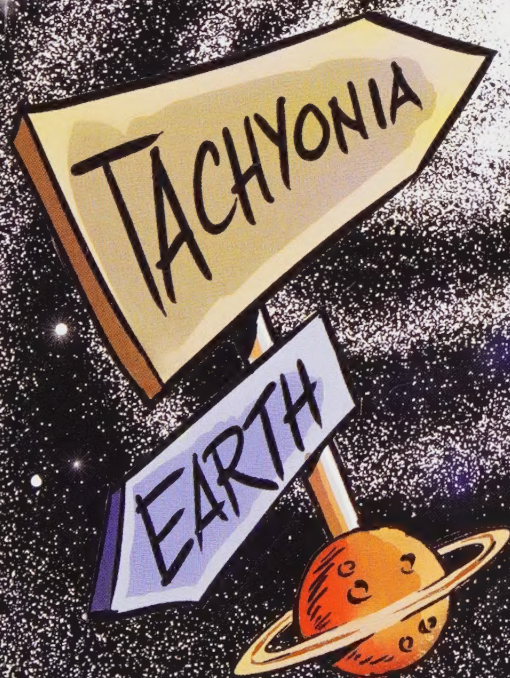
MANY YEARS AGO, JAMES CLERK MAXWELL,
A SCOT AND A GENIUS PHYSICIST,
IMAGINED A CREATURE WHO COULD
VIOLATE THE SECOND LAW OF THERMODYNAMICS*.
LITTLE DID MAXWELL KNOW THAT ONE DAY HIS
IMAGINARY DEMON WOULD BE CALLED UPON
TO SAVE THE WORLD...



*THE SECOND LAW SAYS: WITHOUT EXTERNAL INTERFERENCE
HEAT CAN ONLY FLOW FROM HOT TO COLD, AND ENTROPY
CAN ONLY GROW LARGER.

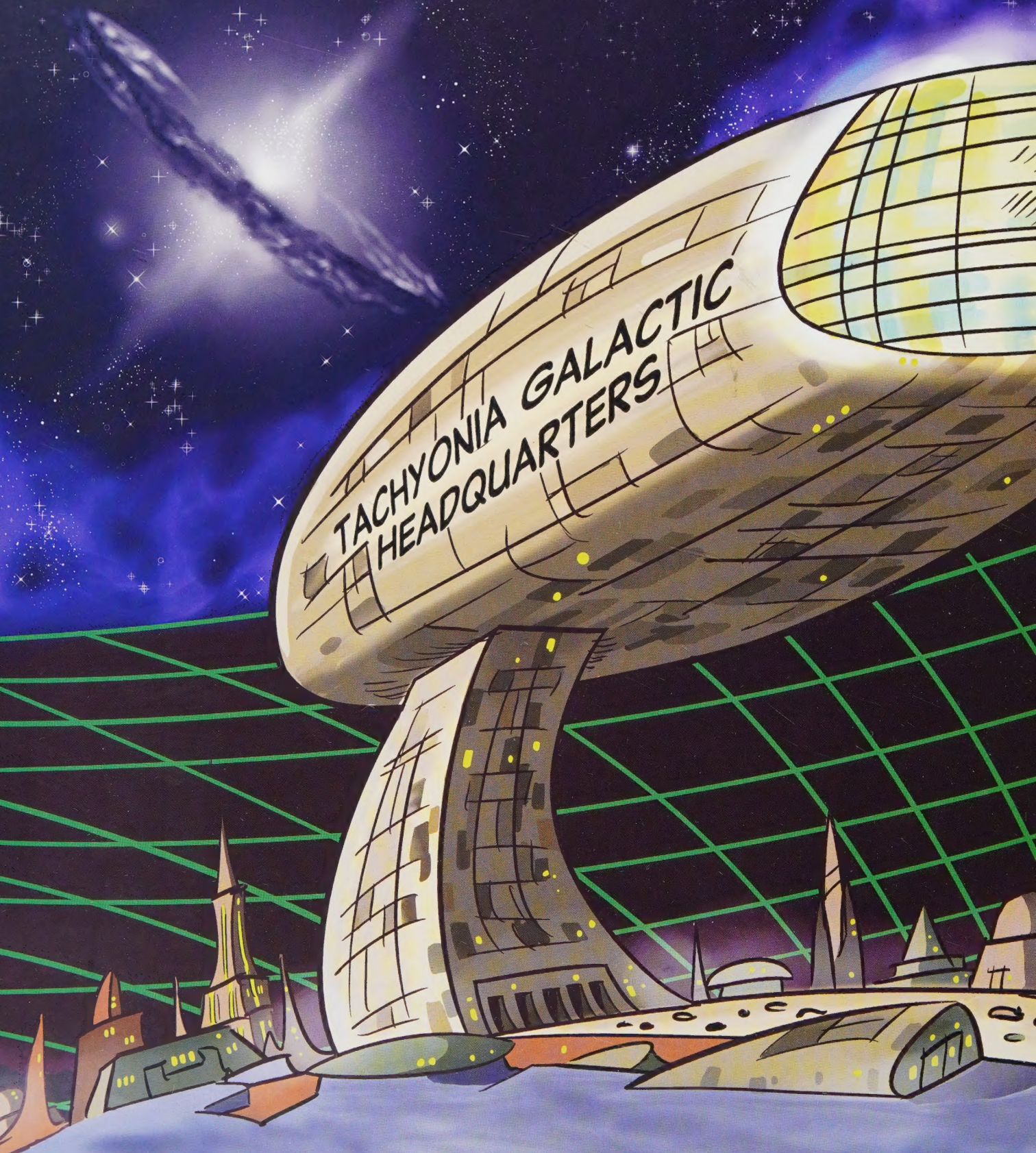
PROLOGUE

THE BLACK HOLE AT THE CENTER
OF THE MILKY WAY



POK-KLACK
-KLACK

INSIDE THE BLACK HOLE. . .



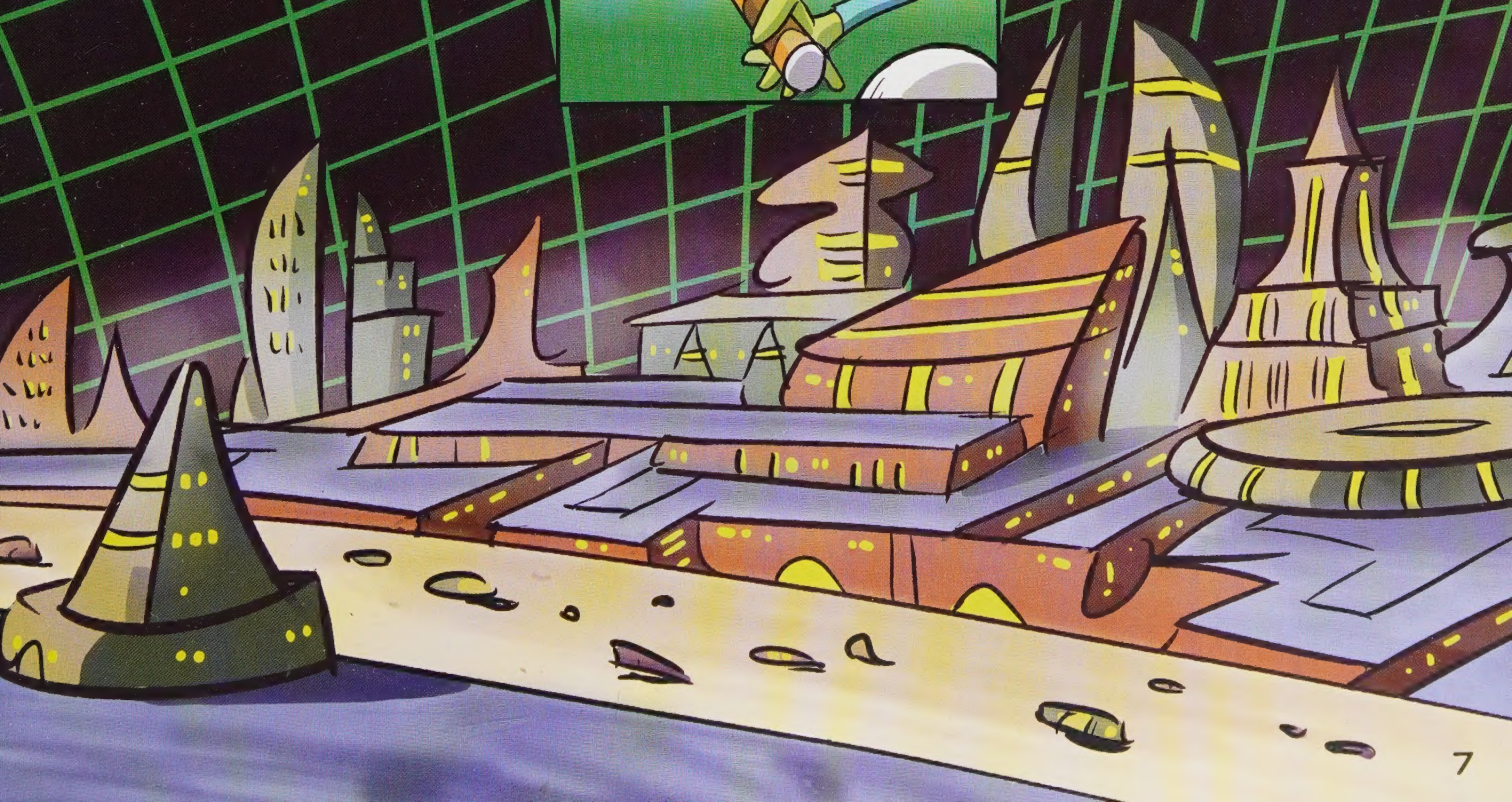
POK-KLACK-WHOOSH

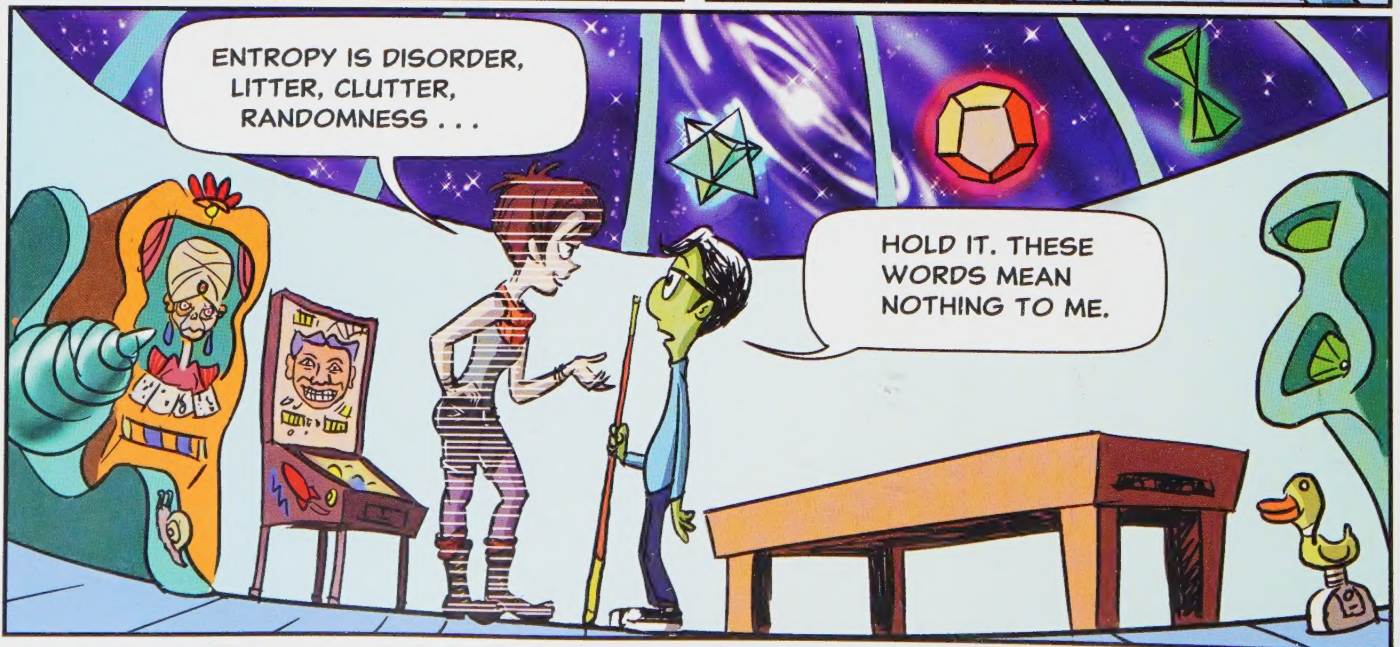
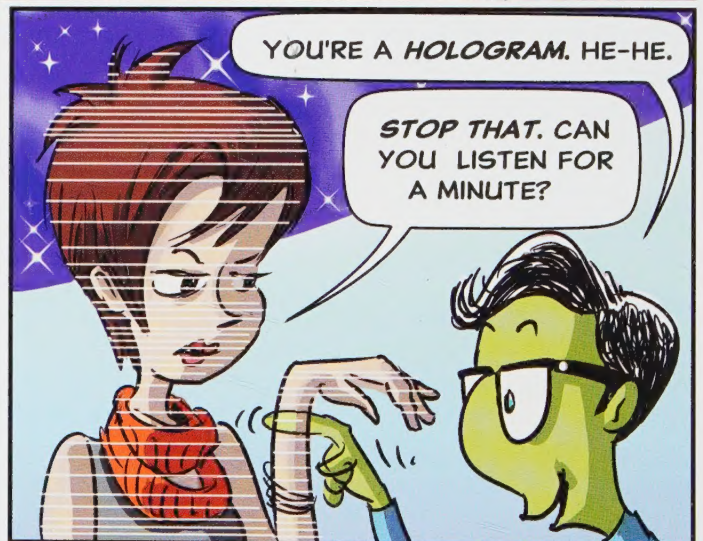
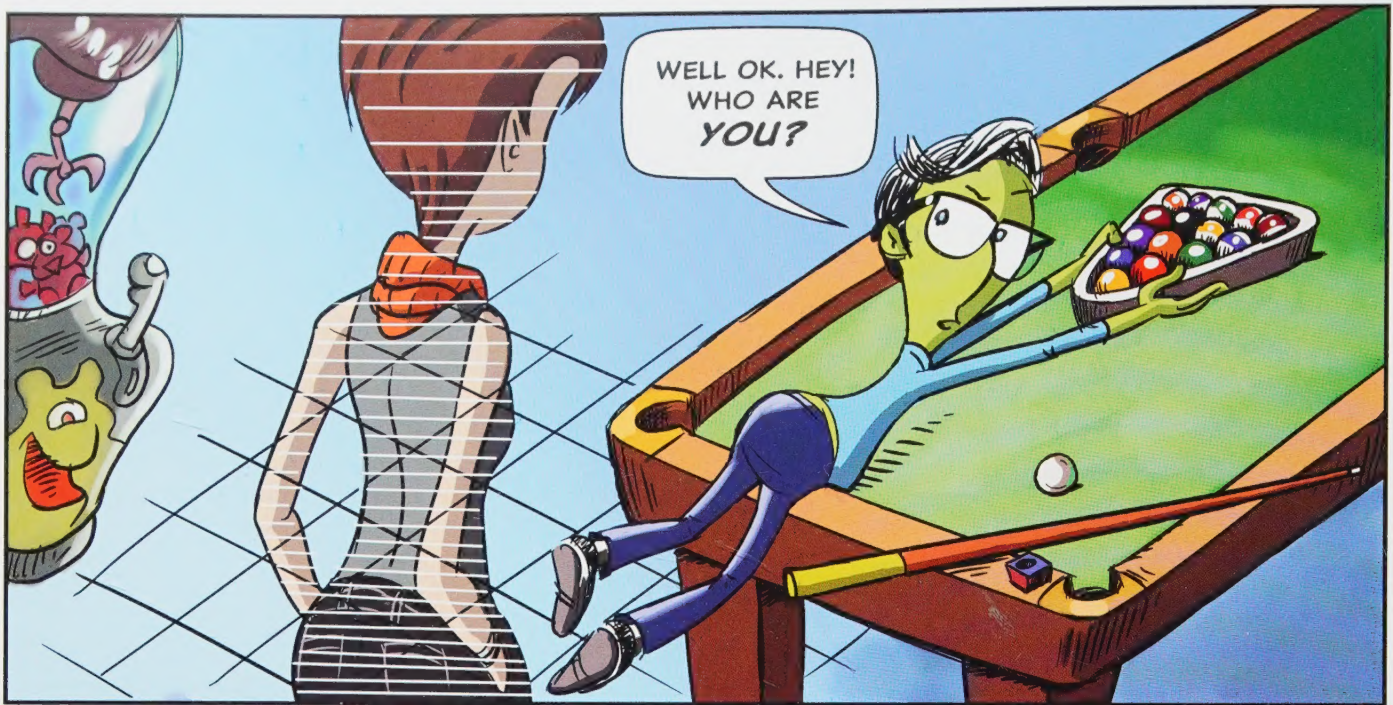
9 BALL IN THE SIDE POCKET... YES!

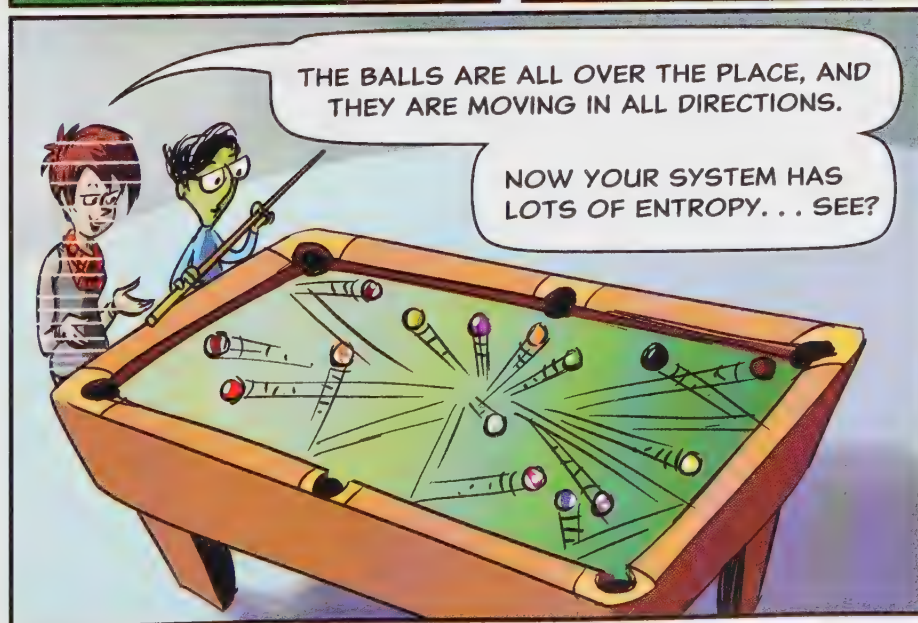
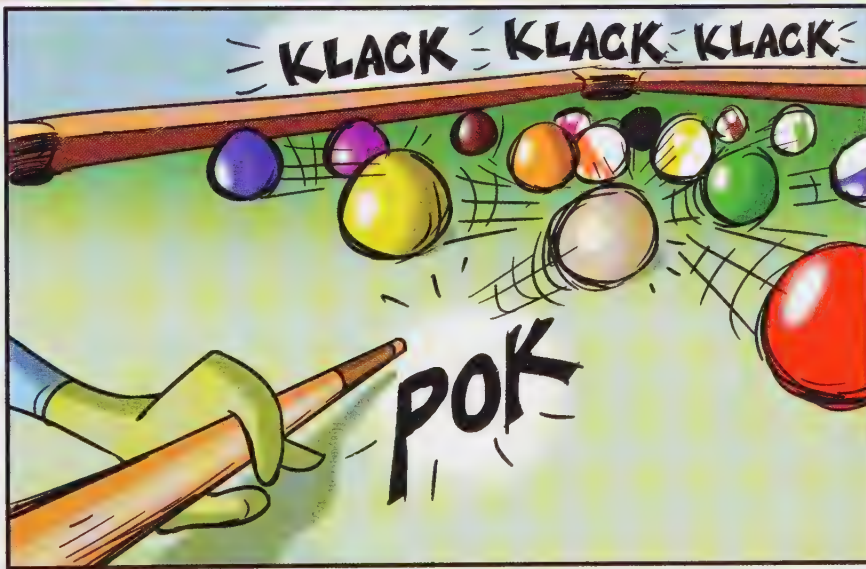
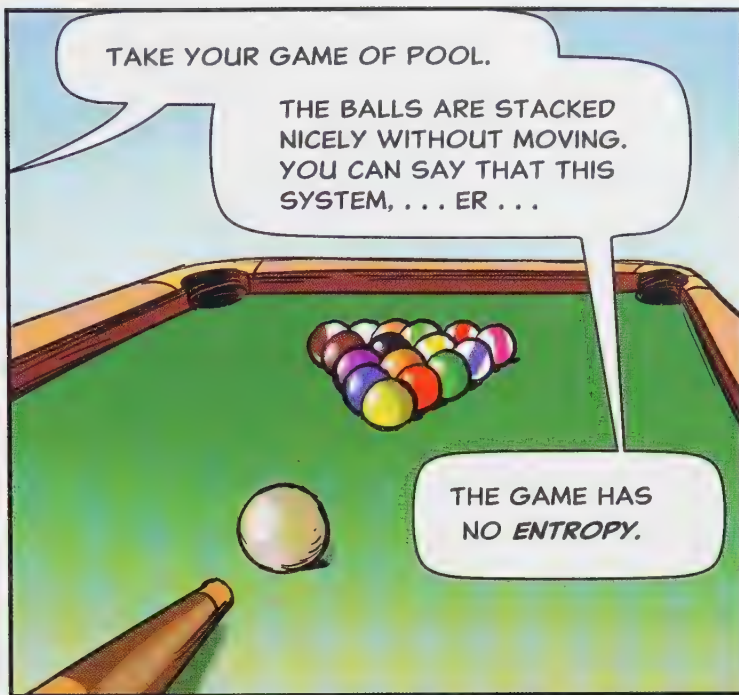
YEAH MAX, BUT THAT'S NOT GOING TO GET YOU THROUGH SIR BIO'S ENTROPY TEST...

ENTROPY? IS THAT PHYSICS?

YES, MAYBE I CAN HELP YOU.







YOU KNOW, I HAVE SPECIAL POWERS OF VISION IN MY RETINAS, SO SIR BIO MADE ME THESE GLASSES WITH A FEATURE CALLED *MICROSTATE DETERMINATOR*.

WHEN I TOUCH THIS BUTTON...

THEN I CAN SEE **ATOMS!**

THAT'S AWESOME! WHAT DO THEY LOOK LIKE?

THE ATOMS IN MY COFFEE LOOK JUST LIKE TINY BILLIARD BALLS...

BOUNCING AROUND IN ALL DIRECTIONS.

SO THE COFFEE HAS LOTS OF ENTROPY, RIGHT?

I ALSO SEE ATOMS IN YOUR ICE TEA, BUT THEY ARE MOVING MUCH SLOWER.

LESS ENTROPY, AS YOU WOULD SAY?

COOL. YOU REALLY DO SEE ATOMS. I'M IMPRESSED!
WHAT'S THAT NOISE?

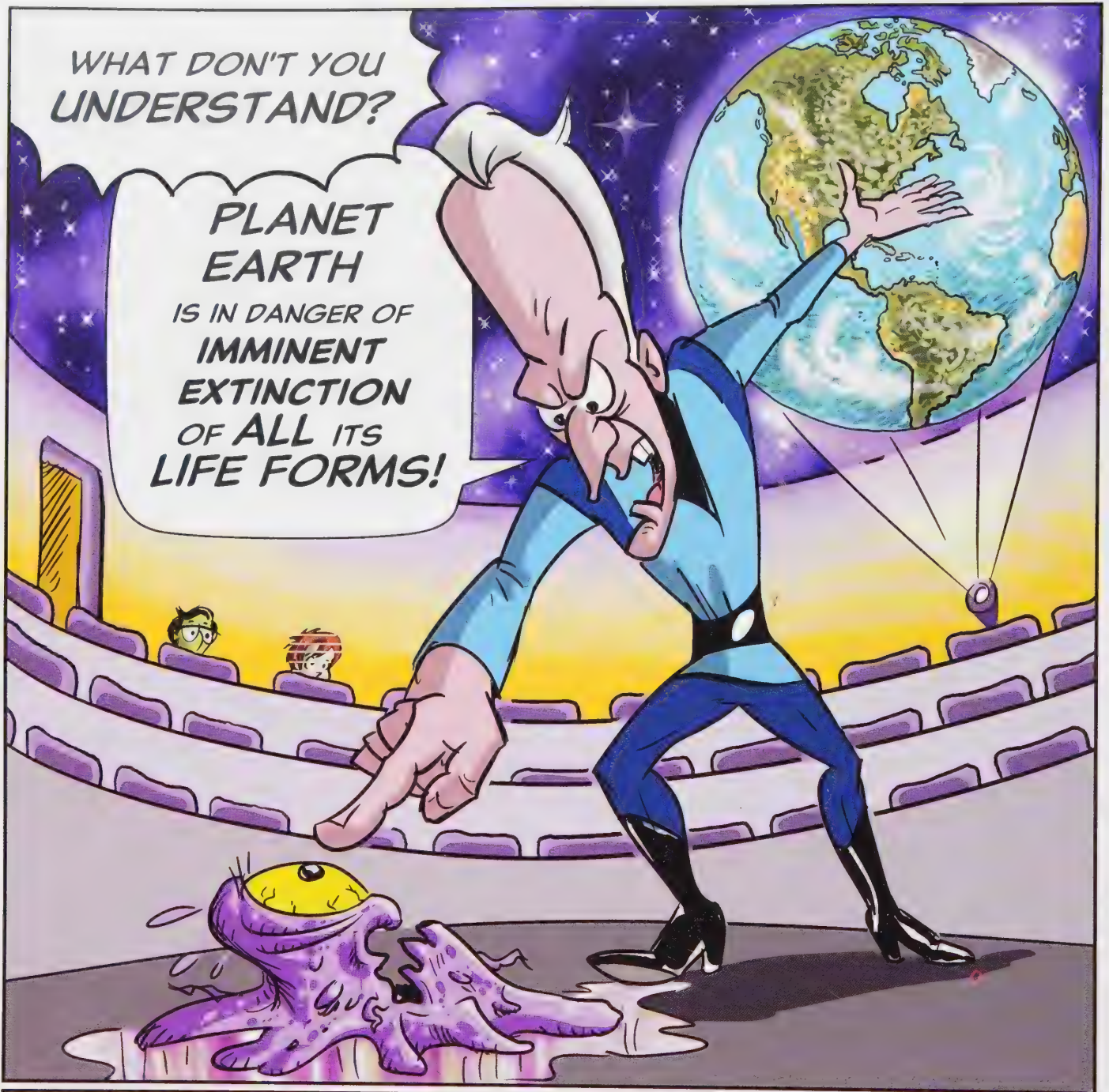
CRASH!
BANG!
ROWR
GRRR

OUT OF THE WAY.
SIR BIO IS ON A RAMPAGE!



WHAT DON'T YOU UNDERSTAND?

PLANET EARTH
IS IN DANGER OF
IMMINENT
EXTINCTION
OF ALL ITS
LIFE FORMS!



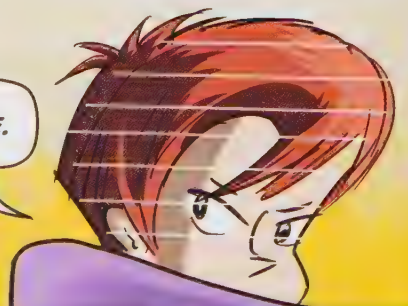
WHY IS HE SO UPSET ABOUT ONE SMALL PLANET?

SIR BIO IS RESPONSIBLE FOR ALL LIFE IN THE GALAXY. EARTH IS THE ONLY PLANET HOSPITABLE TO SUCH A WIDE VARIETY OF CREATURES.

HE'S OBSESSED.

IT'S ALSO MY HOME.

OOPS... OF COURSE!





WHAT HAVE YOU BEEN DOING THAT IS SO AWFUL?

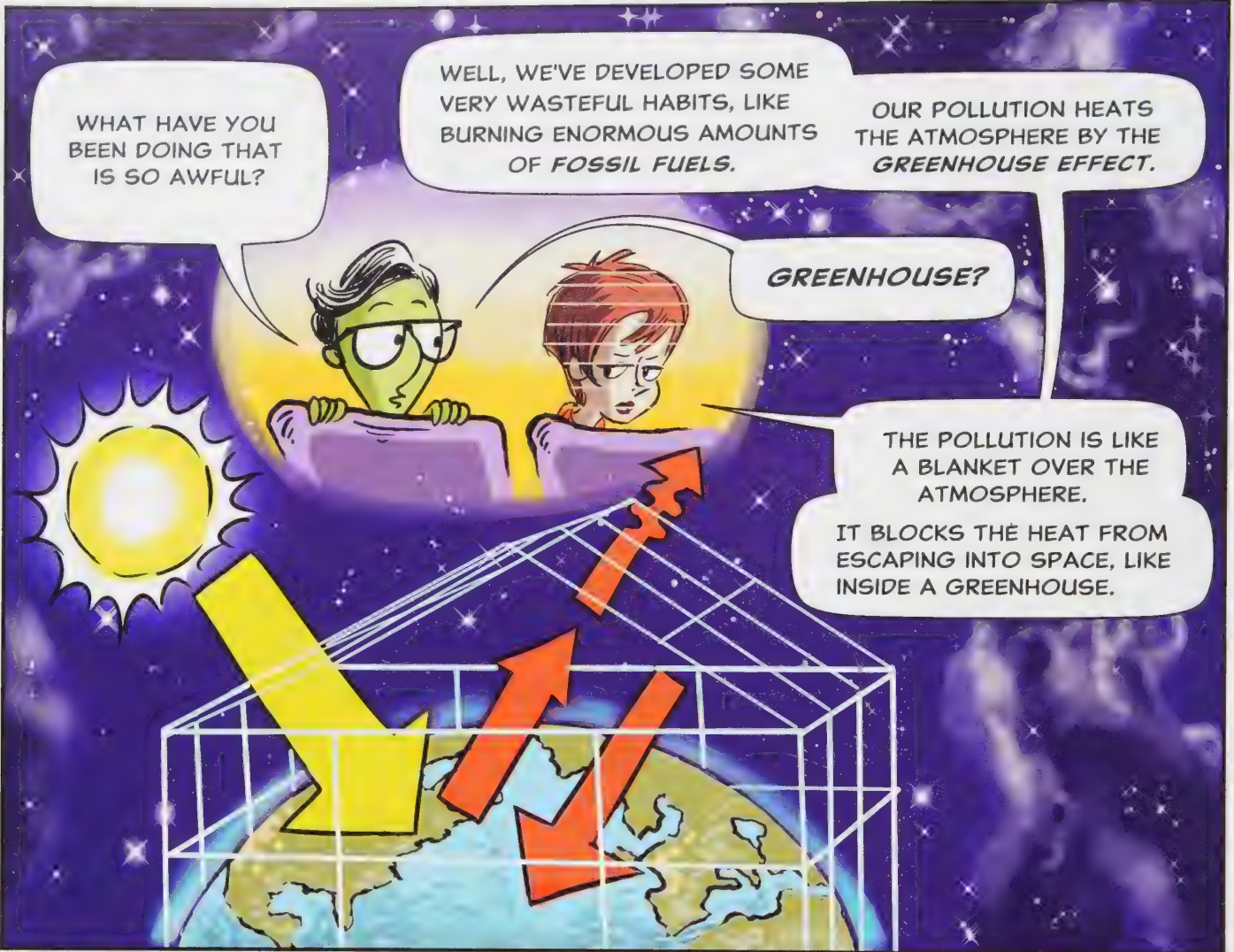
WELL, WE'VE DEVELOPED SOME VERY WASTEFUL HABITS, LIKE BURNING ENORMOUS AMOUNTS OF *FOSSIL FUELS*.

OUR POLLUTION HEATS THE ATMOSPHERE BY THE *GREENHOUSE EFFECT*.

GREENHOUSE?

THE POLLUTION IS LIKE A BLANKET OVER THE ATMOSPHERE.

IT BLOCKS THE HEAT FROM ESCAPING INTO SPACE, LIKE INSIDE A GREENHOUSE.

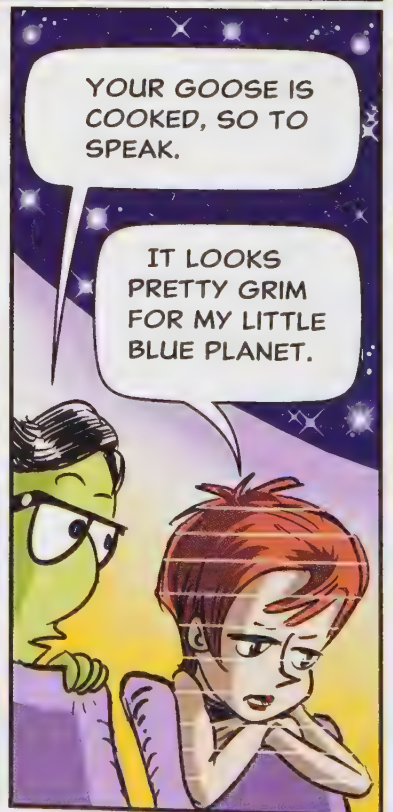


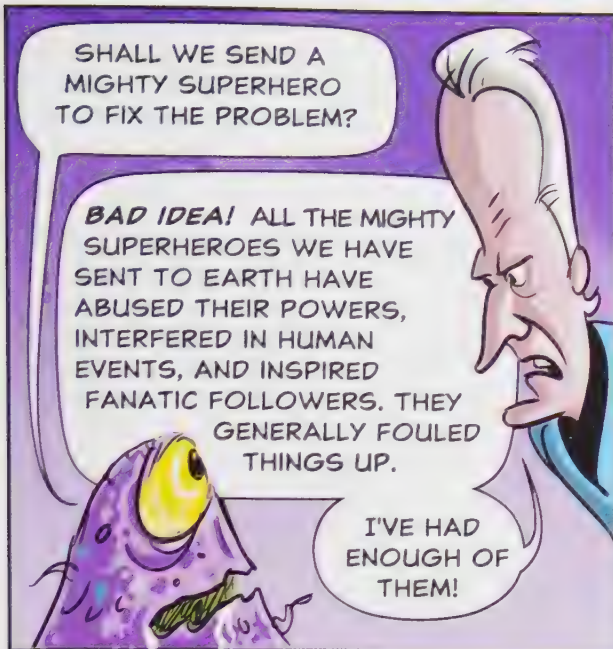
IT'S BECOMING HOT UNDER THIS POLLUTION BLANKET AND THE HEAT WILL KILL US.



YOUR GOOSE IS COOKED, SO TO SPEAK.

IT LOOKS PRETTY GRIM FOR MY LITTLE BLUE PLANET.

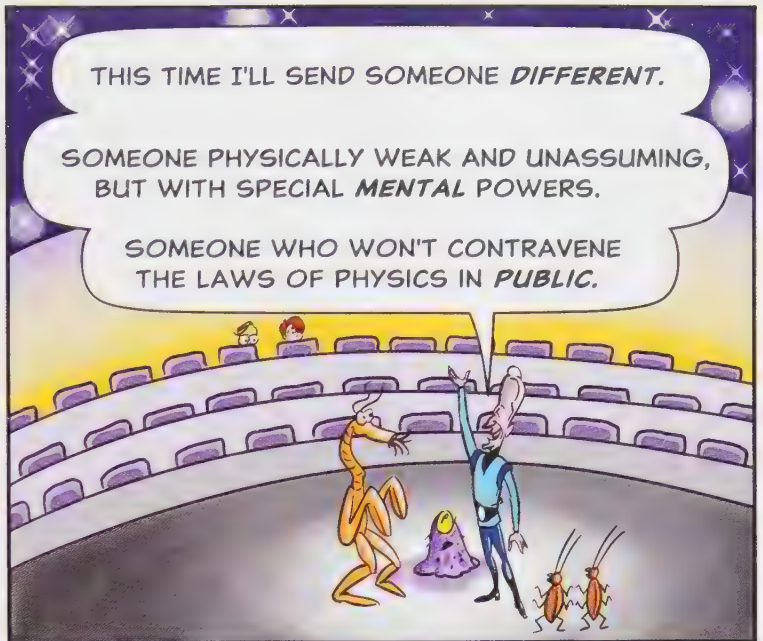




SHALL WE SEND A MIGHTY SUPERHERO TO FIX THE PROBLEM?

BAD IDEA! ALL THE MIGHTY SUPERHEROES WE HAVE SENT TO EARTH HAVE ABUSED THEIR POWERS, INTERFERED IN HUMAN EVENTS, AND INSPIRED FANATIC FOLLOWERS. THEY GENERALLY FOULED THINGS UP.

I'VE HAD ENOUGH OF THEM!



THIS TIME I'LL SEND SOMEONE *DIFFERENT*.

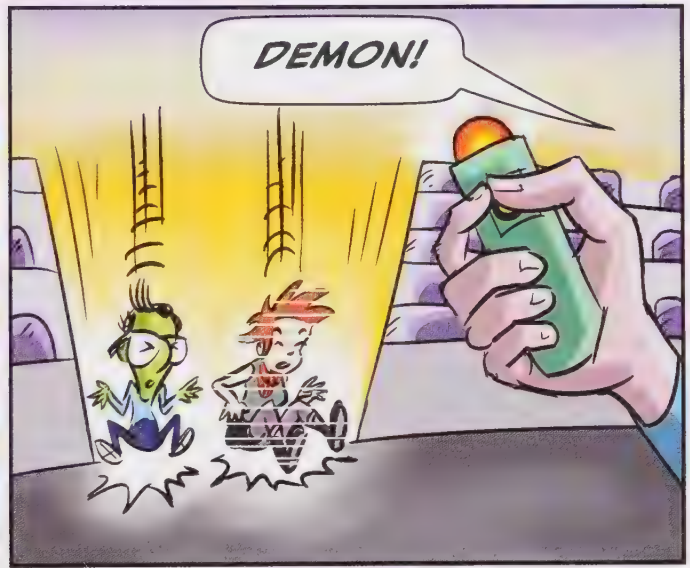
SOMEONE PHYSICALLY WEAK AND UNASSUMING, BUT WITH SPECIAL *MENTAL* POWERS.

SOMEONE WHO WON'T CONTRAVENE THE LAWS OF PHYSICS IN *PUBLIC*.



SOMEONE WHO WILL SHOW THEM HOW TO STOP GLOBAL WARMING AND REDUCE *ENTROPY*.

OUR NEW HERO WILL BE A ...



DEMON!



WHAT'S A DEMON? IS IT A GOOD THING?

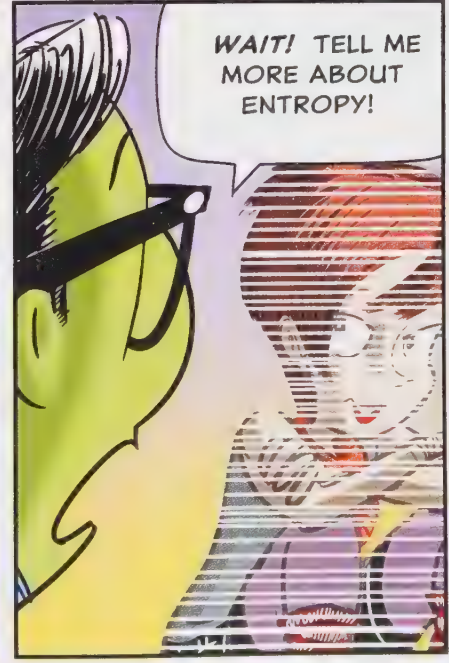
DEMONS ARE USUALLY NASTY. .



BUT PERHAPS HE'S TALKING ABOUT A NICE DEMON.

IT'S TIME FOR ME TO GO.

SEE YOU AGAIN, SOON.
CIAO, MAX ...

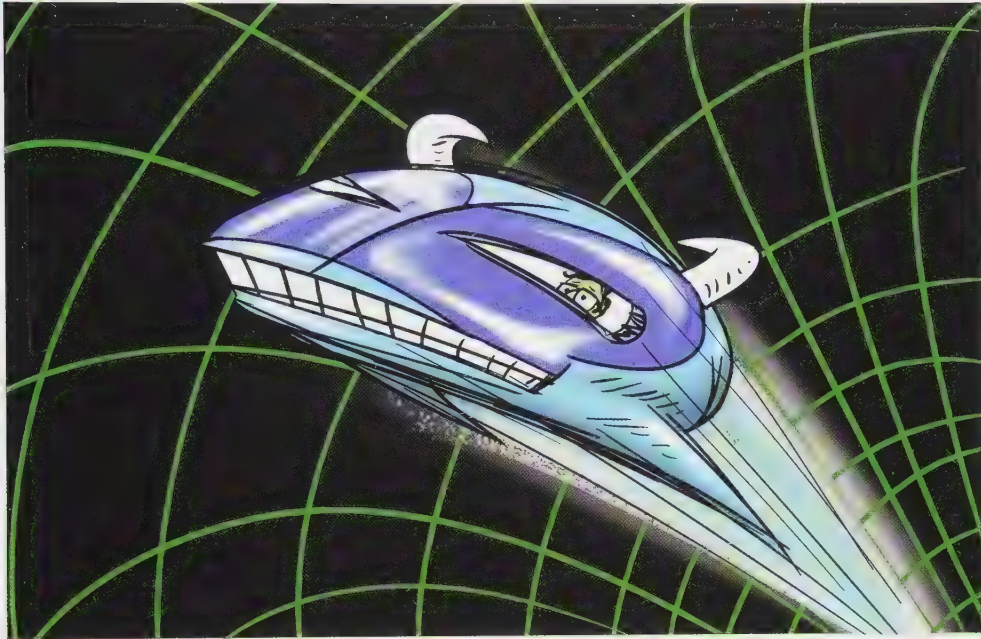


WAIT! TELL ME MORE ABOUT ENTROPY!

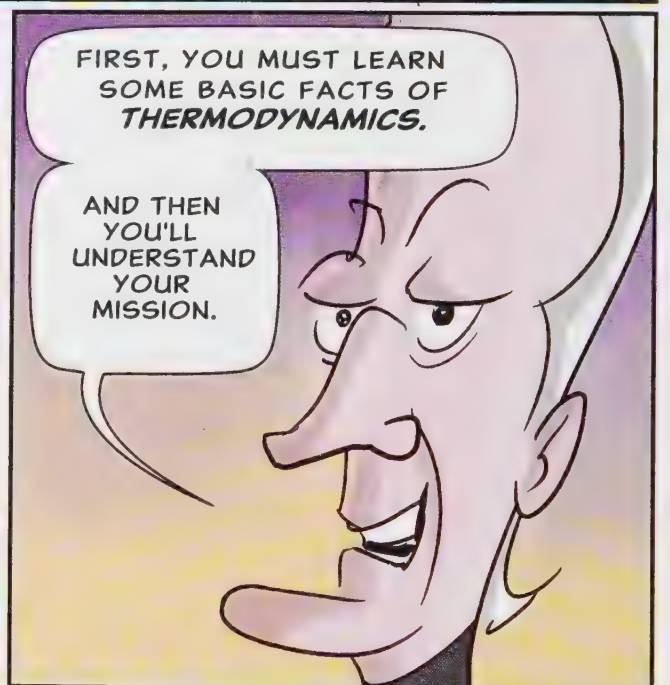
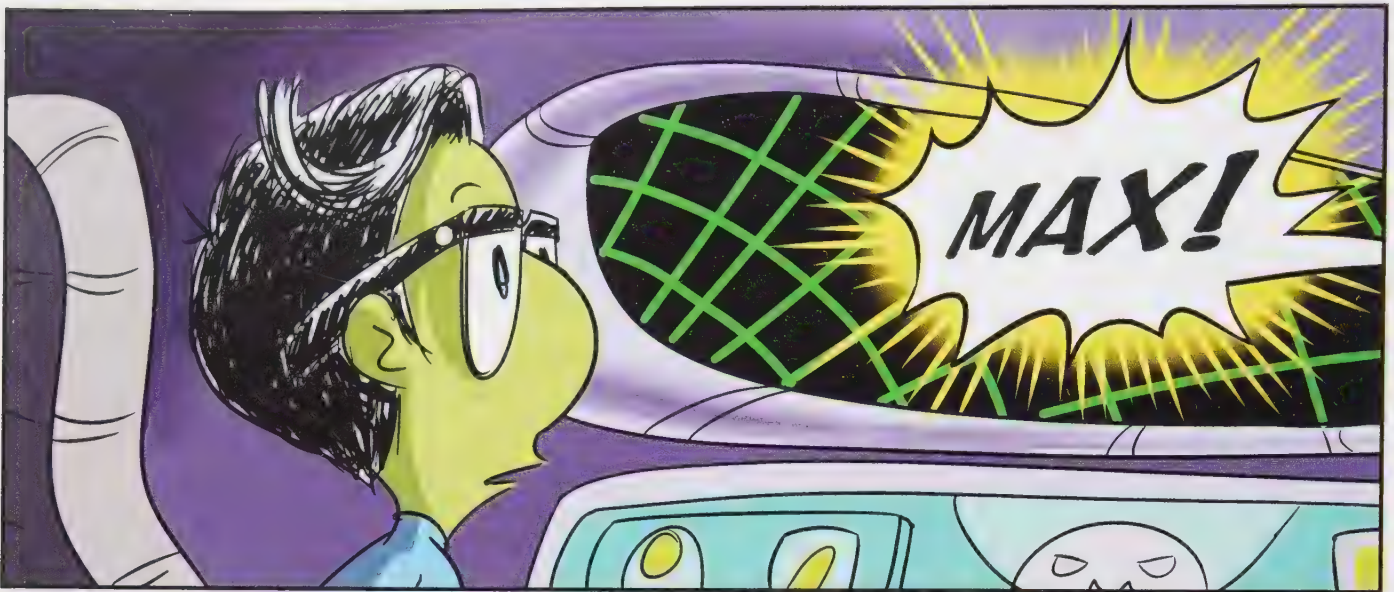


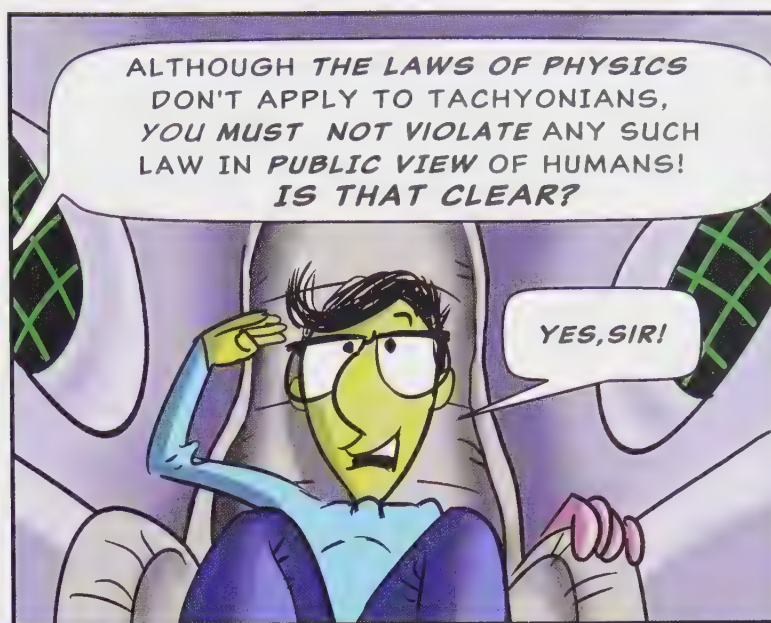
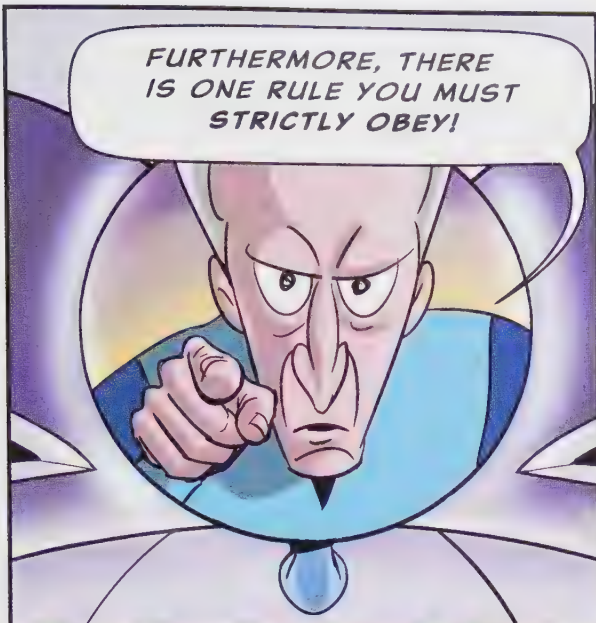
CHAPTER I

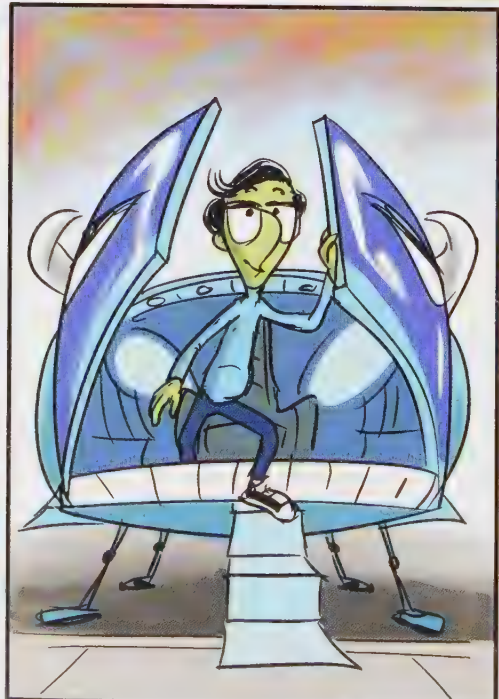
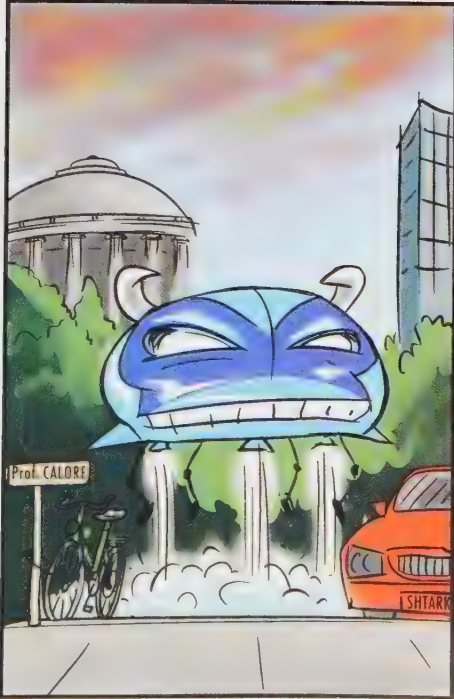
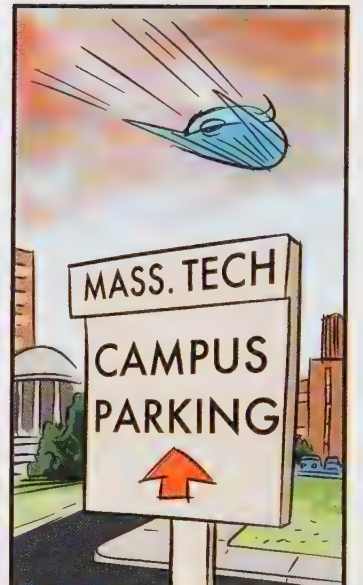
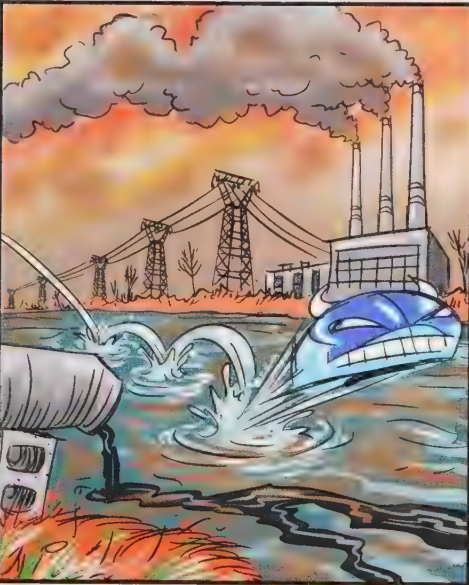
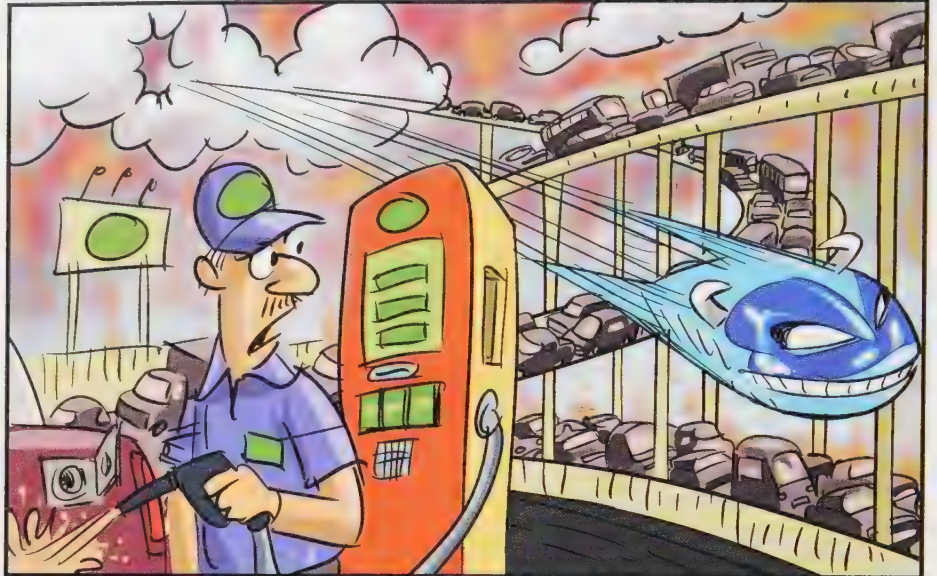
PRESENT TIME



MAX TRAVELS TO EARTH





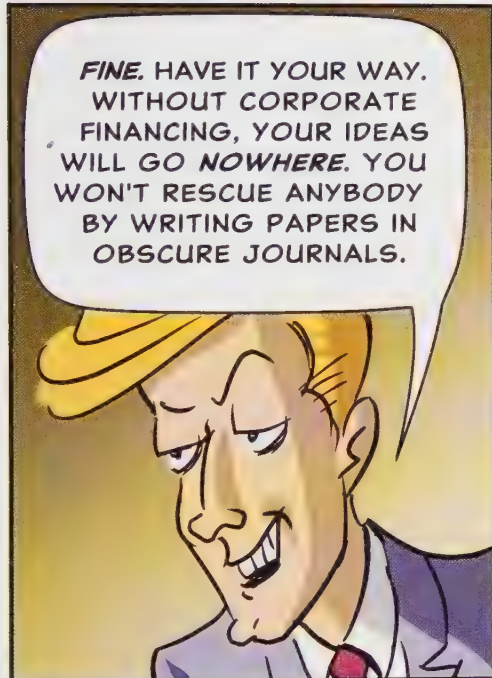




CRAWL BACK TO YOUR CORPORATE BOSSES, YOU GREEDY MONEY GRUBBER!



YOU DON'T CARE ABOUT THE ENVIRONMENT AT ALL. I DON'T WANT TO HEAR FROM YOU *EVER* AGAIN.



FINE. HAVE IT YOUR WAY. WITHOUT CORPORATE FINANCING, YOUR IDEAS WILL GO *NOWHERE*. YOU WON'T RESCUE ANYBODY BY WRITING PAPERS IN OBSCURE JOURNALS.



I'M OFF TO MAKE A *REAL* MARK ON THE WORLD. *CIAO, JULIE!*

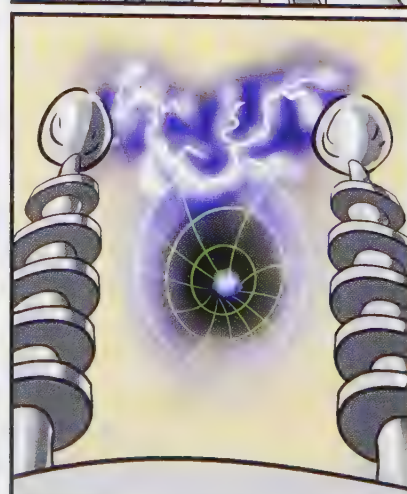
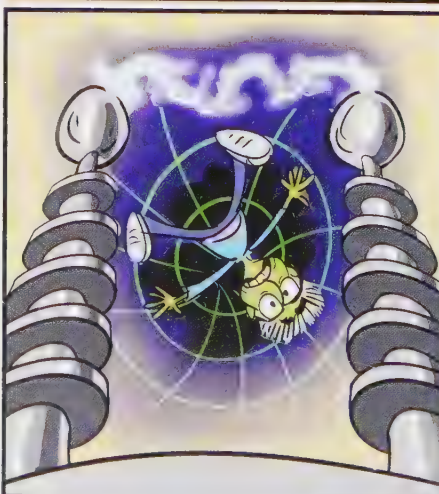
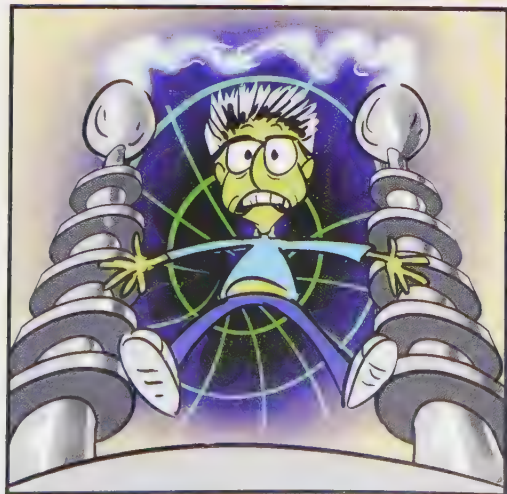
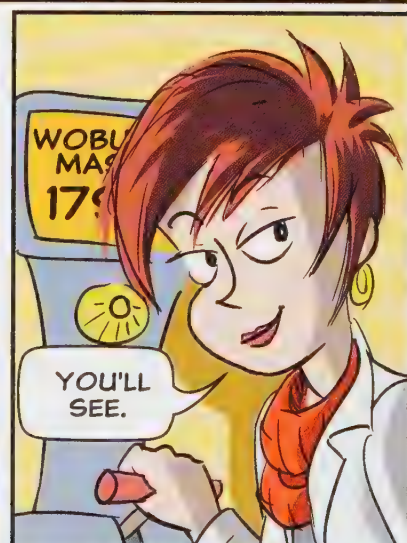
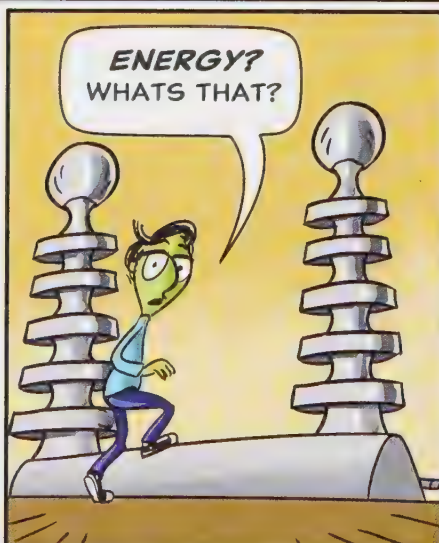
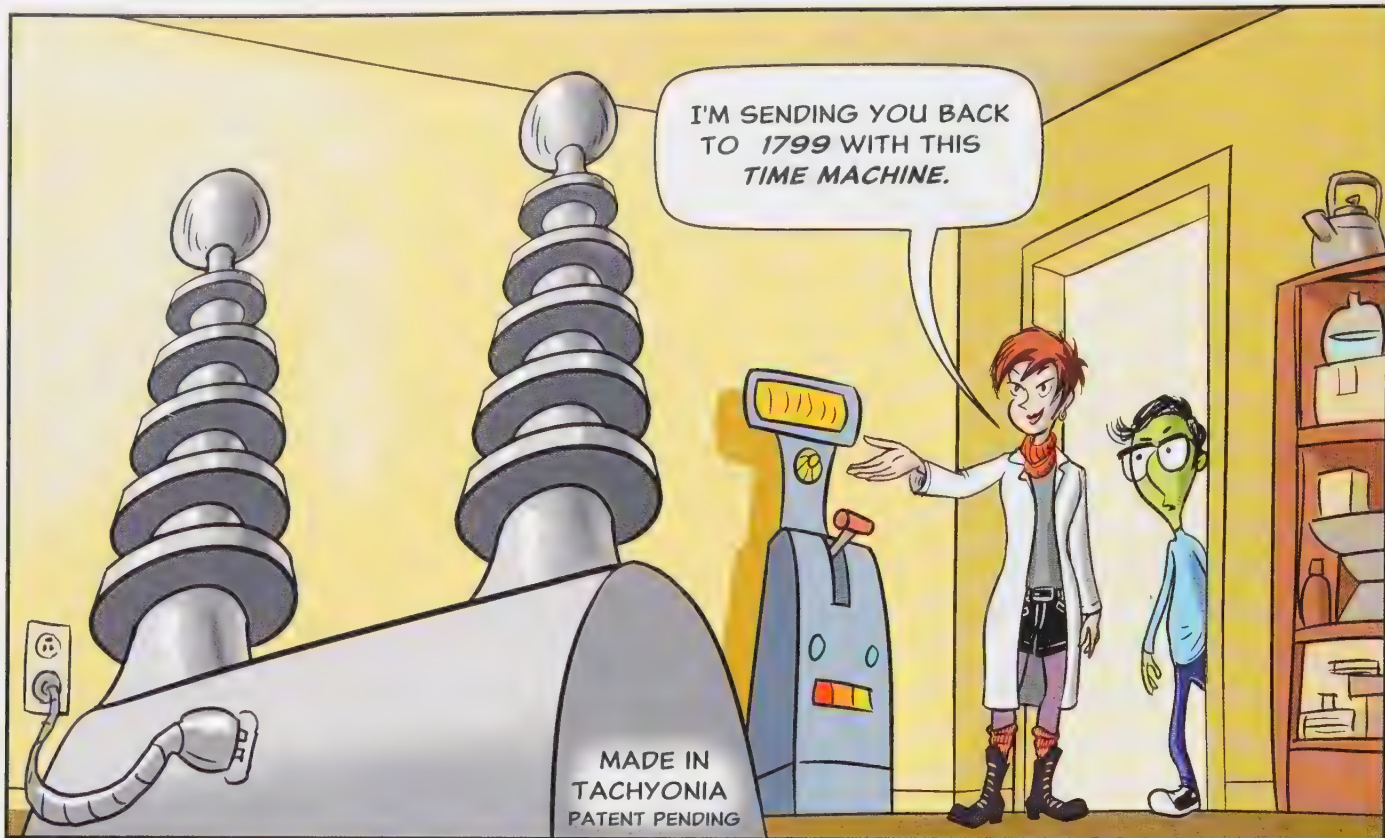


MAX! YOU ARE HERE! SORRY YOU HAD TO WITNESS MY ARGUMENT WITH MY EX, JOHNNY.



WE'RE BETTER OFF WITHOUT HIM. LET'S GET YOU STARTED ON YOUR MISSION. COME WITH ME TO THE BACK ROOM PLEASE.

WHERE AM I GOING?



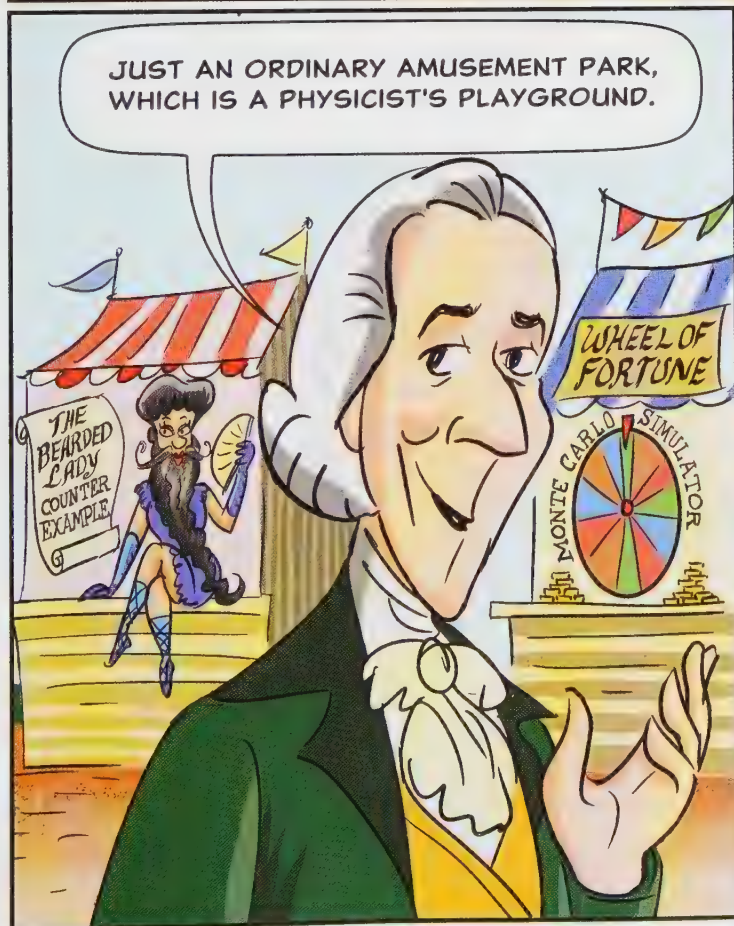
CHAPTER II

WOBURN, MASSACHUSETTS
1799



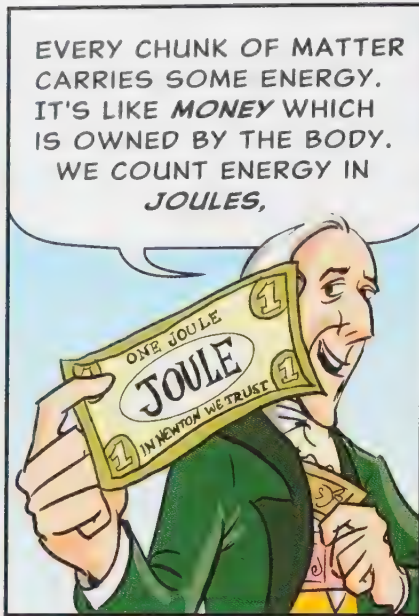
**RUMFORD'S
AMUSEMENT PARK**







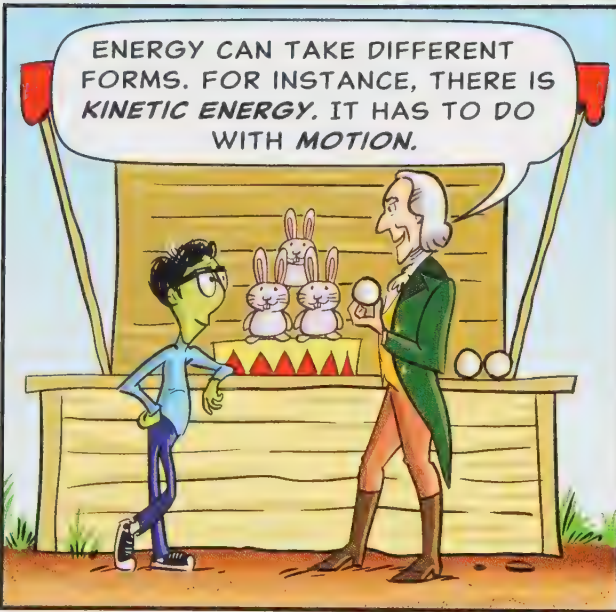
I HEAR ABOUT **ENERGY** ALL THE TIME. WHAT DOES IT MEAN?



EVERY CHUNK OF MATTER CARRIES SOME ENERGY. IT'S LIKE **MONEY** WHICH IS OWNED BY THE BODY. WE COUNT ENERGY IN **JOULES**,



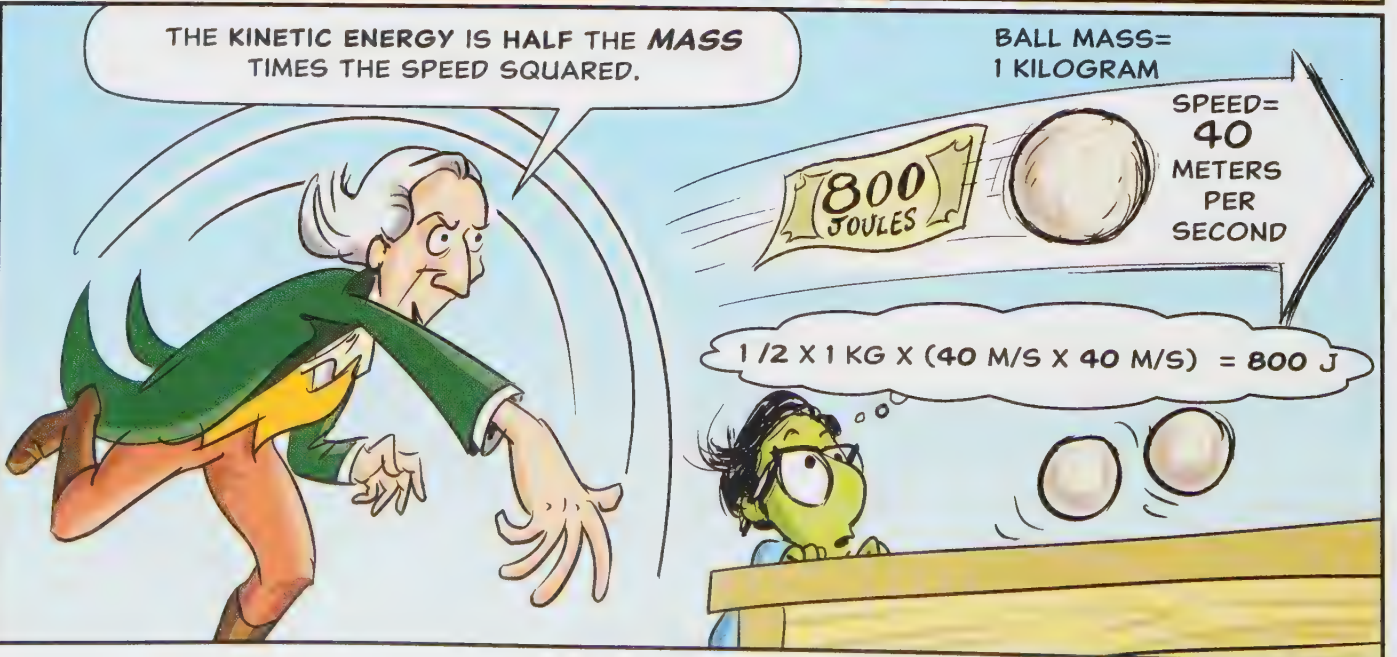
ALTHOUGH ONE COULD USE OTHER UNITS AS WELL.



ENERGY CAN TAKE DIFFERENT FORMS. FOR INSTANCE, THERE IS **KINETIC ENERGY**. IT HAS TO DO WITH **MOTION**.



WATCH ME NOW: I'M GOING TO GIVE THIS BASEBALL SOME **KINETIC ENERGY** ...

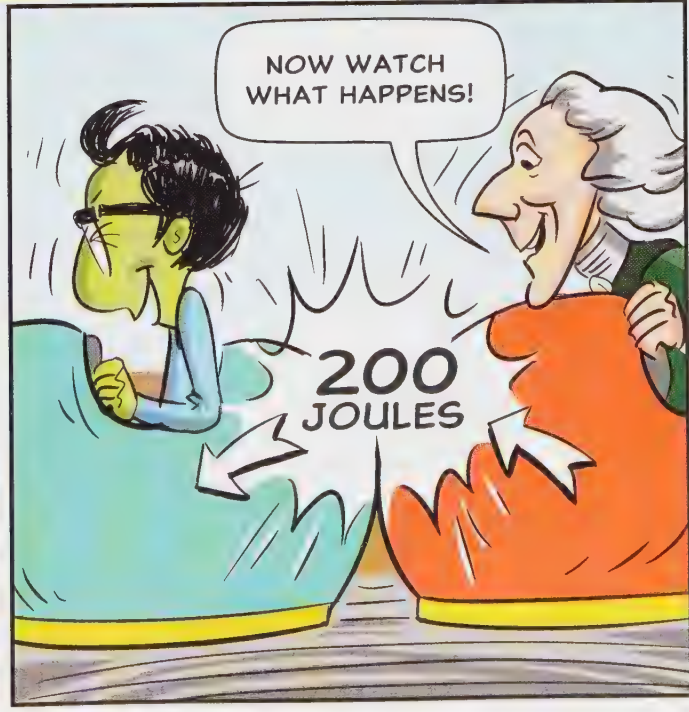
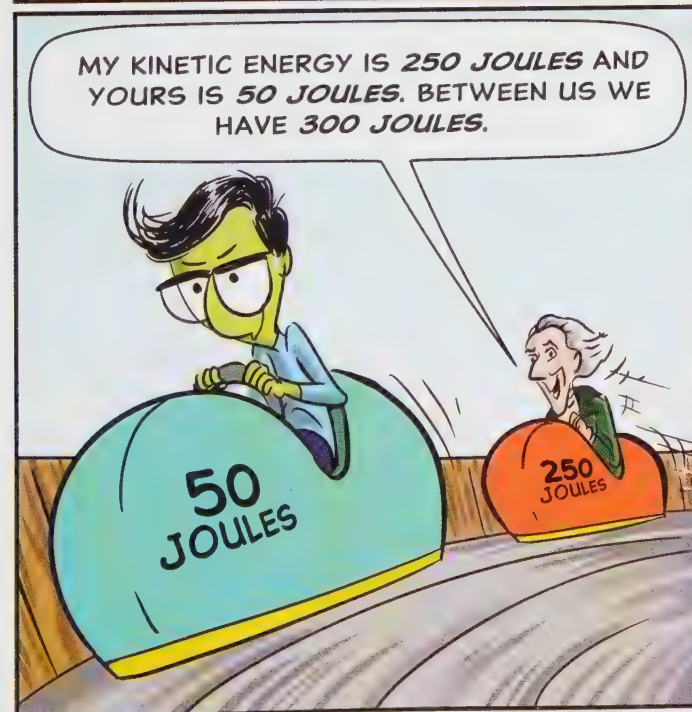
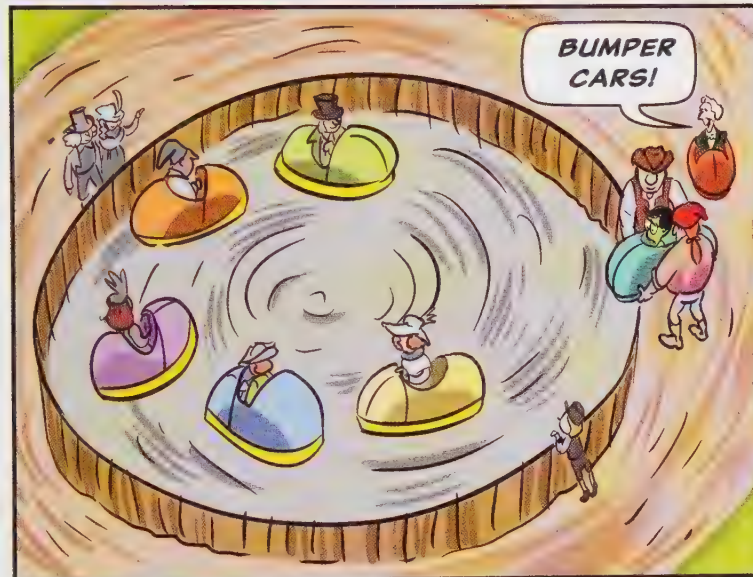
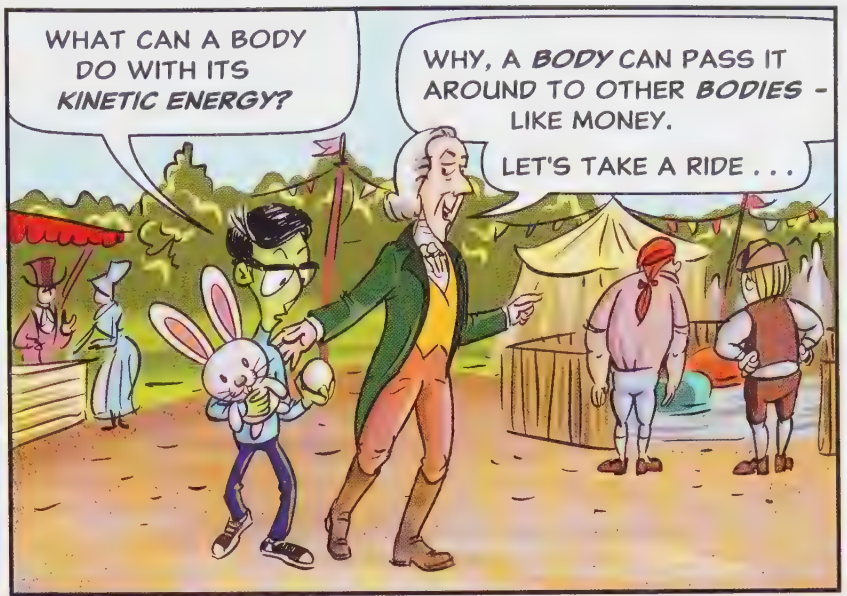
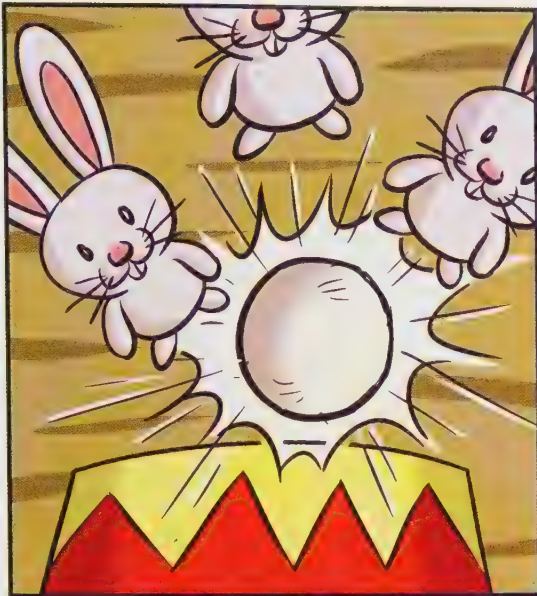


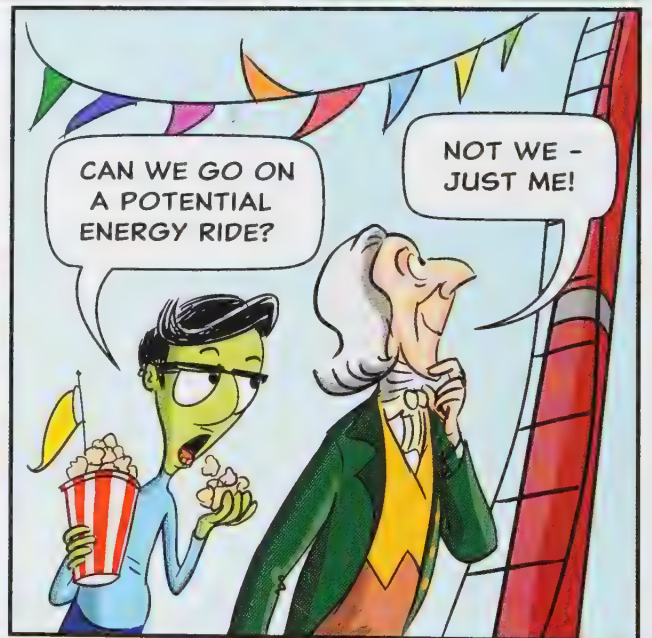
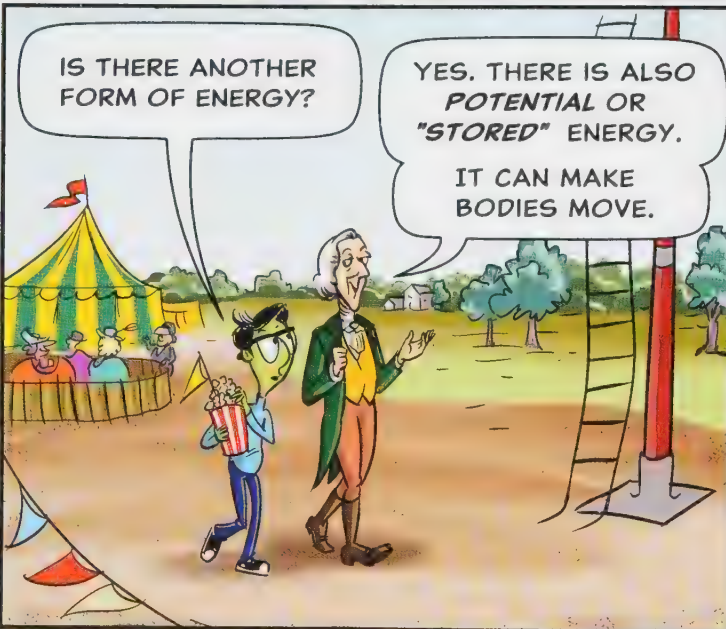
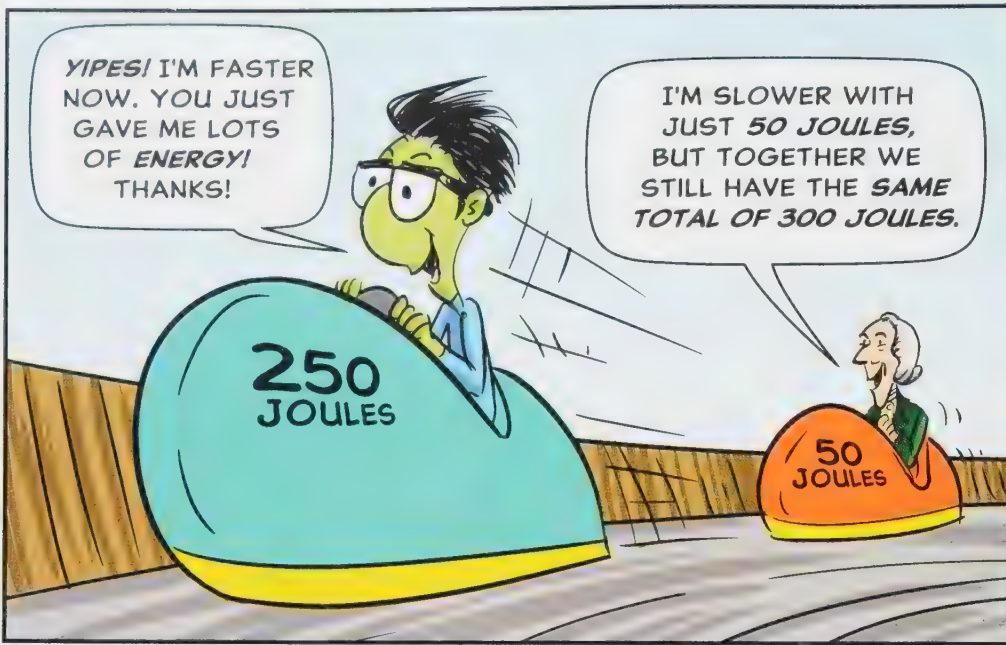
THE **KINETIC ENERGY** IS HALF THE **MASS** TIMES THE **SPEED SQUARED**.

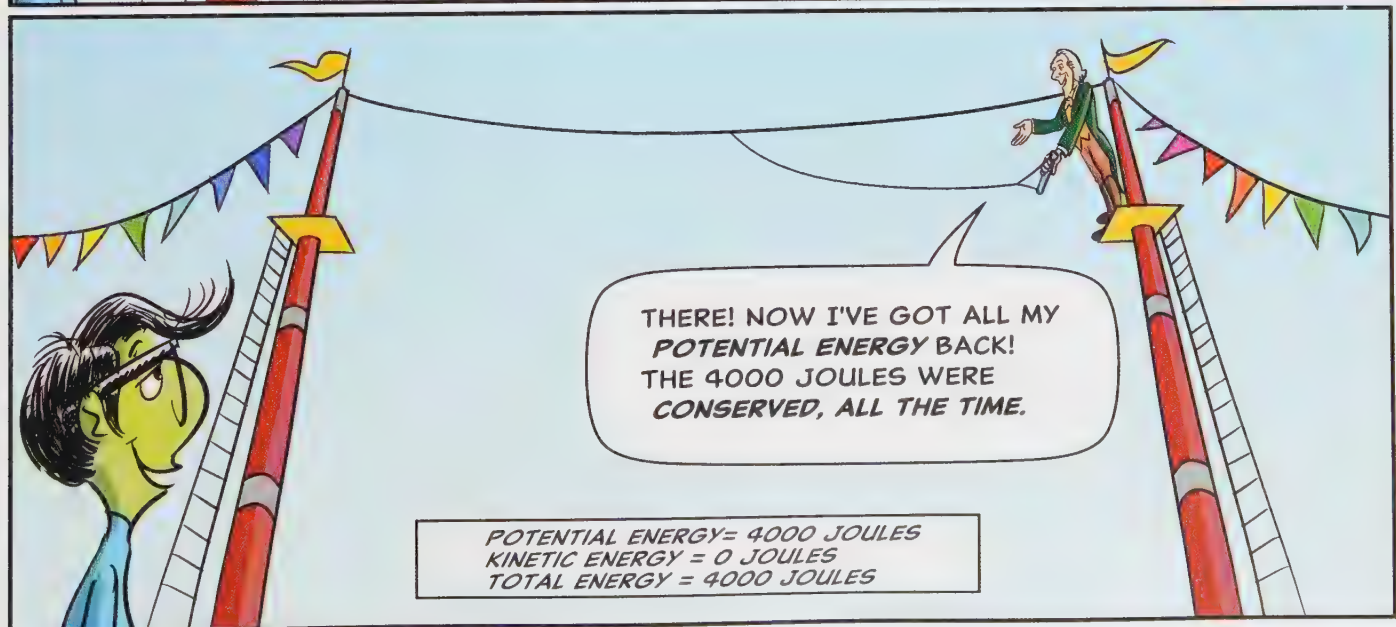
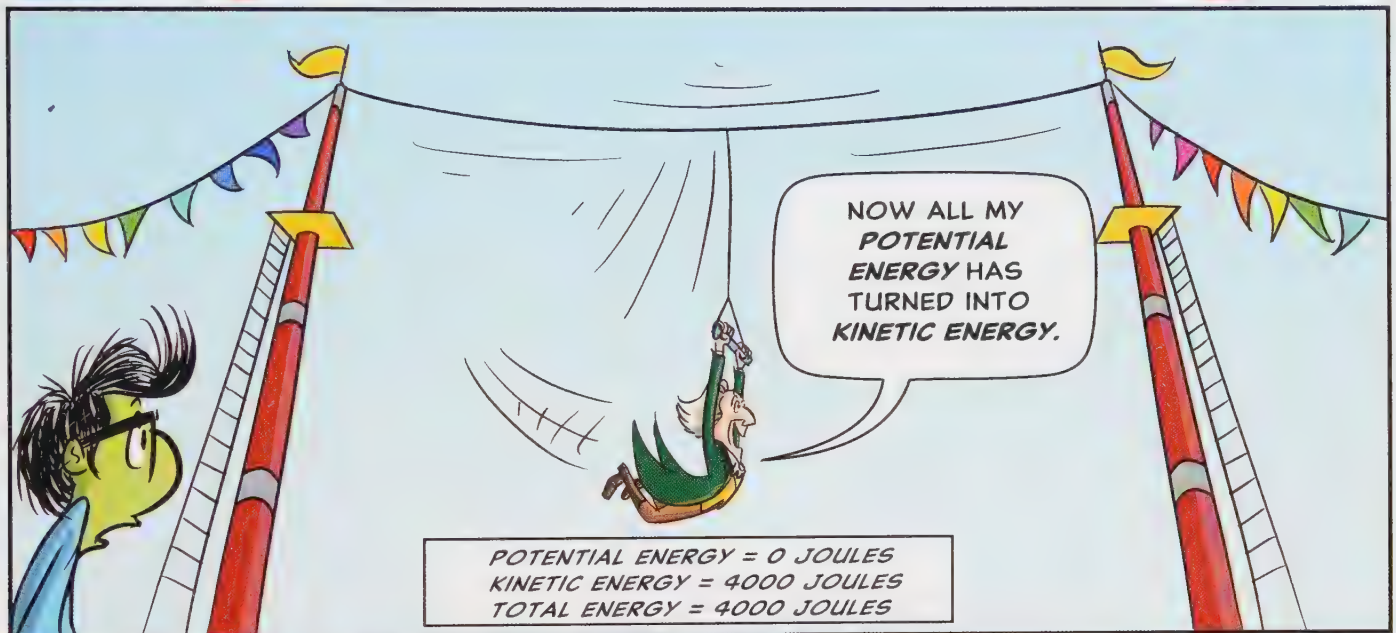
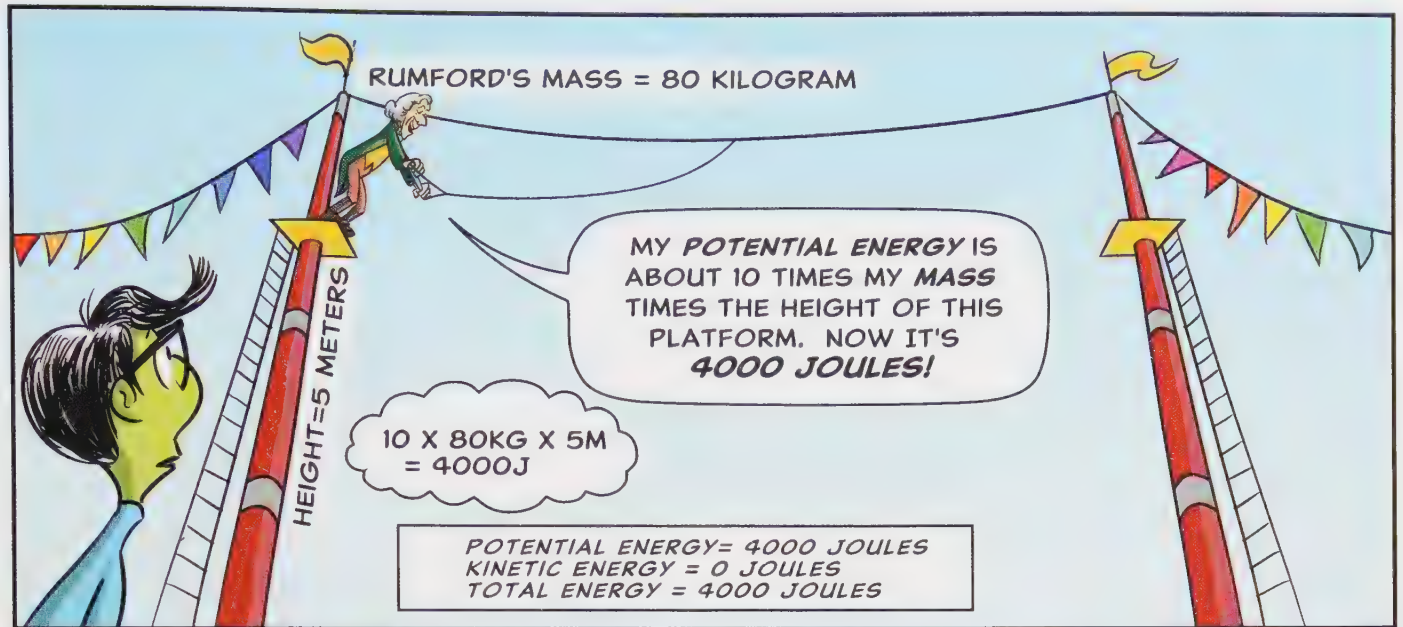
BALL MASS = 1 KILOGRAM

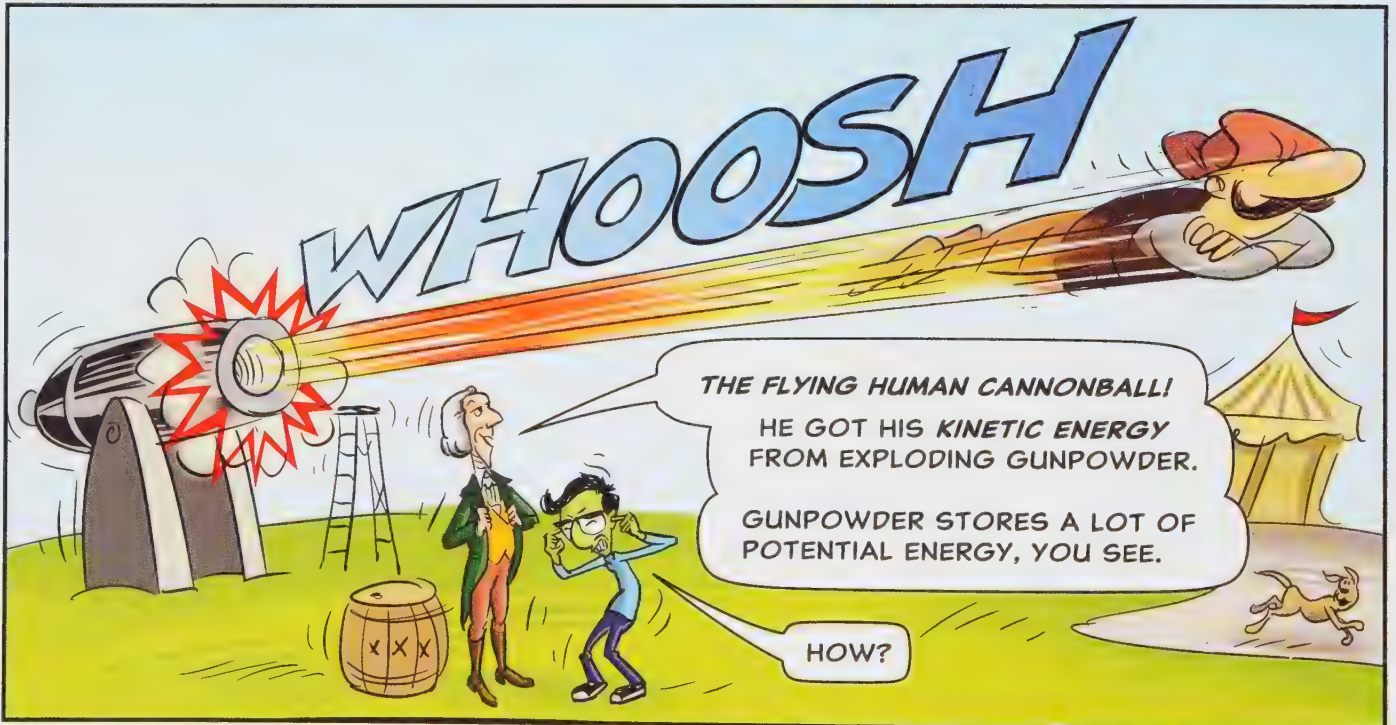
SPEED = 40 METERS PER SECOND

$$\frac{1}{2} \times 1 \text{ KG} \times (40 \text{ M/S} \times 40 \text{ M/S}) = 800 \text{ J}$$











HELP YOURSELF TO A CANDY BAR, MAX.



WHAT ARE THESE "CALORIES"?



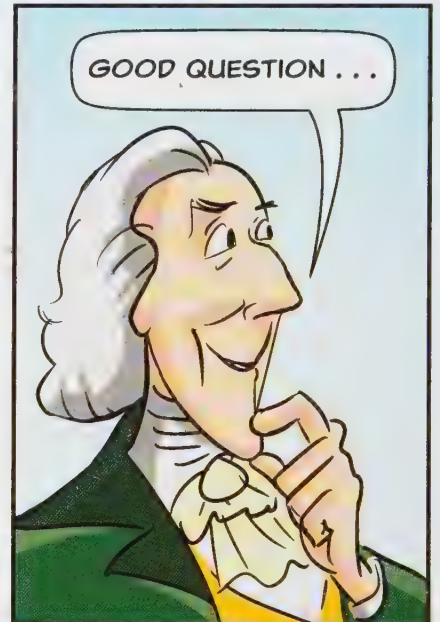
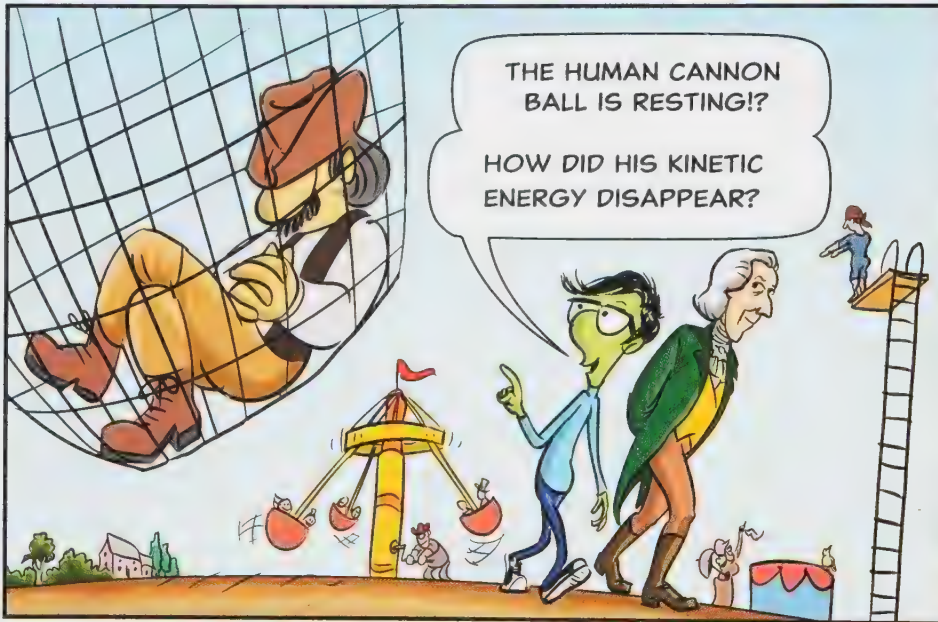
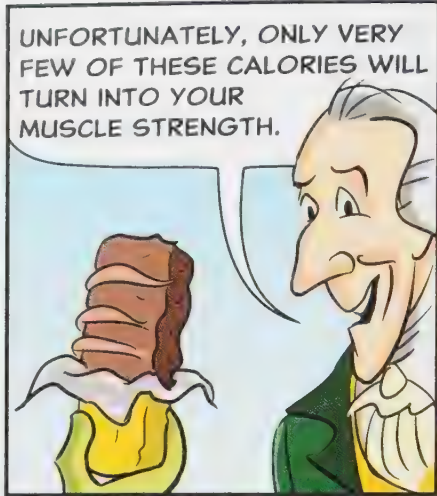
500 FOOD CALORIES ARE ABOUT 2 MILLION JOULES. THAT CANDY BAR STORES CHEMICAL ENERGY, WHICH CAN LIFT ONE TON OF STONE ABOUT 213 METERS IN THE AIR . . .

PRETTY IMPRESSIVE, HUH?



1TON
213 METERS

JUPITER BAR
500 CALORIES



WITH THE CART, WE WEIGH ABOUT 200 KILOGRAMS AND WE'RE 20 METERS HIGH,

SO WE HAVE 40,000 JOULES OF POTENTIAL ENERGY.

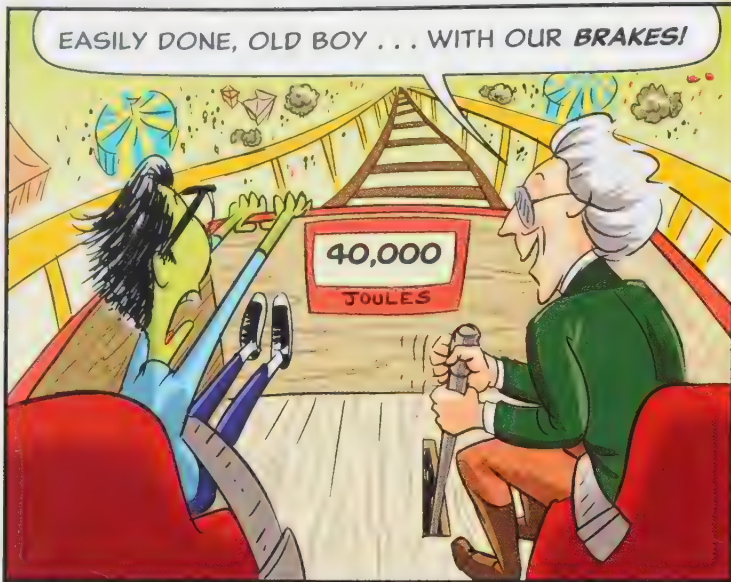


LET'S ROCK AND ROLL!!



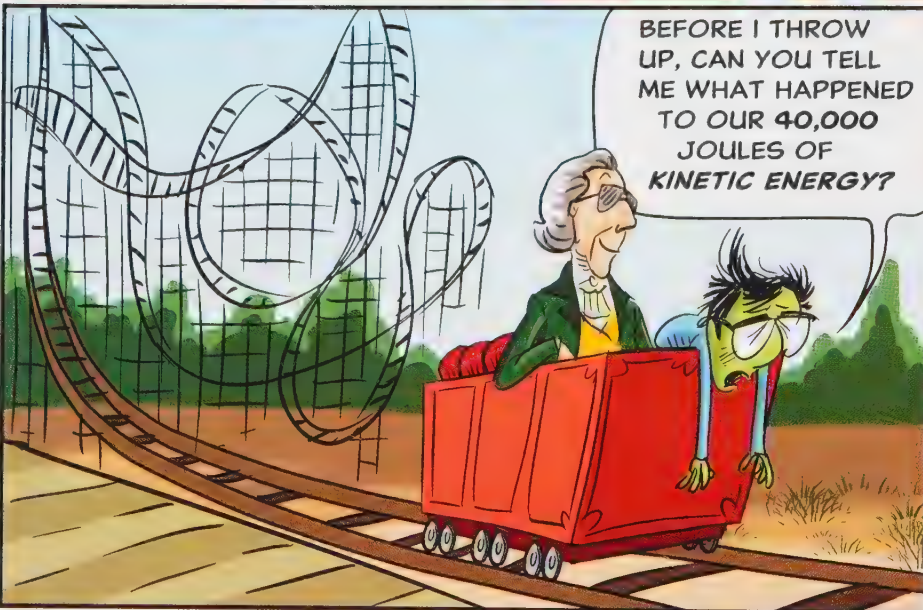
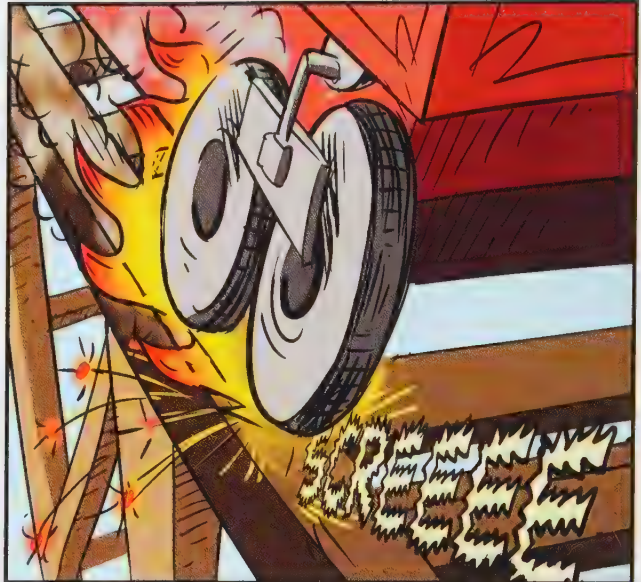
ARGGHH!!
WE'RE GOING TO DIE!
STOP IT! . . .
STOP IT!



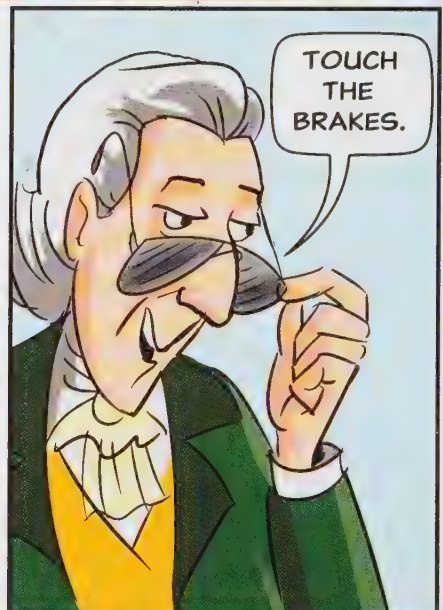


EASILY DONE, OLD BOY . . . WITH OUR BRAKES!

40,000
JOULES



BEFORE I THROW UP, CAN YOU TELL ME WHAT HAPPENED TO OUR 40,000 JOULES OF KINETIC ENERGY?



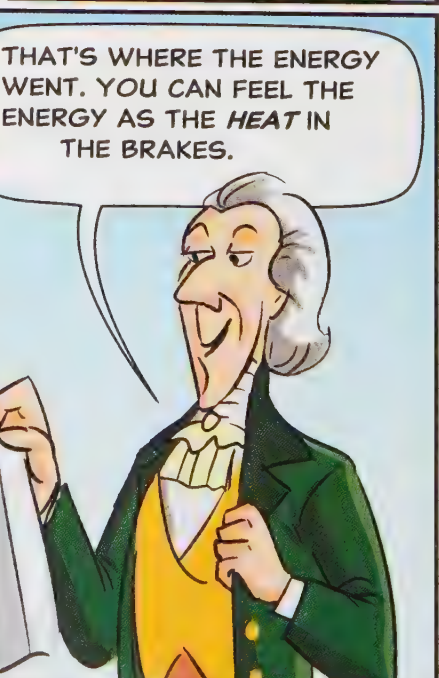
TOUCH THE BRAKES.



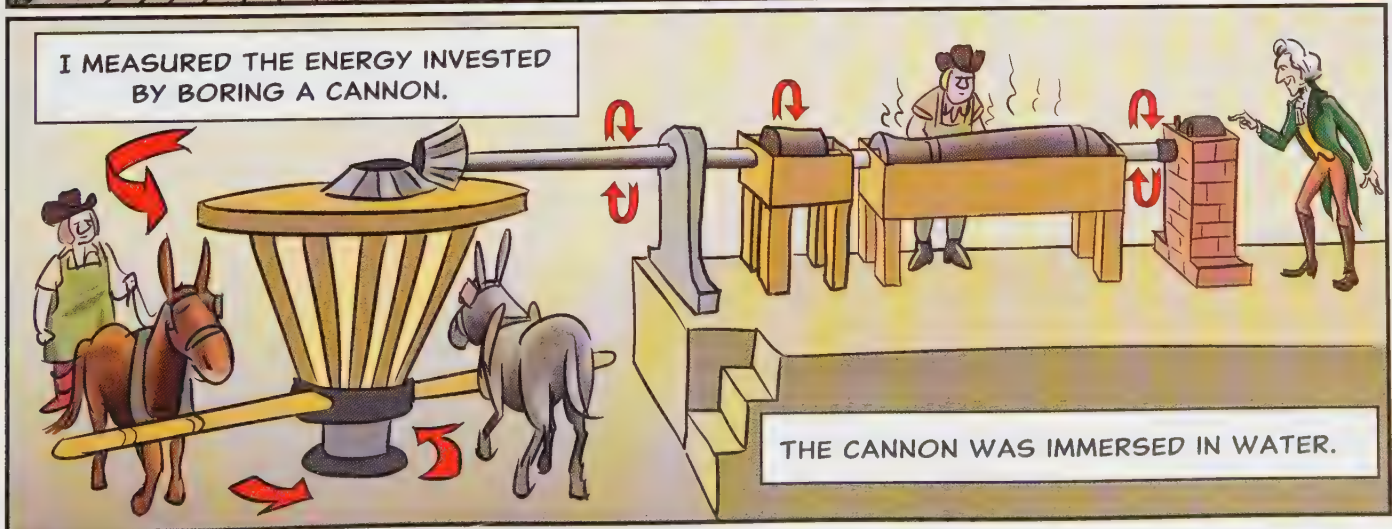
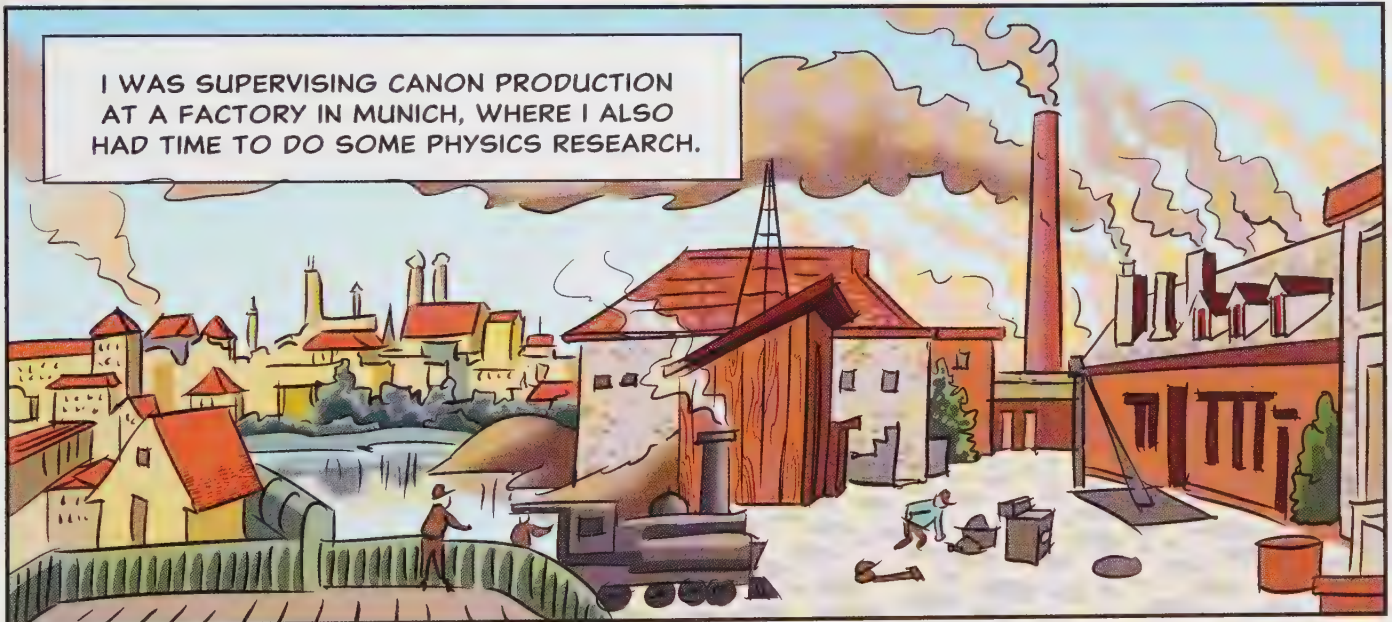
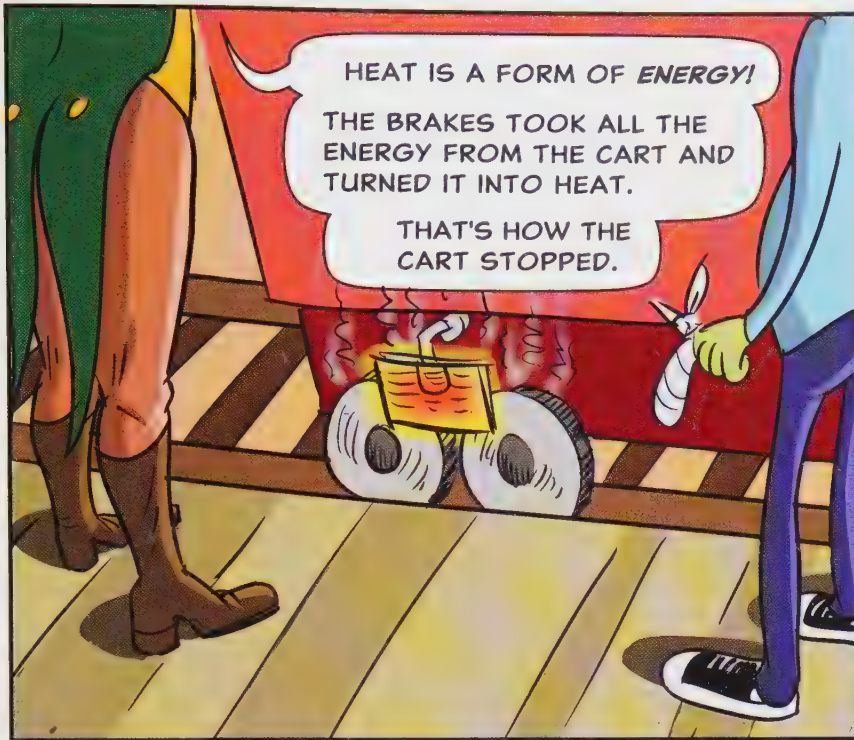
YEOW!!



IT'S HOT. I BURNT MY FINGER. WHY DID YOU MAKE ME DO THAT?

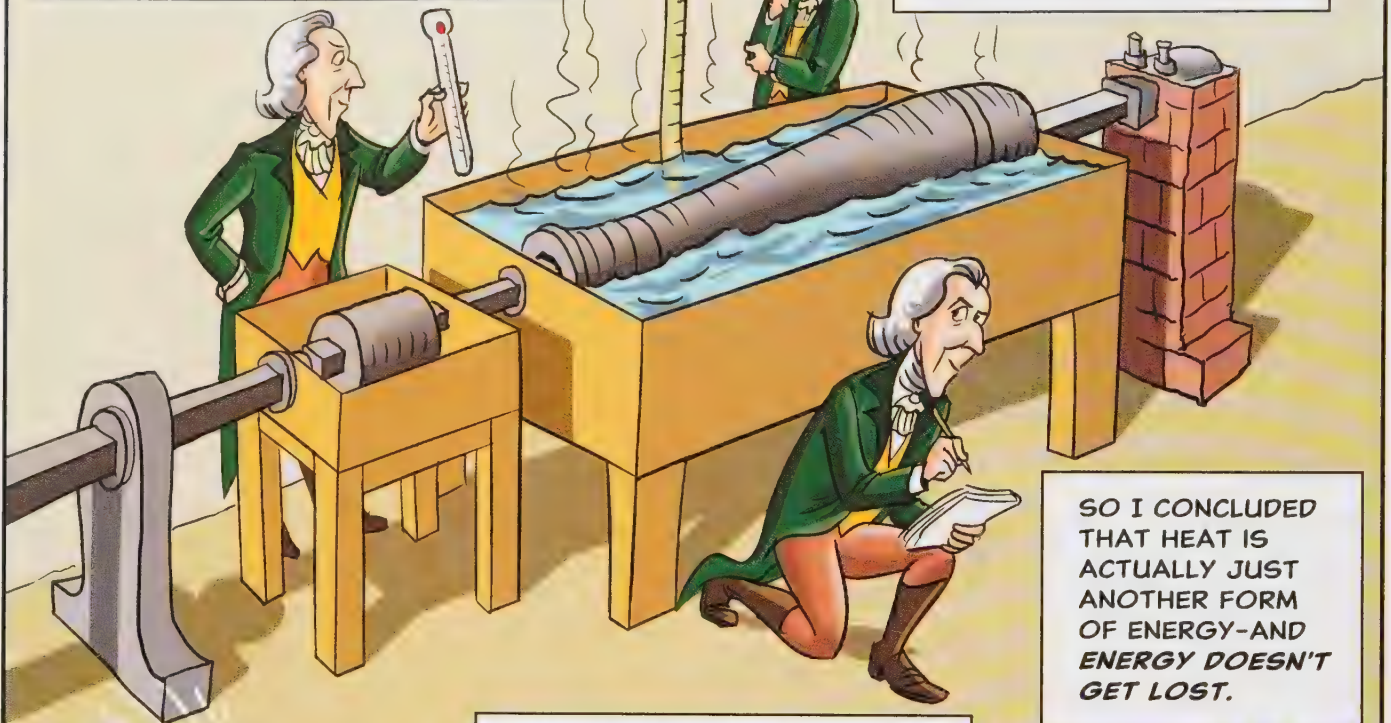


THAT'S WHERE THE ENERGY WENT. YOU CAN FEEL THE ENERGY AS THE HEAT IN THE BRAKES.



I CAREFULLY MEASURED HOW MUCH WATER BOILED OFF DUE TO THE HEAT THAT WAS GENERATED BY BORING.

I DISCOVERED THAT THE AMOUNT OF EVAPORATED WATER WAS *PROPORTIONAL* TO THE ENERGY INVESTED IN THE BORING PROCESS.

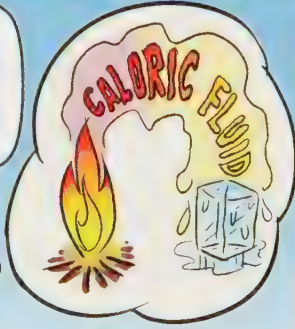


SO I CONCLUDED THAT HEAT IS ACTUALLY JUST ANOTHER FORM OF ENERGY-AND ENERGY DOESN'T GET LOST.

LATER THIS BECAME KNOWN AS

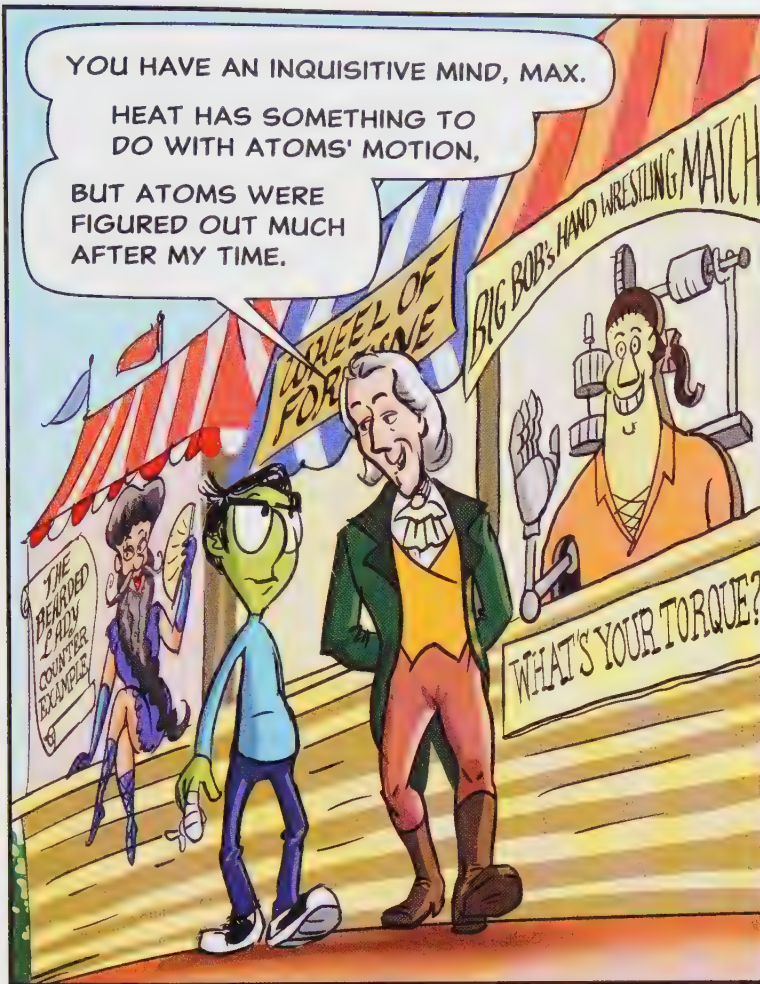
THE FIRST LAW OF THERMODYNAMICS:
ENERGY IS CONSERVED

IN MY DAY, SCIENTISTS BELIEVED IN A SILLY IDEA THAT HEAT IS A "CALORIC FLUID". MY EXPERIMENT BLEW THAT THEORY AWAY.



HOW DID THE BRAKES HEAT THE WHEELS OF OUR CART? AND ACTUALLY...

WHAT KIND OF ENERGY IS HEAT?



YOU HAVE AN INQUISITIVE MIND, MAX.

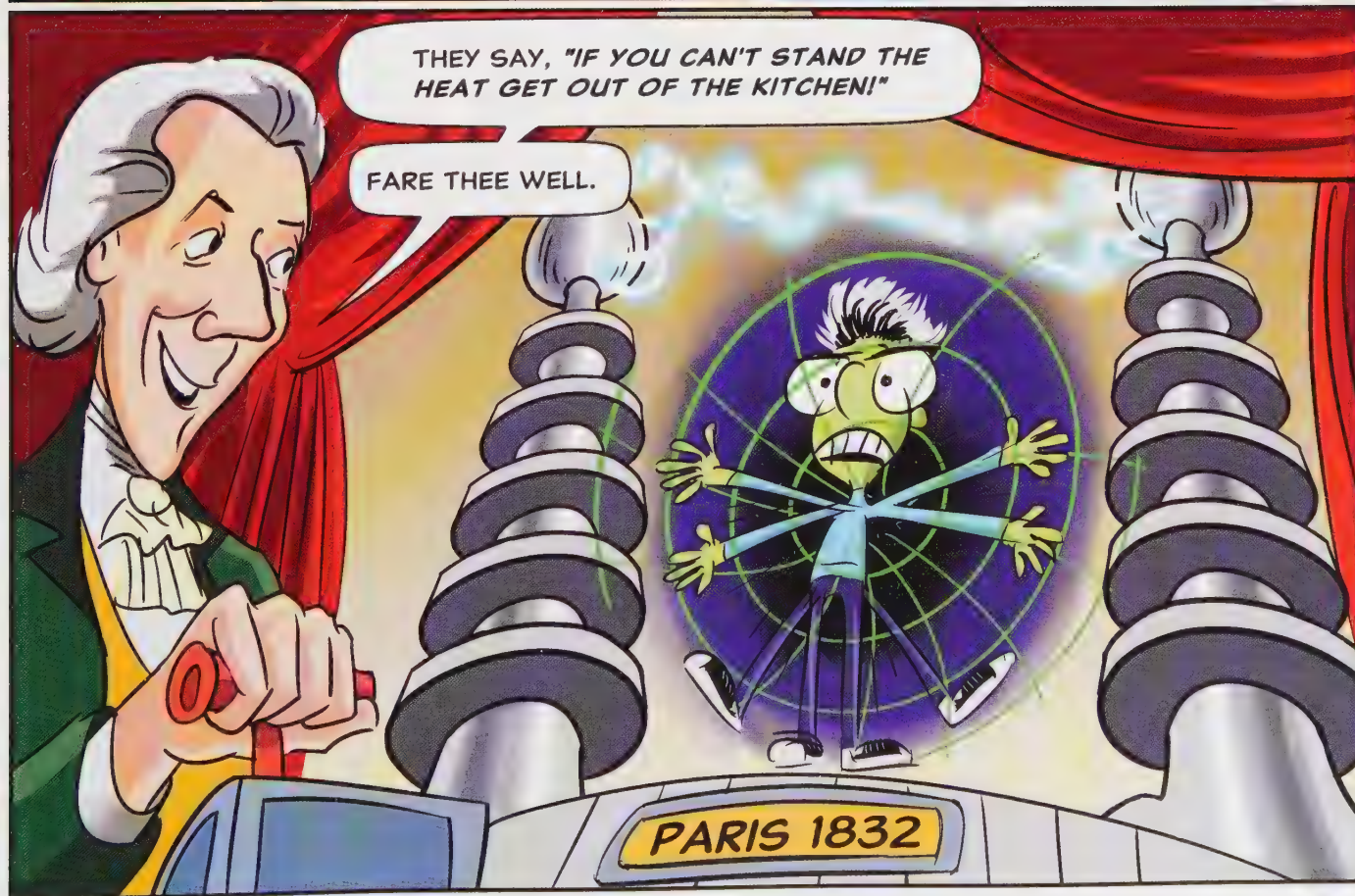
HEAT HAS SOMETHING TO DO WITH ATOMS' MOTION,

BUT ATOMS WERE FIGURED OUT MUCH AFTER MY TIME.



YOU'LL HAVE TO LEARN ABOUT HEAT FROM *SADI CARNOT*.

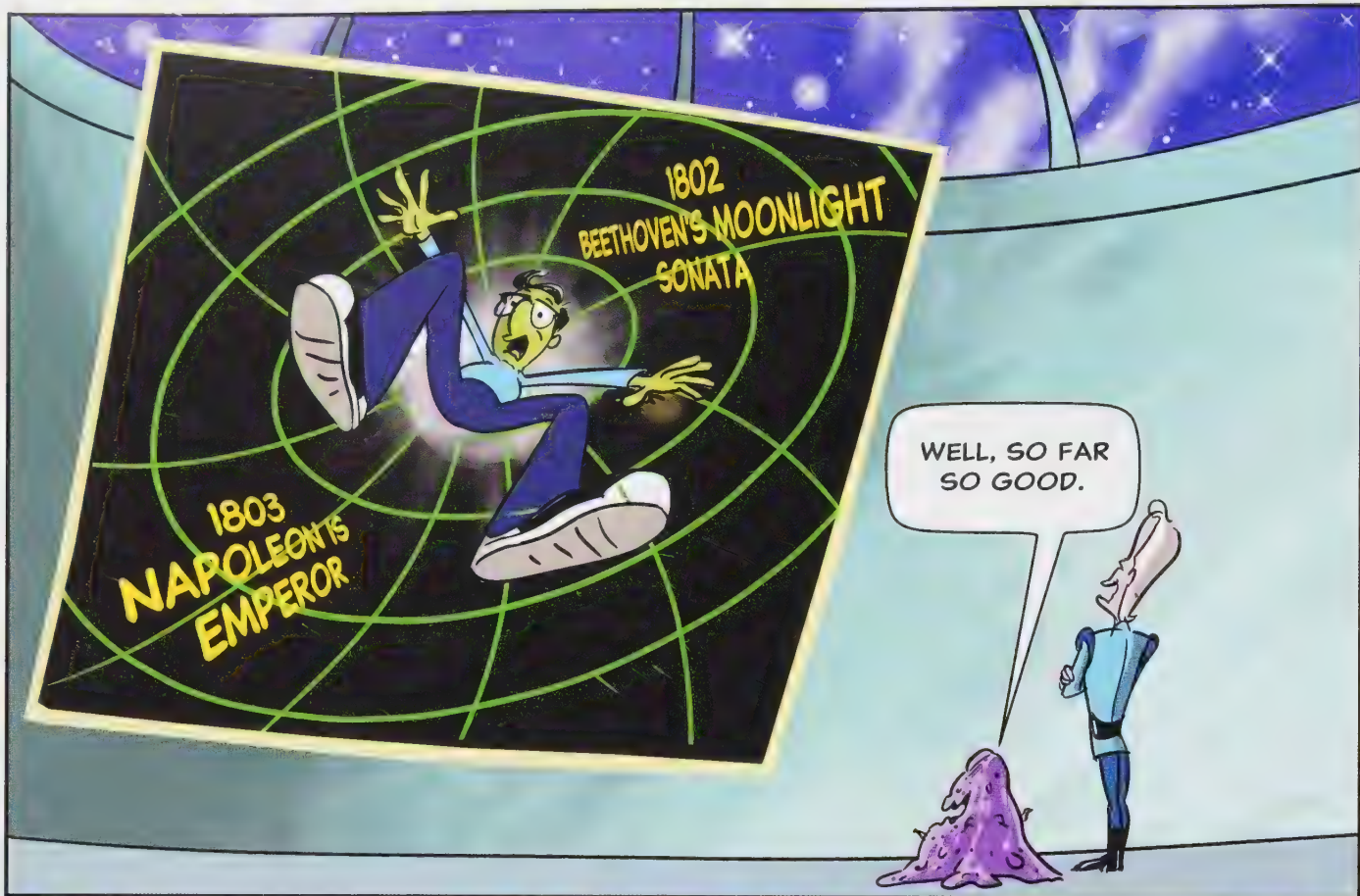
HE'LL BE WAITING FOR YOU IN PARIS - IN HIS KITCHEN, ACTUALLY.



THEY SAY, "IF YOU CAN'T STAND THE HEAT GET OUT OF THE KITCHEN!"

FARE THEE WELL.

PARIS 1832



1803
NAPOLEON'S
EMPEROR

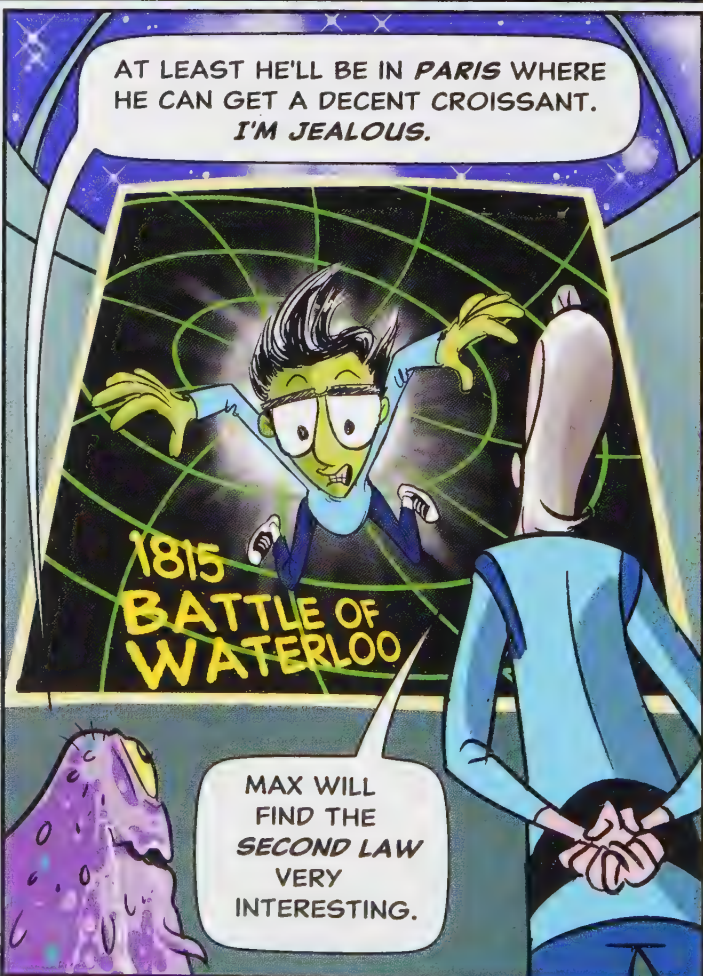
1802
BEETHOVEN'S MOONLIGHT
SONATA

WELL, SO FAR
SO GOOD.



ENERGY CONSERVATION AND
THE FIRST LAW WEREN'T TOO
HARD FOR MAX, I SUPPOSE.

LET'S SEE HOW
HE HANDLES THE
LESSON ON
HEAT.



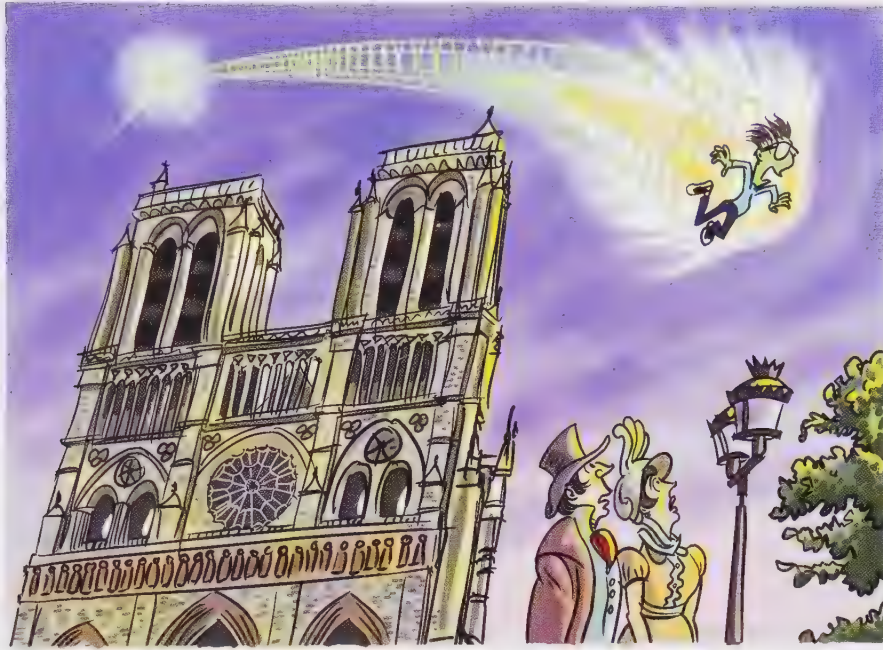
AT LEAST HE'LL BE IN *PARIS* WHERE
HE CAN GET A DECENT CROISSANT.
I'M JEALOUS.

1815
BATTLE OF
WATERLOO

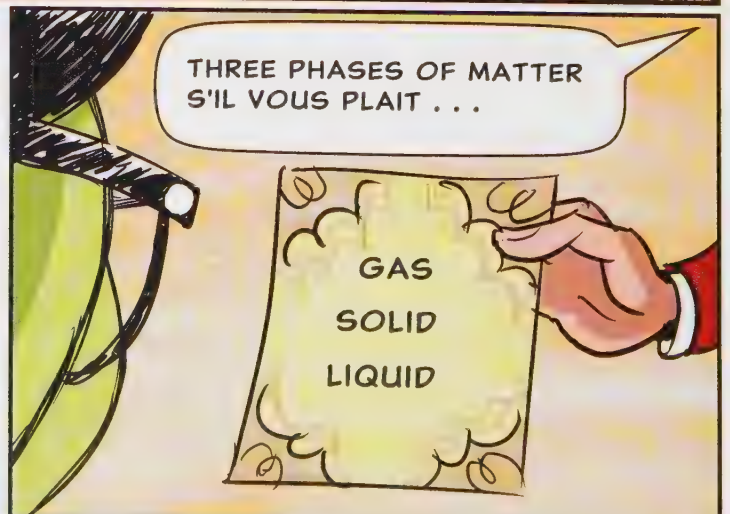
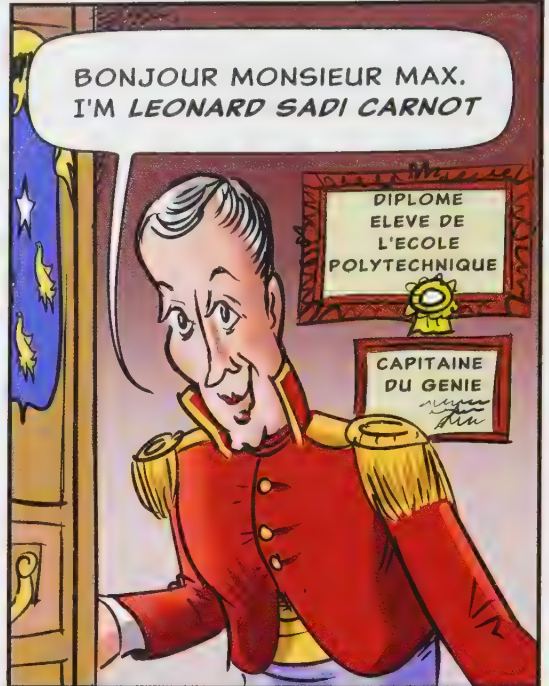
MAX WILL
FIND THE
SECOND LAW
VERY
INTERESTING.

CHAPTER III

PARIS, 1832

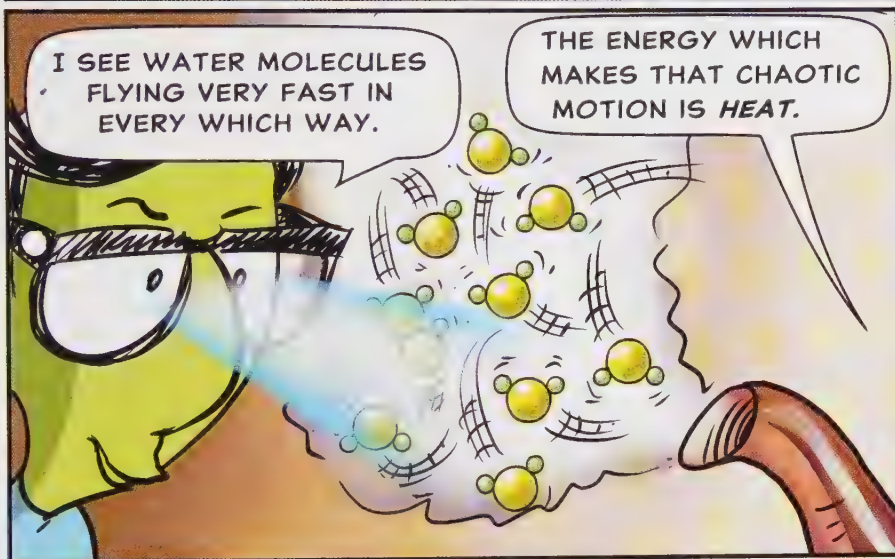


CARNOT'S KITCHEN





LET'S START WITH THE *GAS*.
IT'S HOT. LOOK AT THE VAPOR
WITH YOUR AMAZING GLASSES.

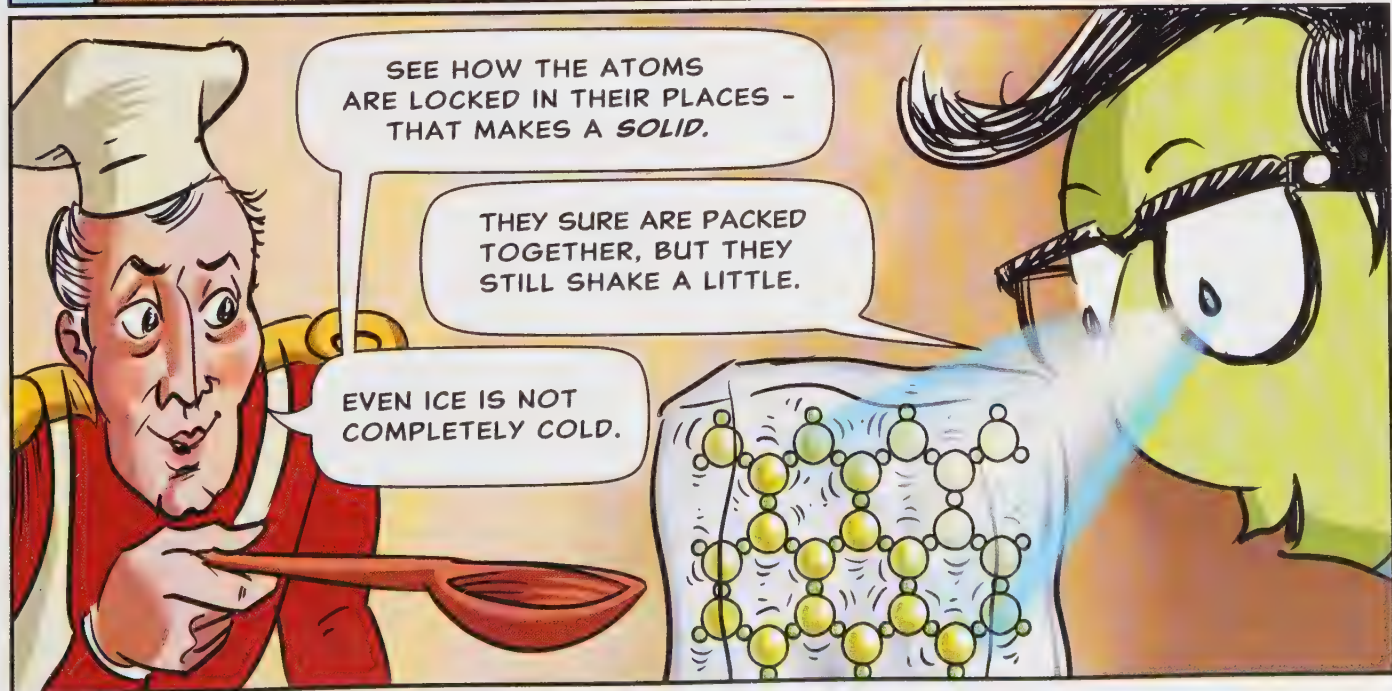


I SEE WATER MOLECULES
FLYING VERY FAST IN
EVERY WHICH WAY.

THE ENERGY WHICH
MAKES THAT CHAOTIC
MOTION IS *HEAT*.



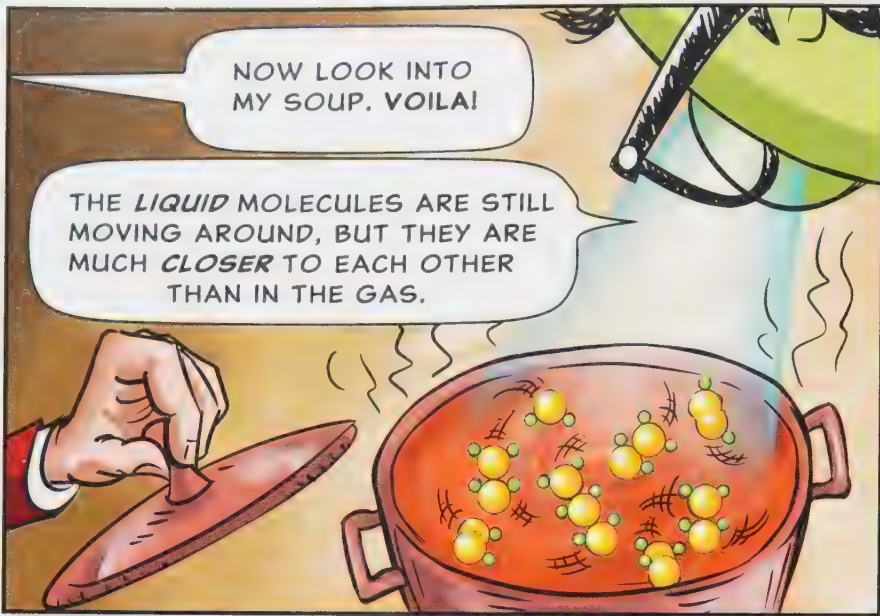
NOW, FOR
COMPARISON,
LOOK AT
THE COLD
ICE CUBE.



SEE HOW THE ATOMS
ARE LOCKED IN THEIR PLACES -
THAT MAKES A *SOLID*.

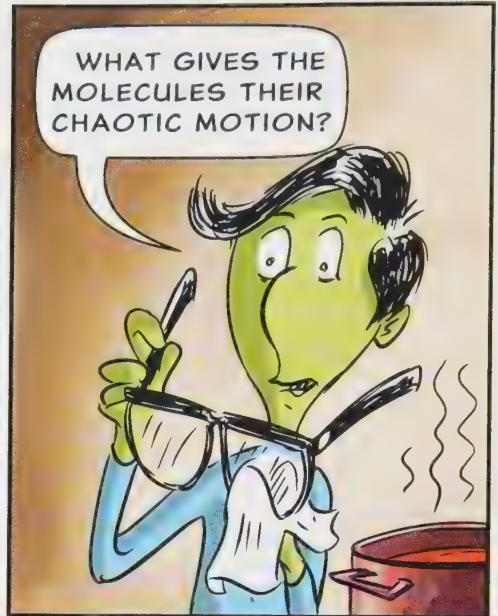
THEY SURE ARE PACKED
TOGETHER, BUT THEY
STILL SHAKE A LITTLE.

EVEN ICE IS NOT
COMPLETELY COLD.



NOW LOOK INTO MY SOUP. VOILAI!

THE *LIQUID* MOLECULES ARE STILL MOVING AROUND, BUT THEY ARE MUCH *CLOSER* TO EACH OTHER THAN IN THE GAS.



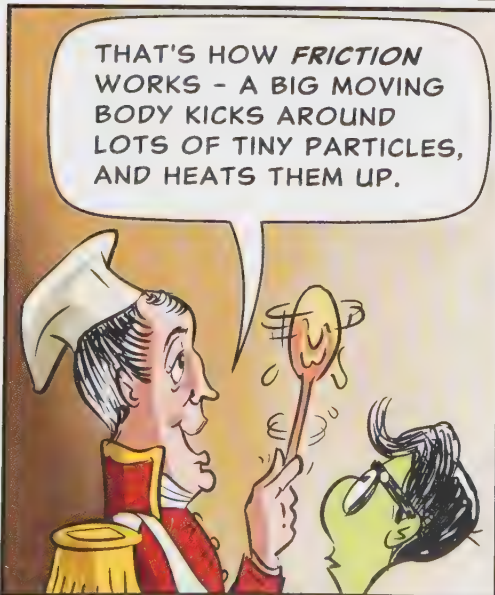
WHAT GIVES THE MOLECULES THEIR CHAOTIC MOTION?



REGARDEZ.
WATCH ME STIR THE BATTER!



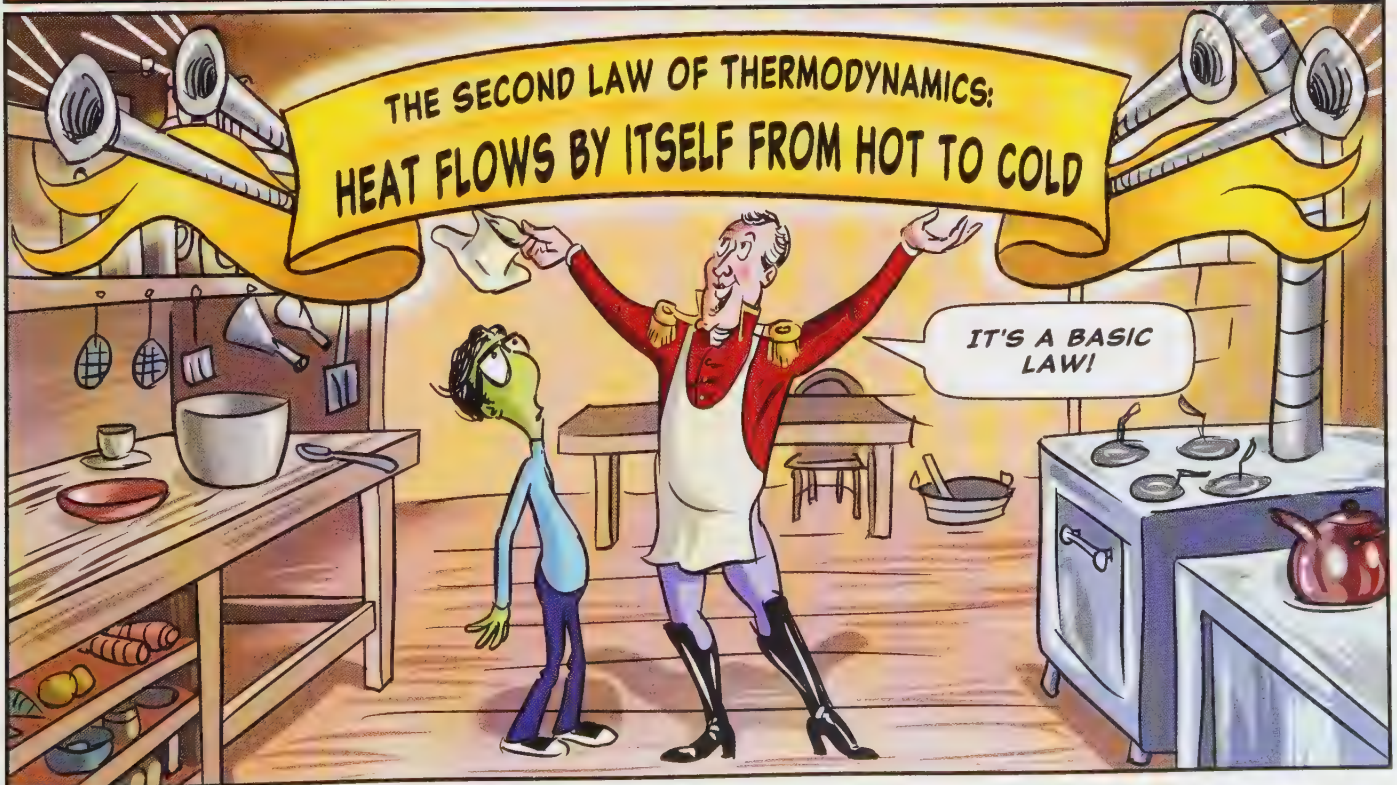
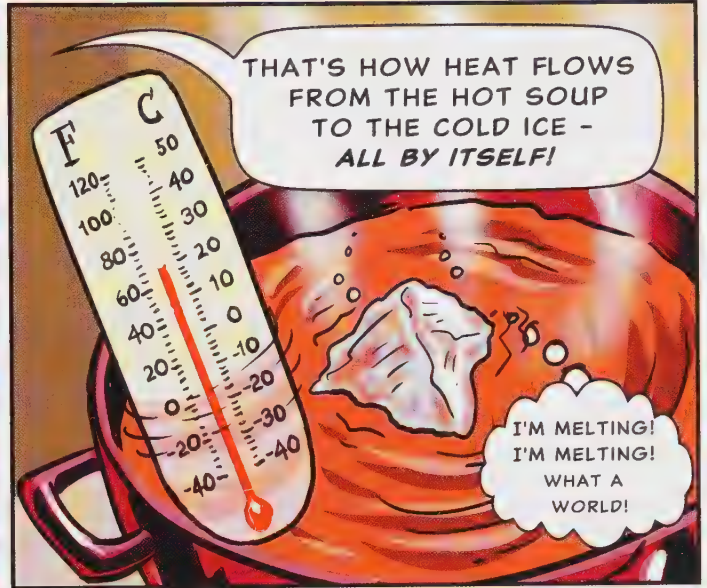
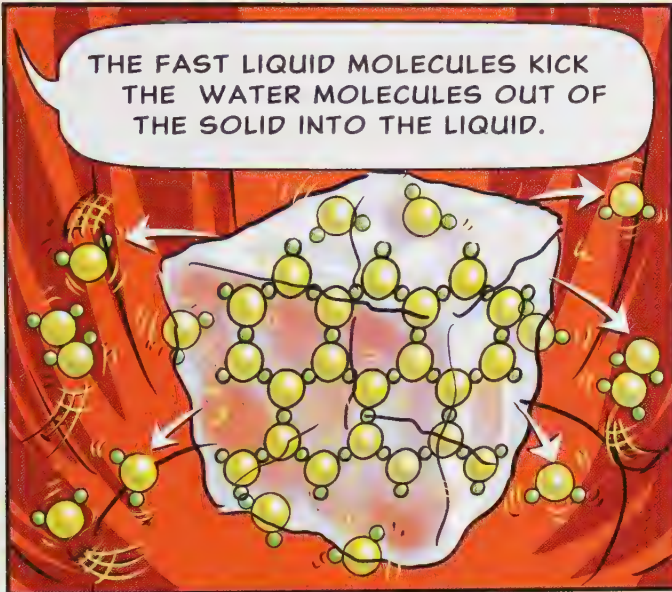
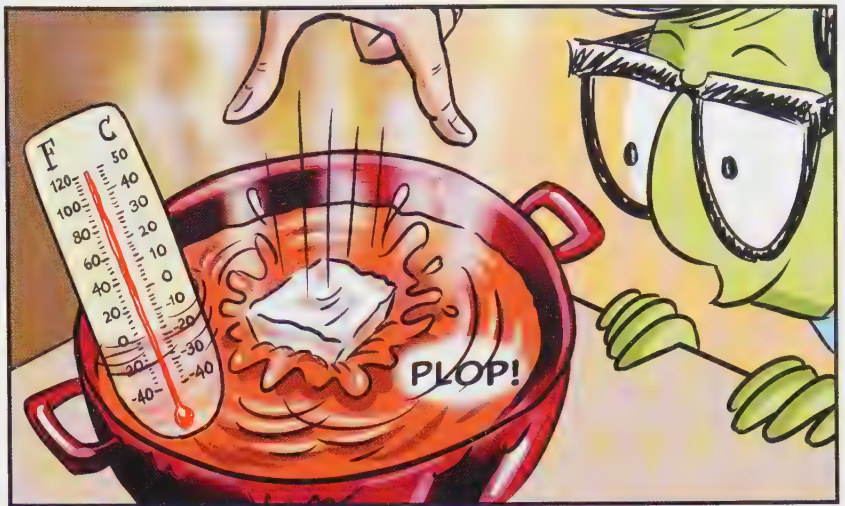
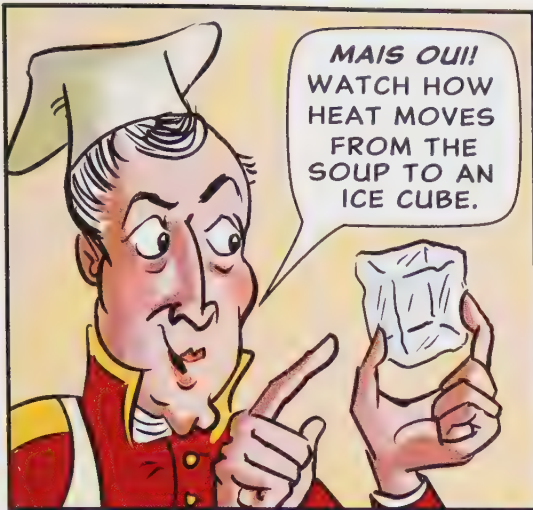
THE BATTER IS HEATED BY THE RAPID STIRRING OF MY SPOON.

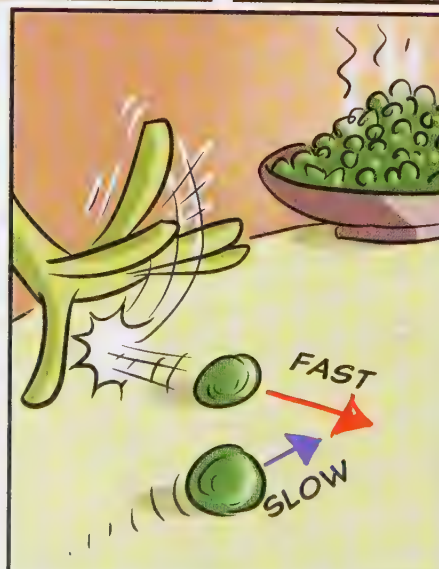
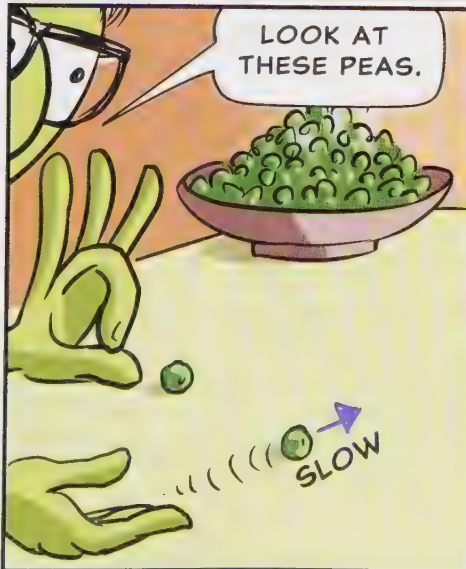
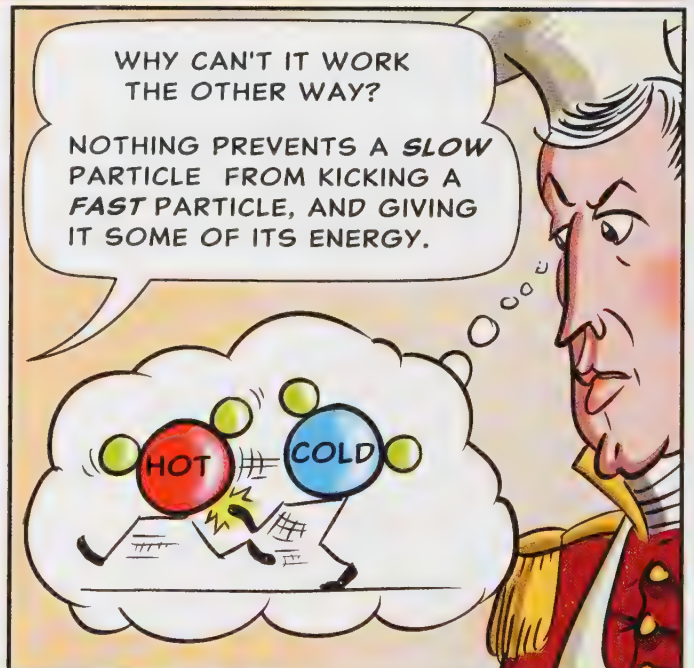
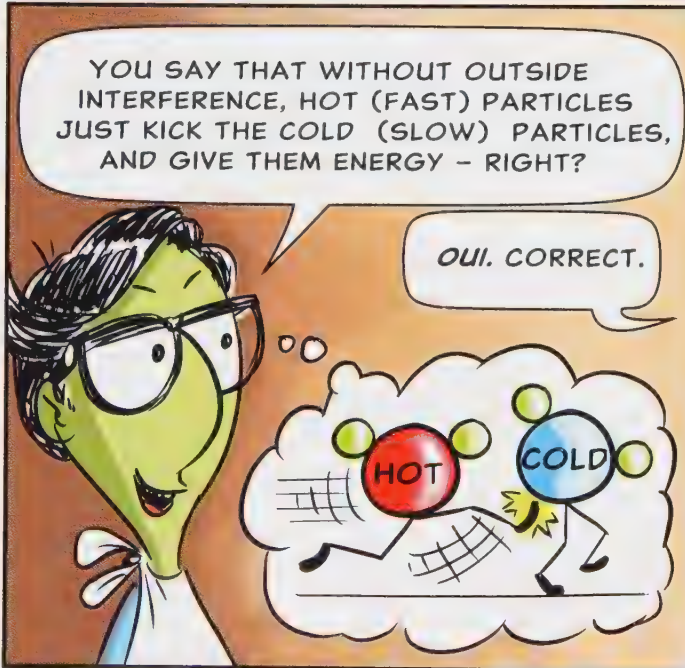
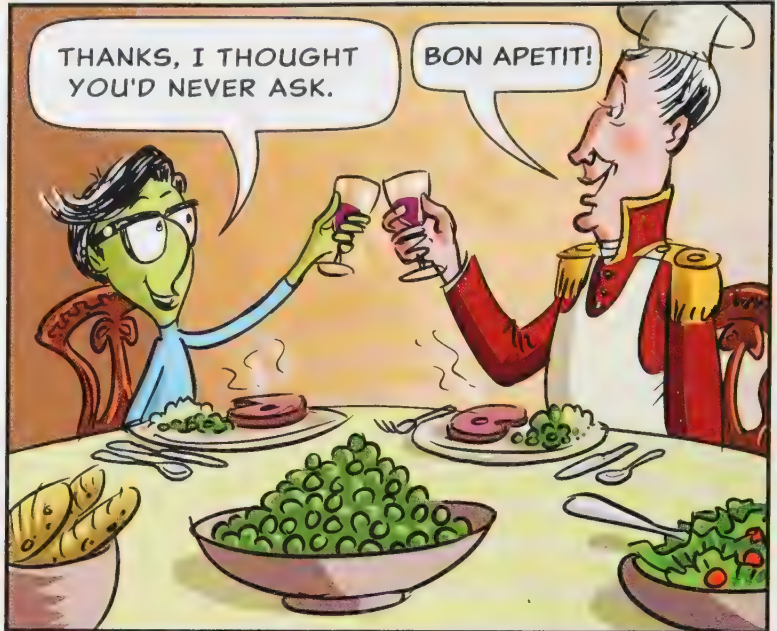


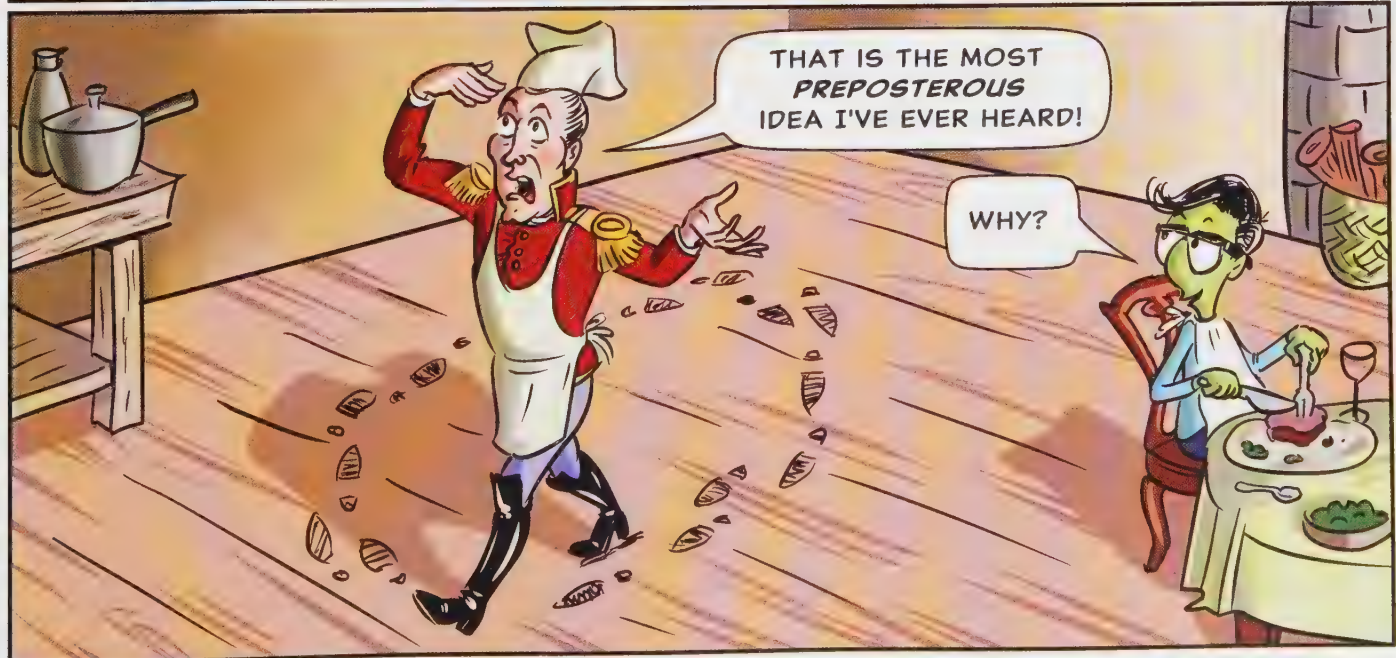
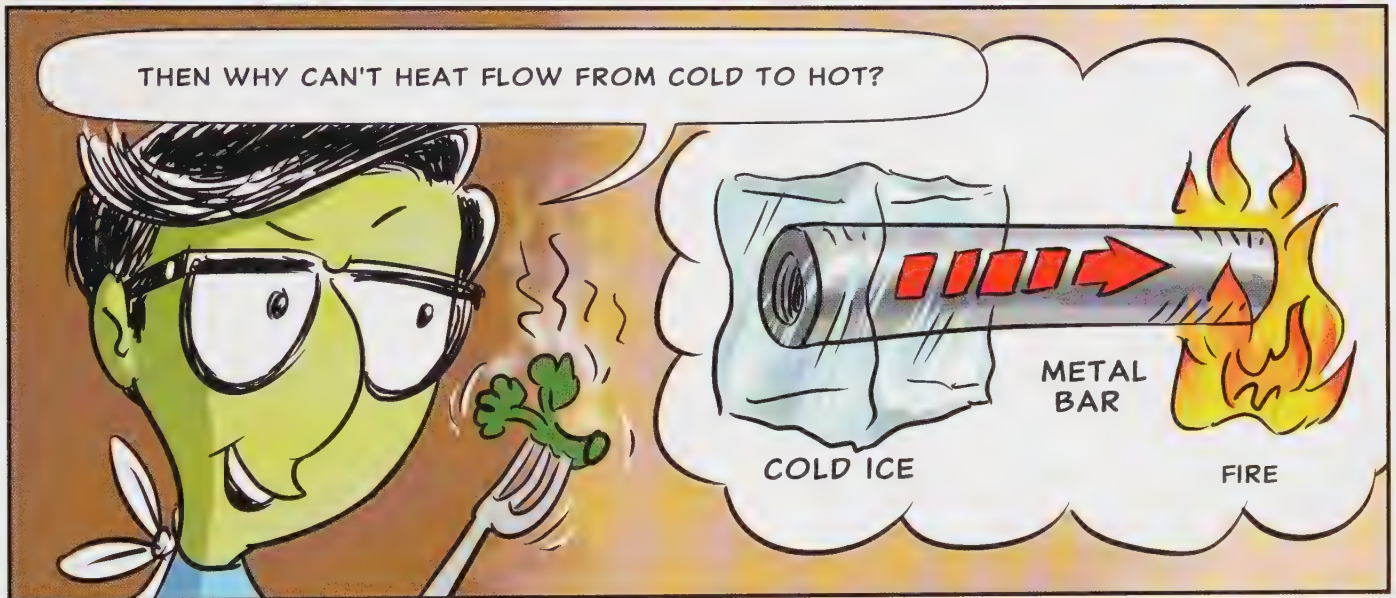
THAT'S HOW *FRICTION* WORKS - A BIG MOVING BODY KICKS AROUND LOTS OF TINY PARTICLES, AND HEATS THEM UP.



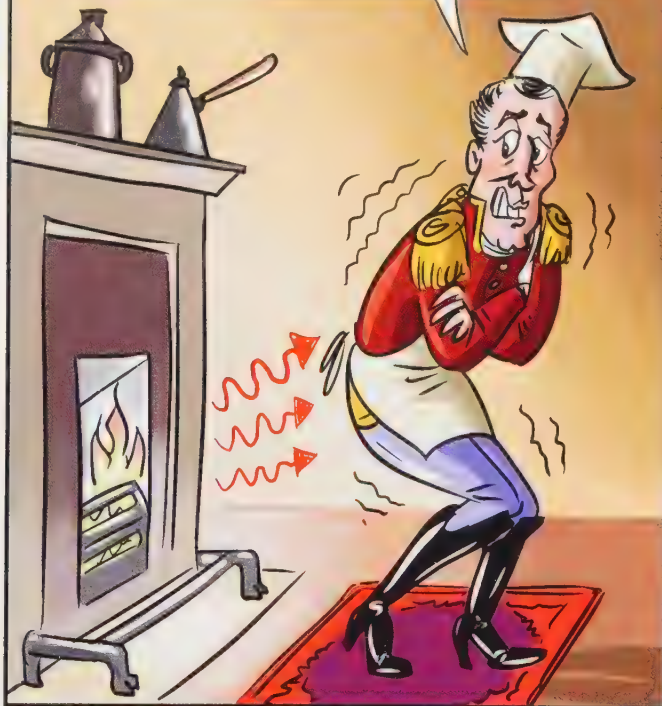
HOW DOES HEAT PASS FROM ONE BODY TO ANOTHER?



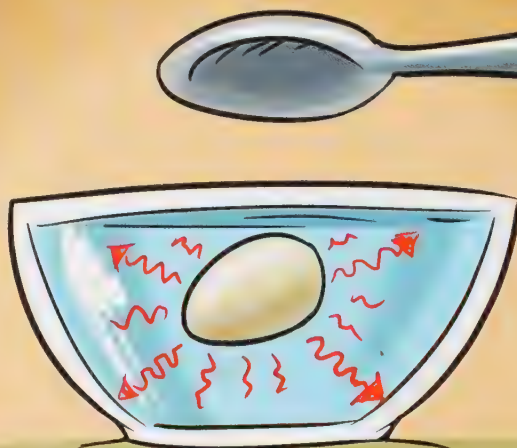




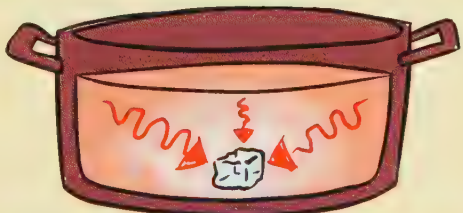
IF I FEEL COLD, I CAN WARM UP BY HEAT FROM THE FIREPLACE, RIGHT?



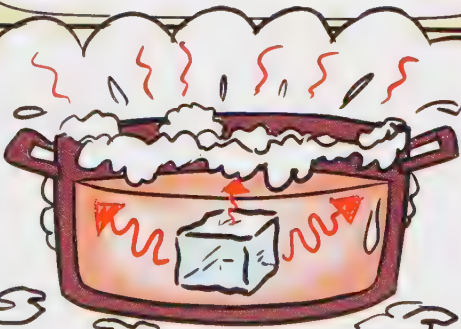
A HOT, HARD-BOILED EGG COOLS DOWN WHEN IT'S DROPPED INTO COLD WATER ...



AND THE WATER HEATS UP A LITTLE. N'EST-CE PAS ??



THE ICE CUBE IN THE SOUP ... YOU SAW THAT IT MELTED AND SHRANK AS THE SOUP COOLED DOWN RIGHT?



BUT IF HEAT WERE TO FLOW THE OTHER WAY, THE SOUP WOULD HEAT UP, THE ICE CUBE WOULD *GROW* INSTEAD OF SHRINK. CAN YOU IMAGINE THAT?

PREPOSTEROUS, I SAY!





I STILL DON'T GET IT. IF COLLISIONS CAN TRANSFER ENERGY FROM SLOW TO FAST PARTICLES, THEN WHY CAN'T HEAT *EVER* FLOW FROM COLD TO HOT SYSTEMS?

WELL . . . THAT'S A HARD QUESTION. I AM AFRAID I CANNOT *JUSTIFY* THE SECOND LAW.

BUT DON'T WORRY! YOUR NEXT APPOINTMENT IS WITH THE GREAT PROFESSOR *LUDWIG BOLTZMANN*. HE WILL ANSWER YOUR QUESTION I'M SURE.

I'VE TAUGHT YOU WHAT I KNOW.



WELL, THANKS!

ENCHANTE, MON AMI!

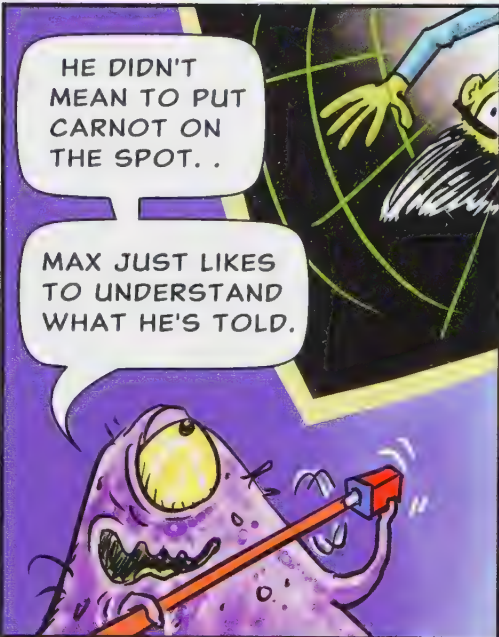
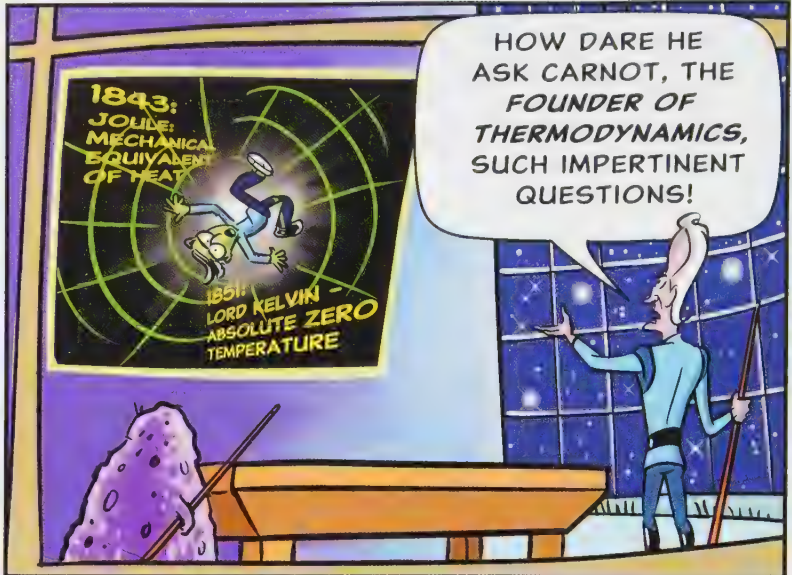
OH, NO. NOT ANOTHER TIME TRAVEL.



AU REVOIR!!

IF ONLY MY PEERS WERE AS CURIOUS AS MAX . . .

REFLECTIONS ON THE MOTIVE POWER OF FIRE BY SADI CARNOT

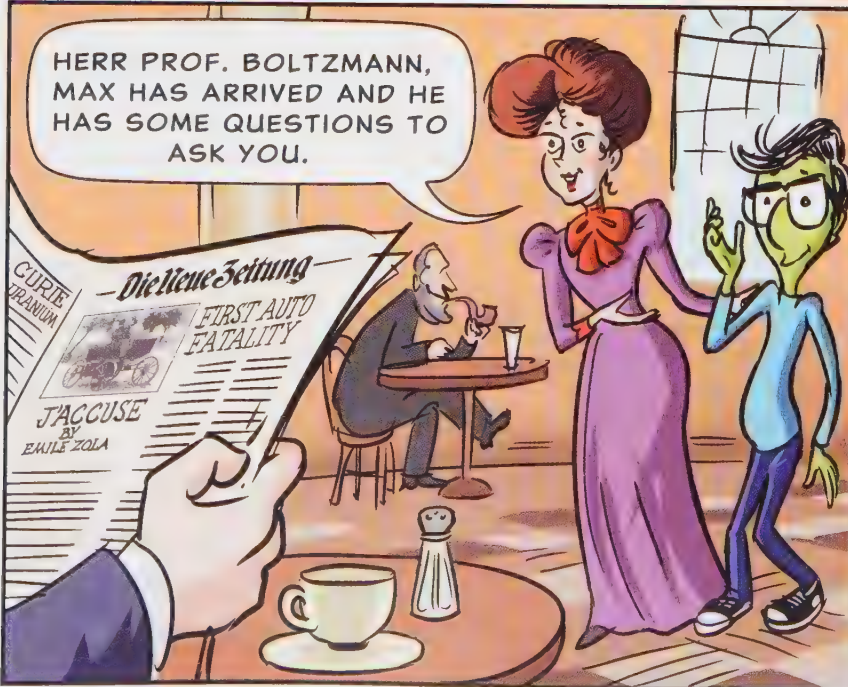
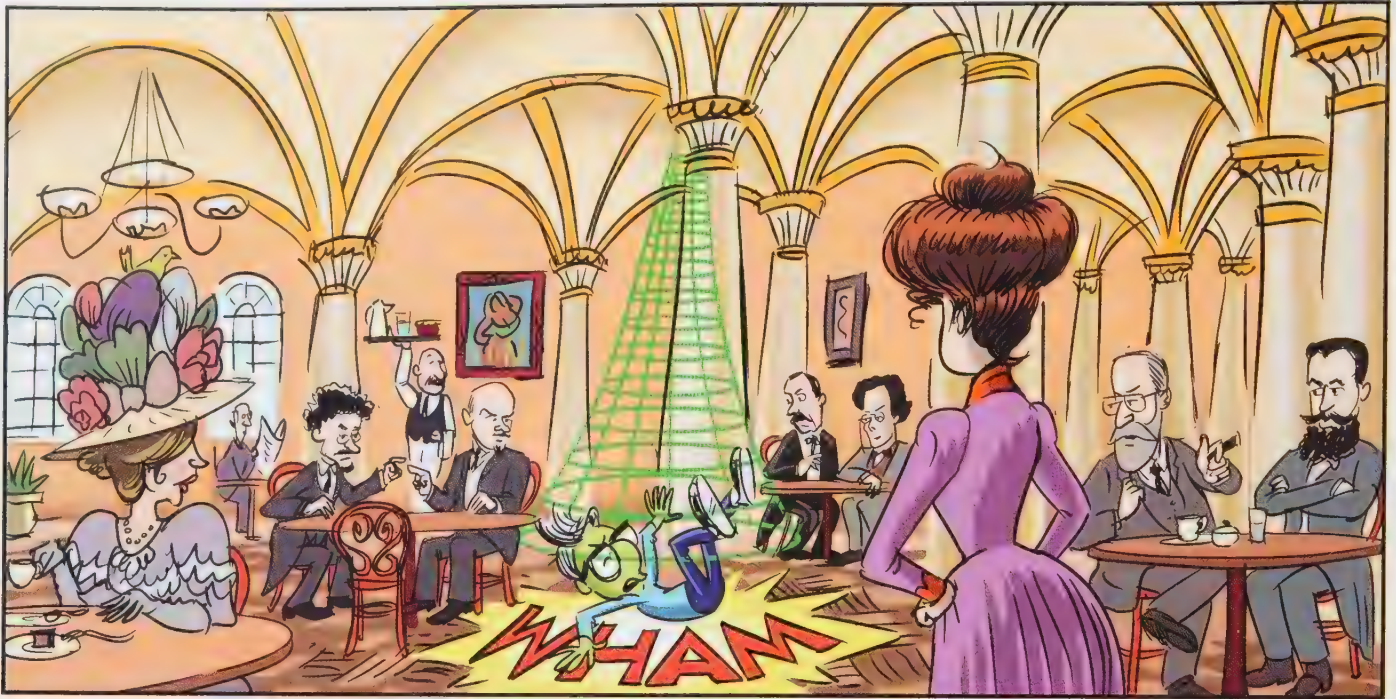


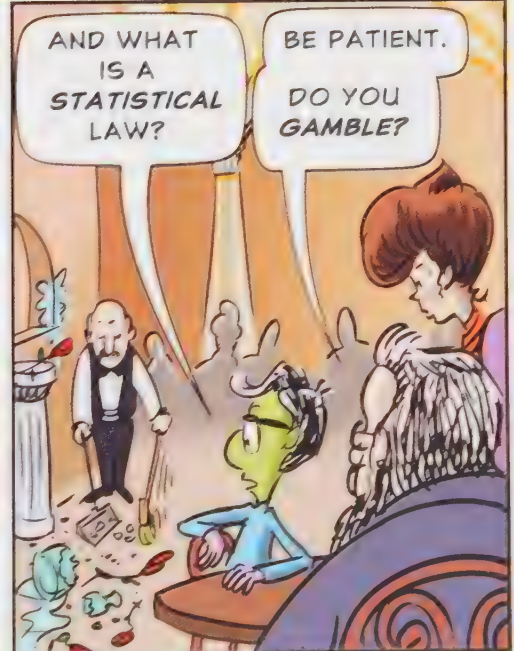
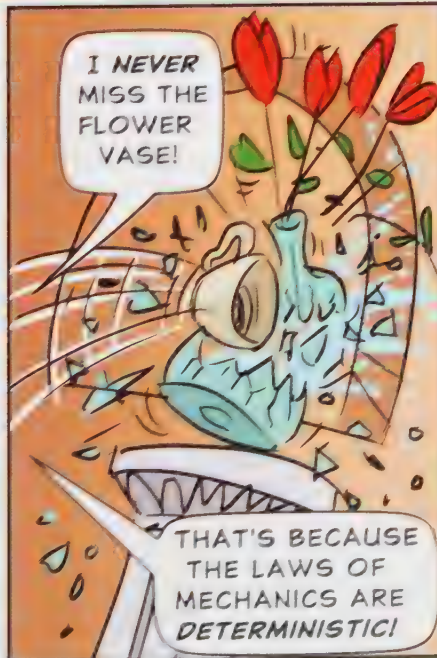
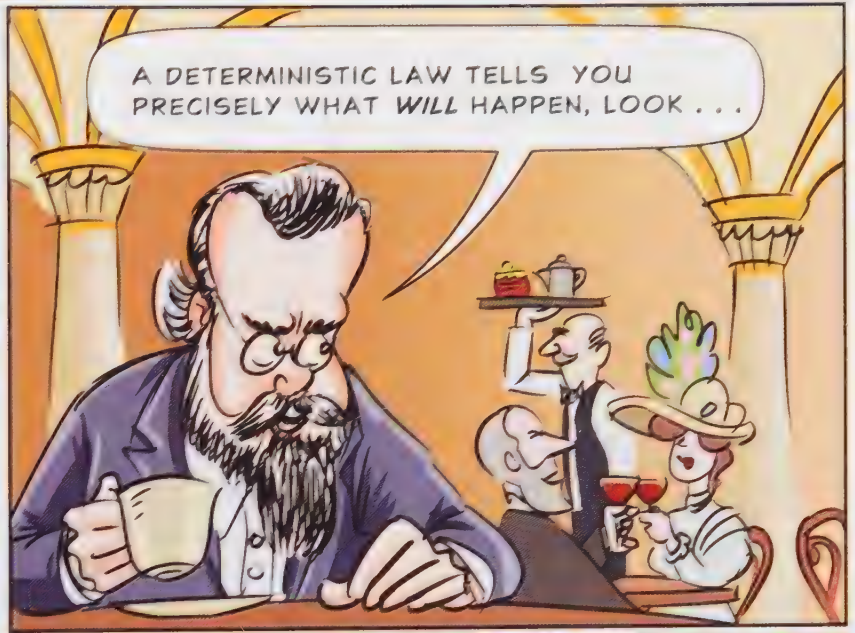
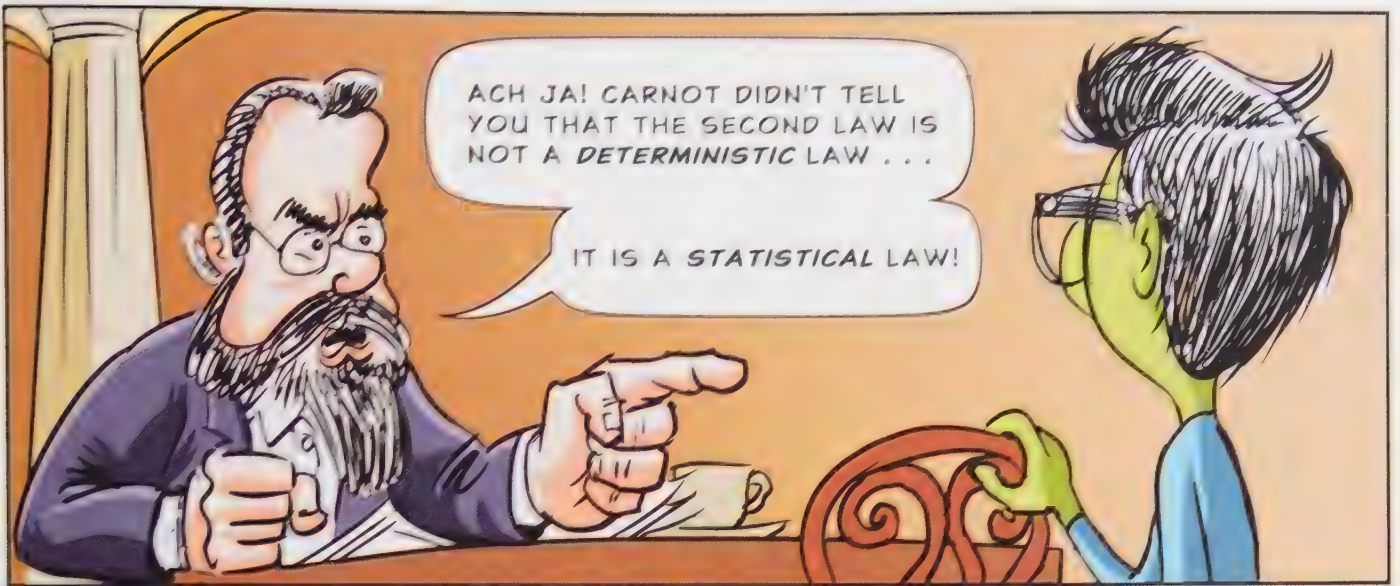
CHAPTER IV

1898, VIENNA



BOLTZMANN'S GAMES OF CHANCE





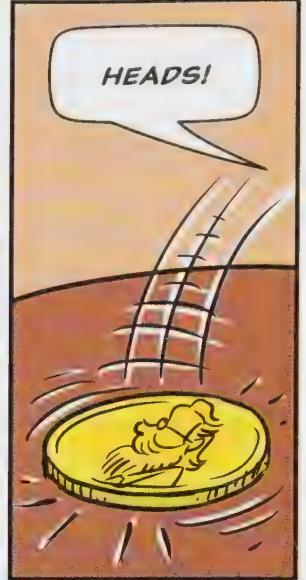


NO. I'M AFRAID TO TAKE RISKS.

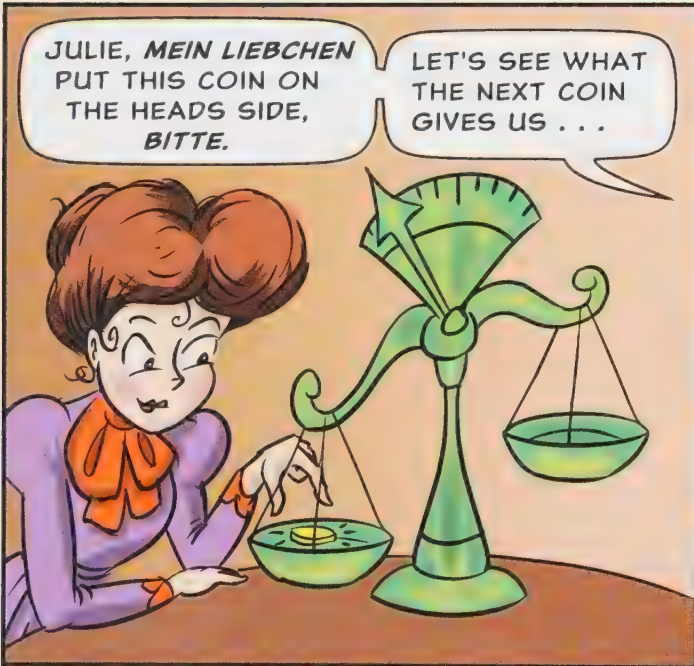


TOO BAD. WE HUMANS WHEN WE DON'T KNOW WHAT TO DO . . . WE GAMBLE.

HEADS OR TAILS?



HEADS!



JULIE, MEIN LIEBCHEN PUT THIS COIN ON THE HEADS SIDE, BITTE.

LET'S SEE WHAT THE NEXT COIN GIVES US . . .



HEADS AGAIN!

GAMBLING DOESN'T SEEM VERY SCIENTIFIC...

ACH NEIN, YOU ARE VERY WRONG, LETS KEEP PLAYING . . .



IT IS *VERY LIKELY* THAT EVENTUALLY THE SCALES WILL BECOME BALANCED.

IT'S A STATISTICAL LAW!

TAILS!



SO A STATISTICAL LAW IS WHAT IS *LIKELY* TO HAPPEN, BUT *NOT* WHAT IS *CERTAIN* TO HAPPEN.

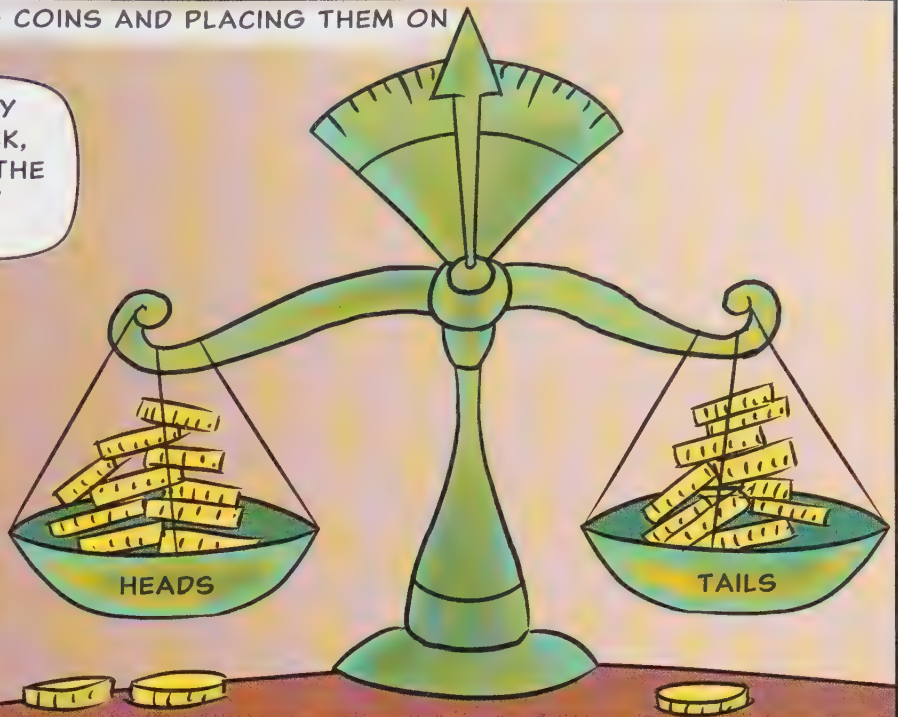
AFTER 15 MINUTES OF TOSsing COINS AND PLACING THEM ON THE SCALES . . .

LOOK AT THE SCALES! EVERY COIN TOSsing WAS SHEER LUCK, BUT AFTER *MANY* TOSSES, THE SCALES ARE PRACTICALLY *BALANCED!*

IT'S THE "*LAW OF LARGE NUMBERS*".

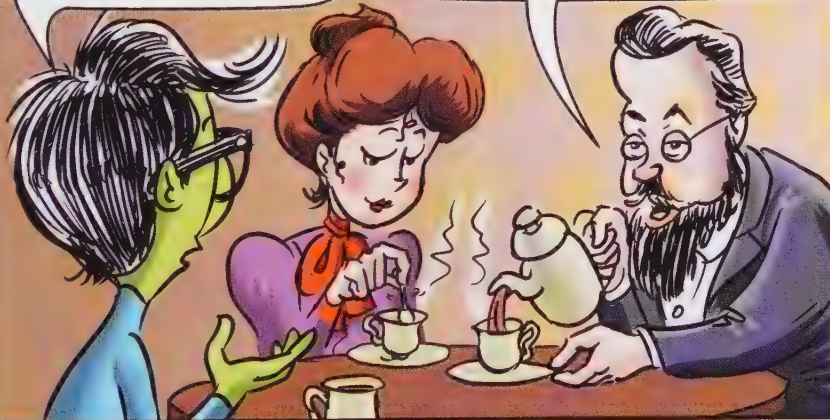
UNCERTAINTY TURNS INTO *CERTAINTY*.

QUITE MAGICAL! JA!

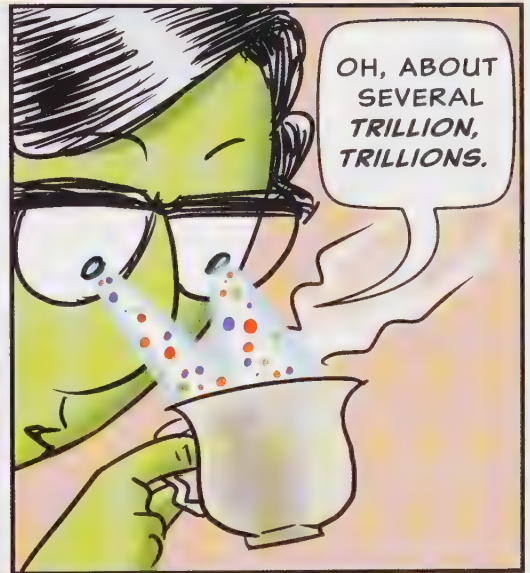


WHY ARE YOU TELLING ME ABOUT "LARGE NUMBERS"?

HOW MANY MOLECULES DO YOU SEE IN YOUR COFFEE?



OH, ABOUT SEVERAL *TRILLION, TRILLIONS*.



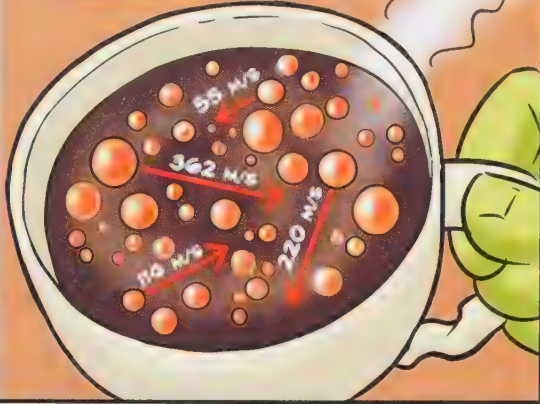
WONDERFUL! YOU CAN ACTUALLY SEE THE *MICROSTATE* OF THE COFFEE!



WHAT'S A *MICROSTATE*?



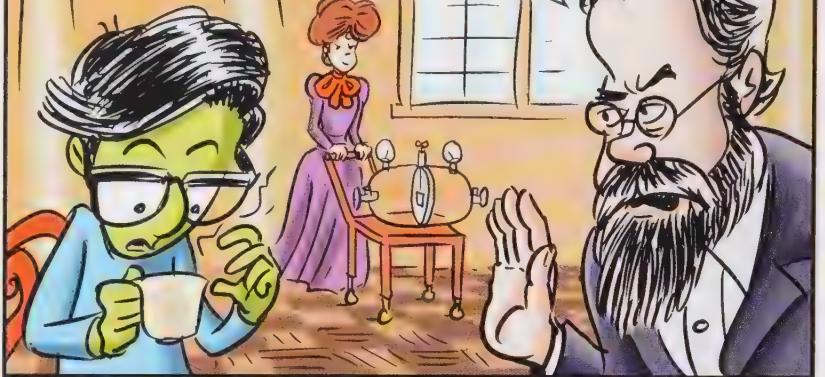
THE MICROSTATE DESCRIBES ALL THE ATOMS IN THE SYSTEM: THEIR *LOCATIONS*, *SPEED*, AND *DIRECTIONS*.



THE MICROSTATE KEEPS *CHANGING!*

YES, THAT'S WHY HUMANS NEVER KNOW THE EXACT MICROSTATE, BUT WE DON'T REALLY CARE!

IT'S *TOO MUCH* INFORMATION.



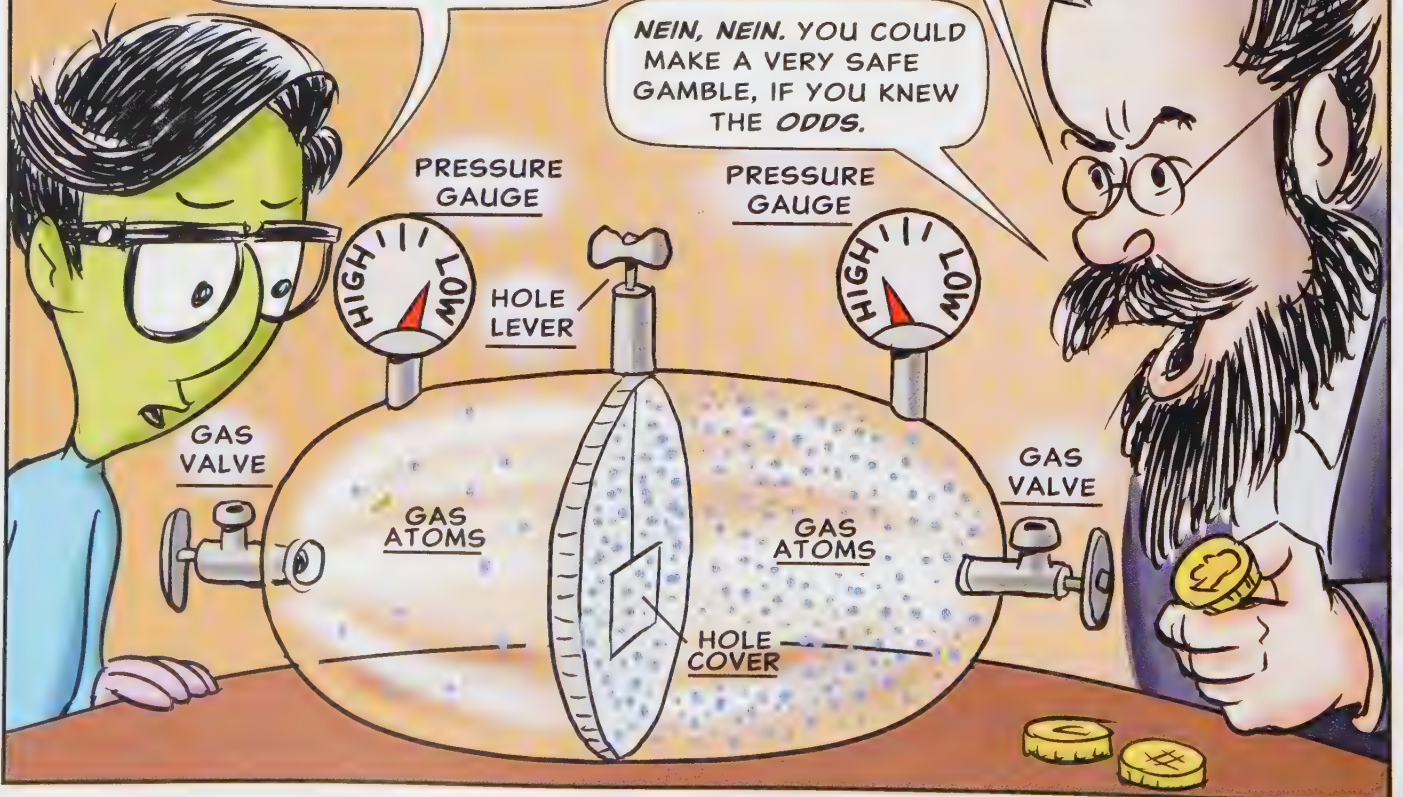
WE CARE, FOR EXAMPLE, ABOUT *PRESSURE*.

JULIE JUST BROUGHT THIS GAS TANK, WHICH HAS TWO EQUAL SIZE CHAMBERS. THE RIGHT CHAMBER HAS MORE ATOMS, SO IT HAS *HIGHER PRESSURE* THAN THE LEFT CHAMBER.

HOW WILL THE *PRESSURES* CHANGE IF WE OPEN A HOLE BETWEEN THE CHAMBERS?

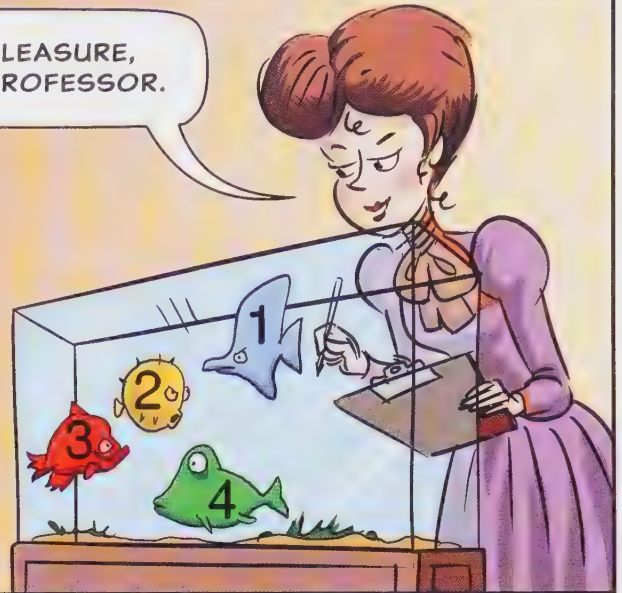
I CAN'T ANSWER WITHOUT FIRST SEEING WHERE ALL THE ATOMS ARE MOVING.

NEIN, NEIN. YOU COULD MAKE A VERY SAFE GAMBLE, IF YOU KNEW THE *ODDS*.



JULIE, WILL YOU SHOW
MAX HOW TO CALCULATE
THE ODDS, USING A ...
FISH AQUARIUM?

WITH PLEASURE,
HERR PROFESSOR.



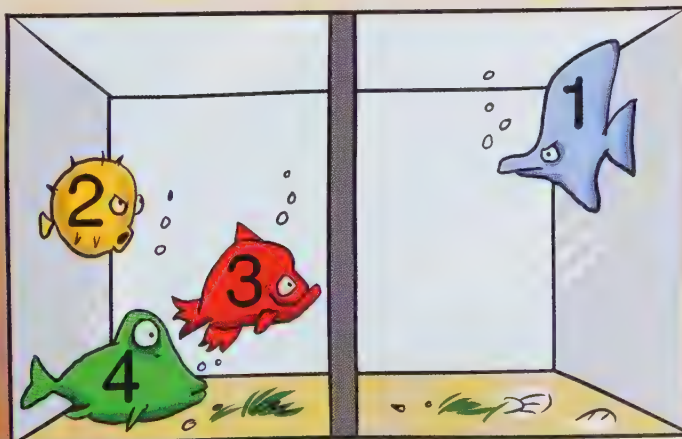
THESE FISH ARE SWIMMING AIMLESSLY,
LIKE THE ATOMS IN THAT GAS TANK.



WITHOUT LOOKING, I SUDDENLY INSERT
A DIVIDER IN THE CENTER, AND THE FISH
GET CAUGHT ON EITHER SIDE.

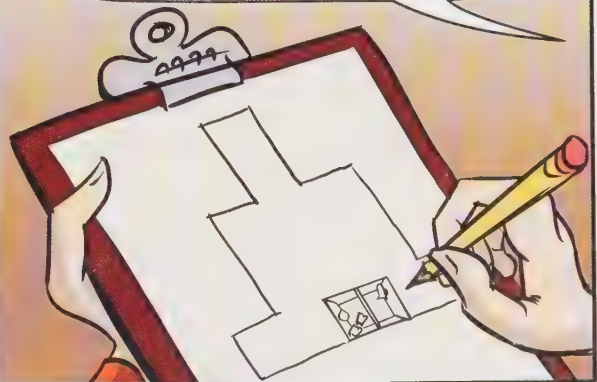


WE CAUGHT FISH 2, 3, AND 4 ON THE
LEFT AND FISH 1, ON THE RIGHT. THAT
OUTCOME IS A *MICROSTATE*.



THE FISH DO AS THEY PLEASE, SO ALL
MICROSTATES ARE EQUALLY LIKELY.

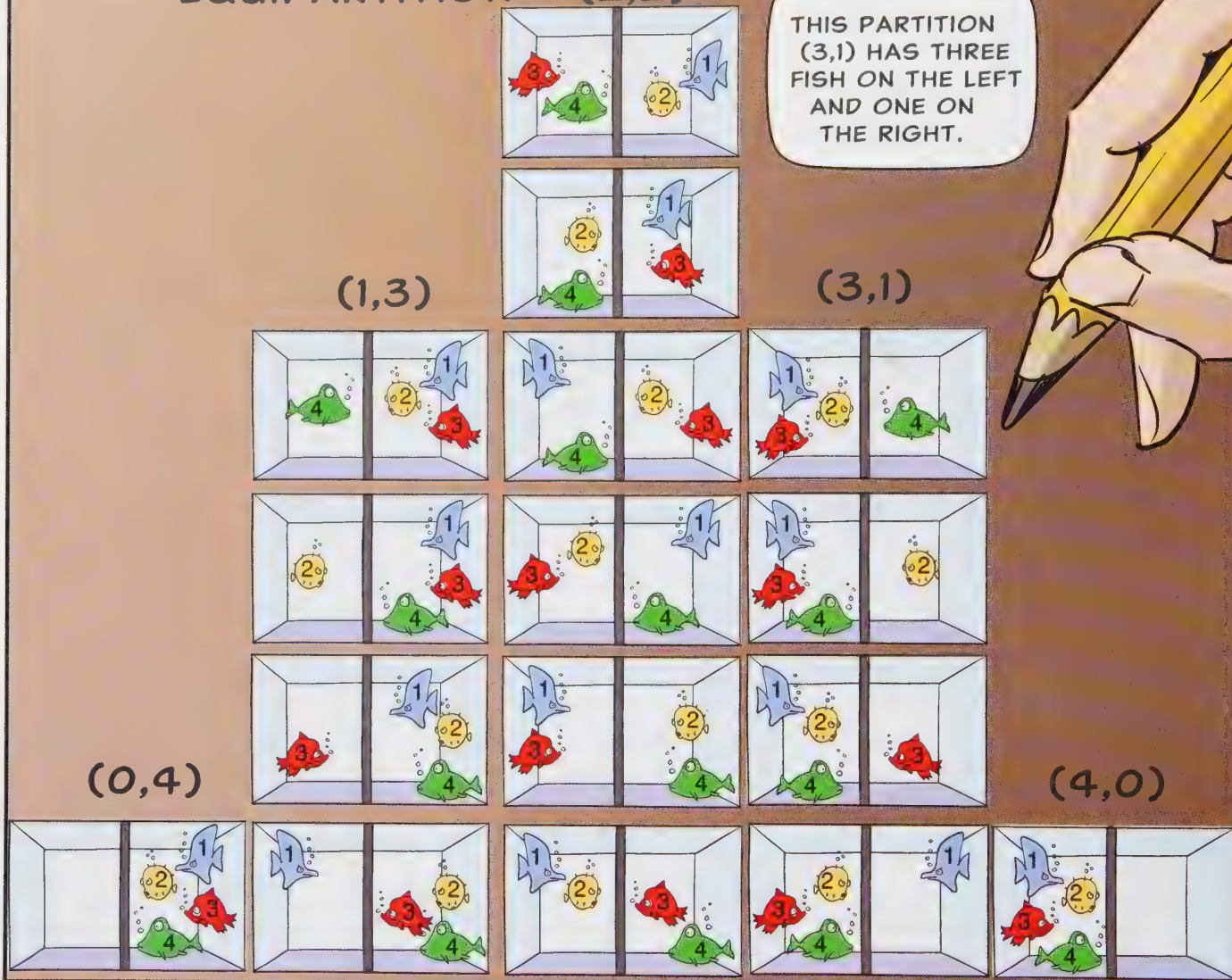
I'LL MAKE A DIAGRAM
OF THESE MICROSTATES ...



PHEW! THAT WAS PAINFUL TO DRAW. NOW YOU SEE ALL THE POSSIBLE MICROSTATES. EACH COLUMN SHOWS THE MICROSTATES WITH THE SAME PARTITION OF FISH BETWEEN THE CHAMBERS.

EQUIPARTITION = (2,2)

THIS PARTITION (3,1) HAS THREE FISH ON THE LEFT AND ONE ON THE RIGHT.

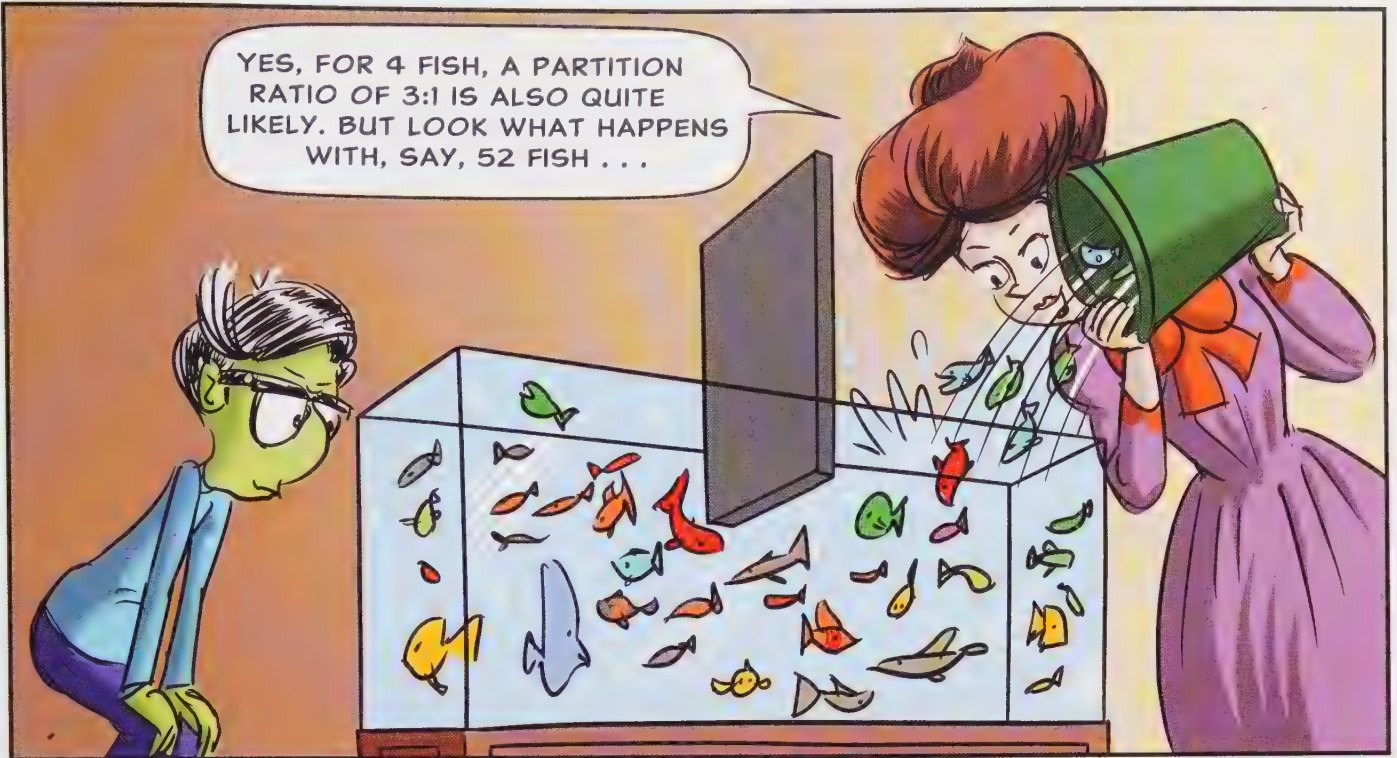


THE CHANCE OF GETTING A CERTAIN PARTITION IS AS LARGE AS THE HEIGHT OF ITS COLUMN.

THE TALLEST COLUMN IS EQUIPARTITION. THAT'S WHY WE'RE MOST LIKELY TO GET (2,2) - TWO FISH IN EACH SIDE.

BUT THERE ARE ALSO 4 MICROSTATES IN THE (3,1) COLUMN.

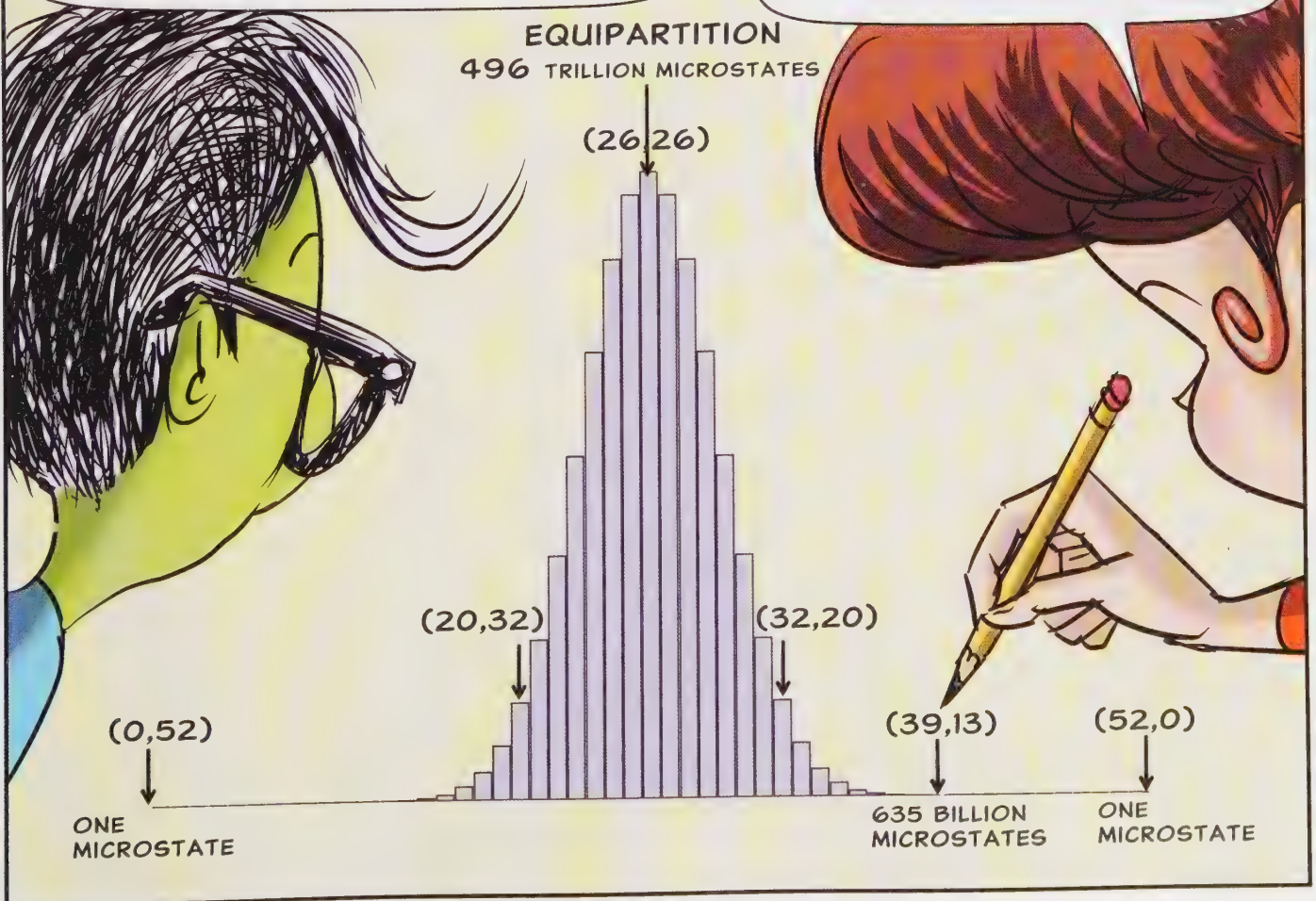
YES, FOR 4 FISH, A PARTITION RATIO OF 3:1 IS ALSO QUITE LIKELY. BUT LOOK WHAT HAPPENS WITH, SAY, 52 FISH . . .



I'LL DRAW THE PARTITIONS, BUT NOW WE HAVE ENORMOUSLY MORE MICROSTATES. AGAIN, EQUIPARTITION (26,26) IS THE HIGHEST COLUMN.

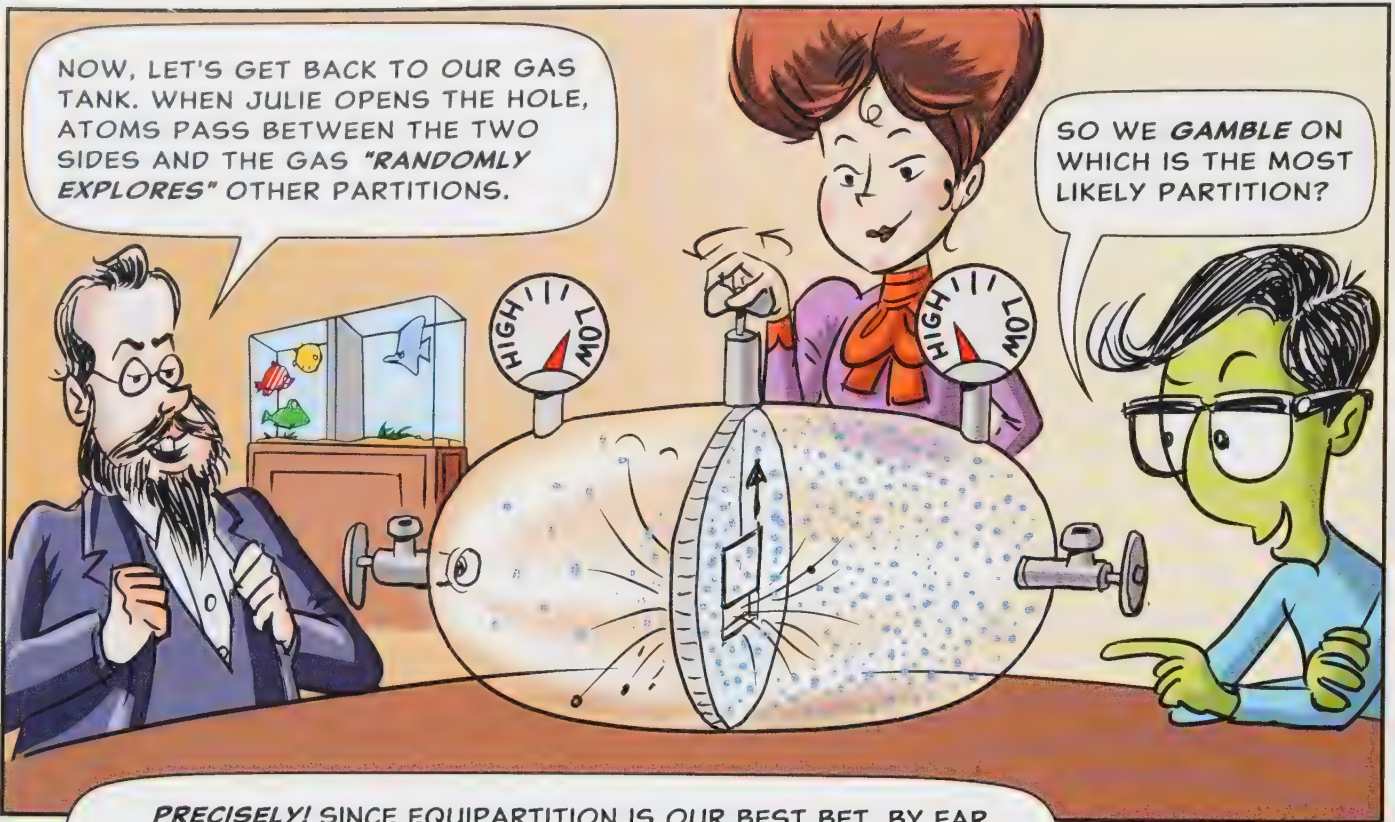
NOW THE ODDS OF A 3:1 RATIO ARE 780 TIMES SMALLER THAN EQUIPARTITION.

EQUIPARTITION
496 TRILLION MICROSTATES



NOW, LET'S GET BACK TO OUR GAS TANK. WHEN JULIE OPENS THE HOLE, ATOMS PASS BETWEEN THE TWO SIDES AND THE GAS "RANDOMLY EXPLORES" OTHER PARTITIONS.

SO WE GAMBLE ON WHICH IS THE MOST LIKELY PARTITION?

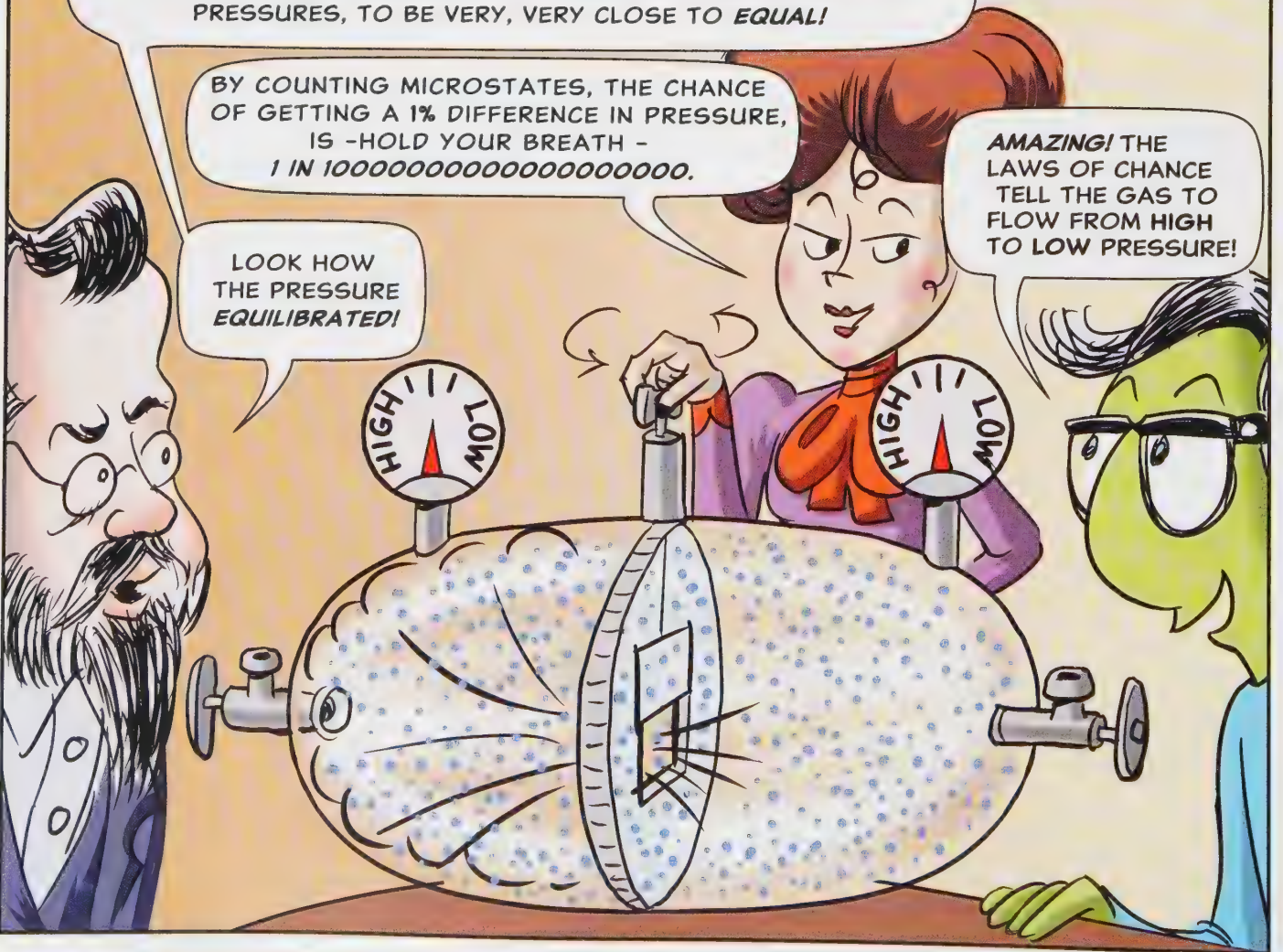


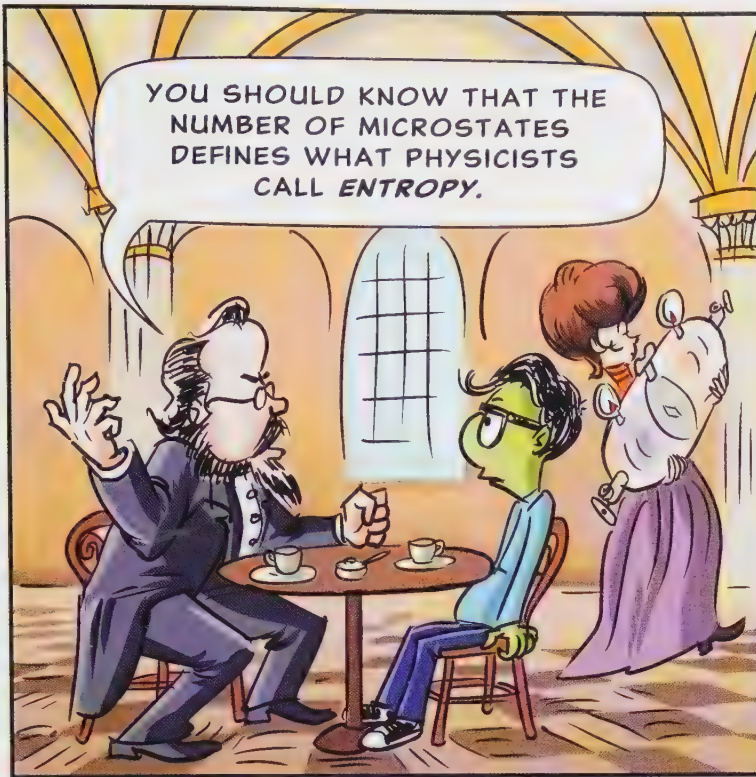
PRECISELY! SINCE EQUIPARTITION IS OUR BEST BET, BY FAR, WE EXPECT THE NUMBERS OF ATOMS, AND THEREFORE THE PRESSURES, TO BE VERY, VERY CLOSE TO *EQUAL*!

BY COUNTING MICROSTATES, THE CHANCE OF GETTING A 1% DIFFERENCE IN PRESSURE, IS -HOLD YOUR BREATH - 1 IN 100000000000000000000.

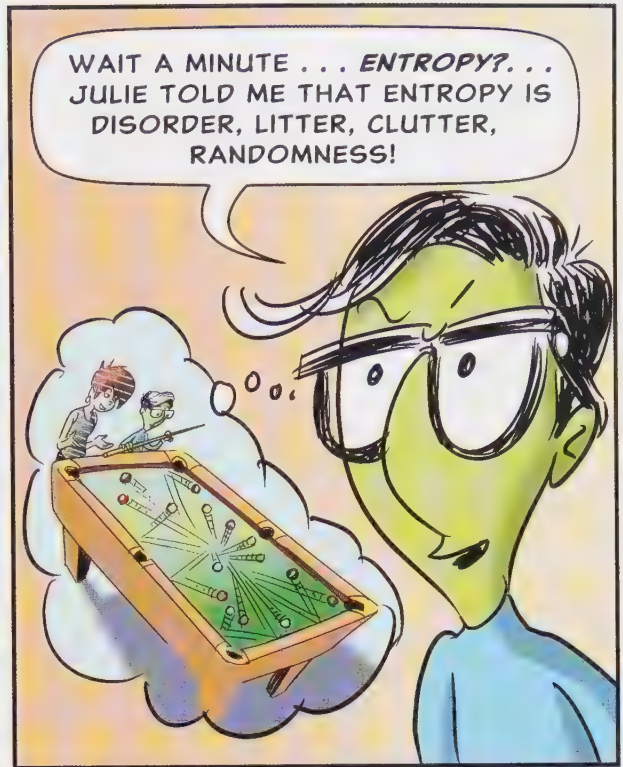
AMAZING! THE LAWS OF CHANCE TELL THE GAS TO FLOW FROM HIGH TO LOW PRESSURE!

LOOK HOW THE PRESSURE EQUILIBRATED!





YOU SHOULD KNOW THAT THE NUMBER OF MICROSTATES DEFINES WHAT PHYSICISTS CALL *ENTROPY*.



WAIT A MINUTE . . . *ENTROPY?* . . . JULIE TOLD ME THAT ENTROPY IS DISORDER, LITTER, CLUTTER, RANDOMNESS!

THERMODYNAMICS AND STATISTICAL PHYSICS

BOLTZMANN'S ENTROPY FORMULA

$S = K \times \text{LOG}(W)$

S = ENTROPY

K = BOLTZMANN'S CONSTANT

3.18×10^{-23} JOULES/°C

W = NUMBER OF MICROSTATES

JULIE IS RIGHT BUT TO BE PRECISE: ENTROPY IS THE *LOGARITHM* OF THE NUMBER OF MICROSTATES.

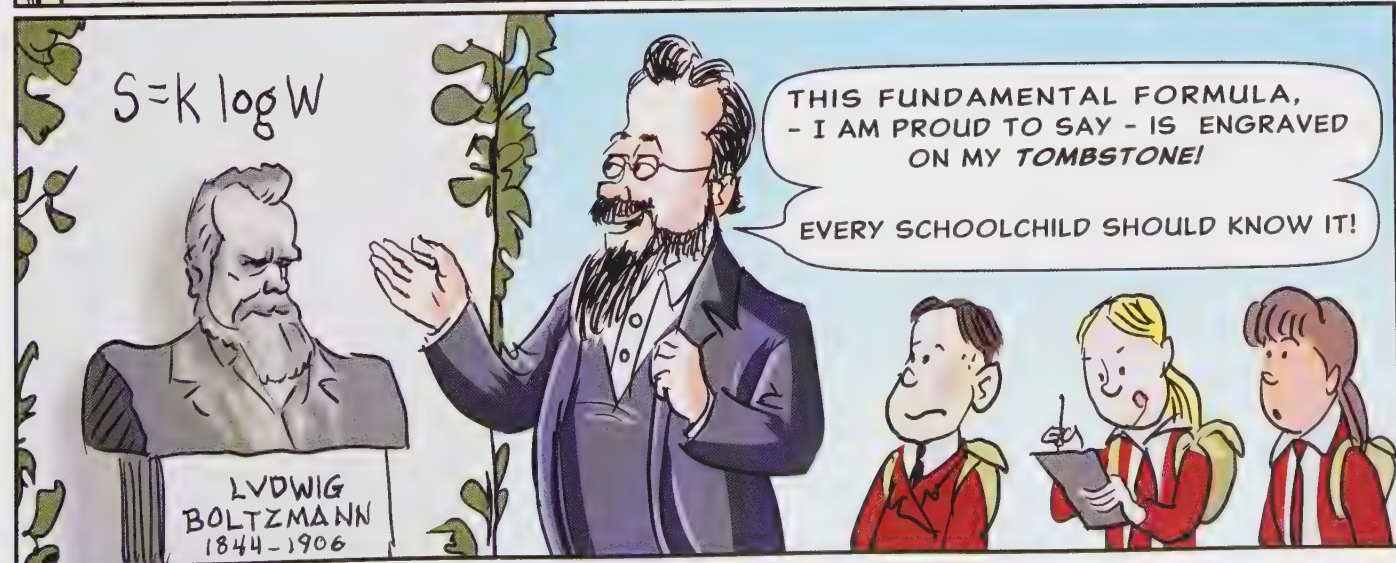
*WHAT'S THE *LOGARITHM* OF A NUMBER? THE NUMBER OF DIGITS (EXCLUDING THE FIRST) EXAMPLES :

LOG (1) = 0

LOG (10) = 1

LOG (1,000) = 3

LOG (1,000,000) = 6



$S = k \log W$

LUDWIG BOLTZMANN
1844-1906

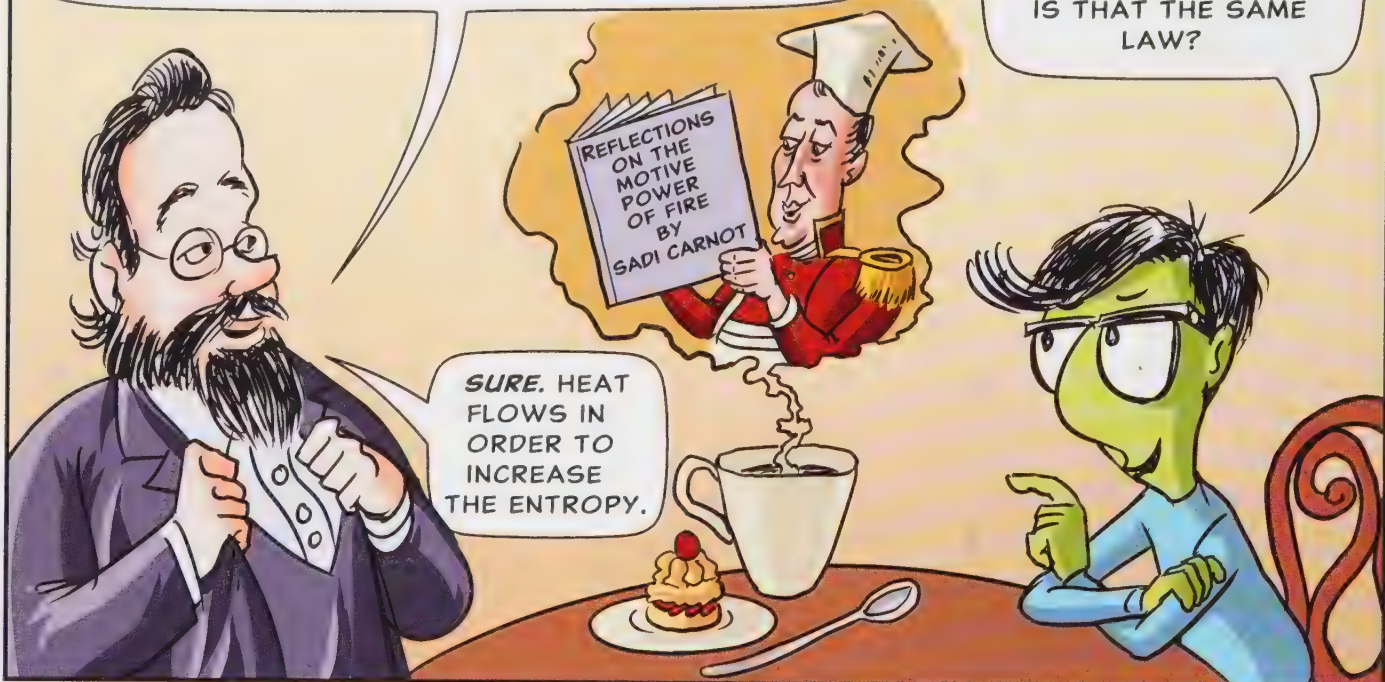
THIS FUNDAMENTAL FORMULA, - I AM PROUD TO SAY - IS ENGRAVED ON MY *TOMBSTONE!*

EVERY SCHOOLCHILD SHOULD KNOW IT!

THE GAS TANK WAS A NEAT DEMONSTRATION OF THE SECOND LAW OF THERMODYNAMICS, WHICH SAYS:

"WITHOUT EXTERNAL INTERFERENCE, THE ENTROPY OF A CLOSED SYSTEM CAN ONLY INCREASE."

BUT CARNOT'S SECOND LAW WAS: "HEAT FLOWS FROM HOT TO COLD" . . . IS THAT THE SAME LAW?



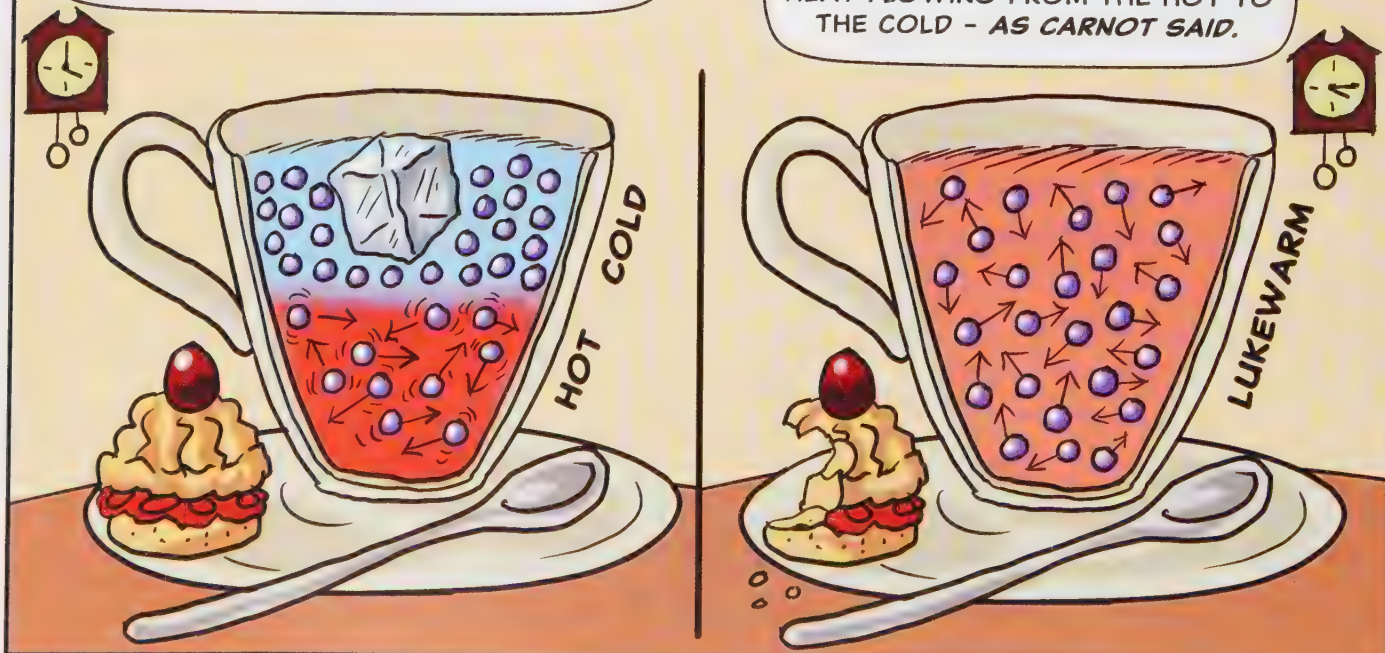
SURE. HEAT FLOWS IN ORDER TO INCREASE THE ENTROPY.

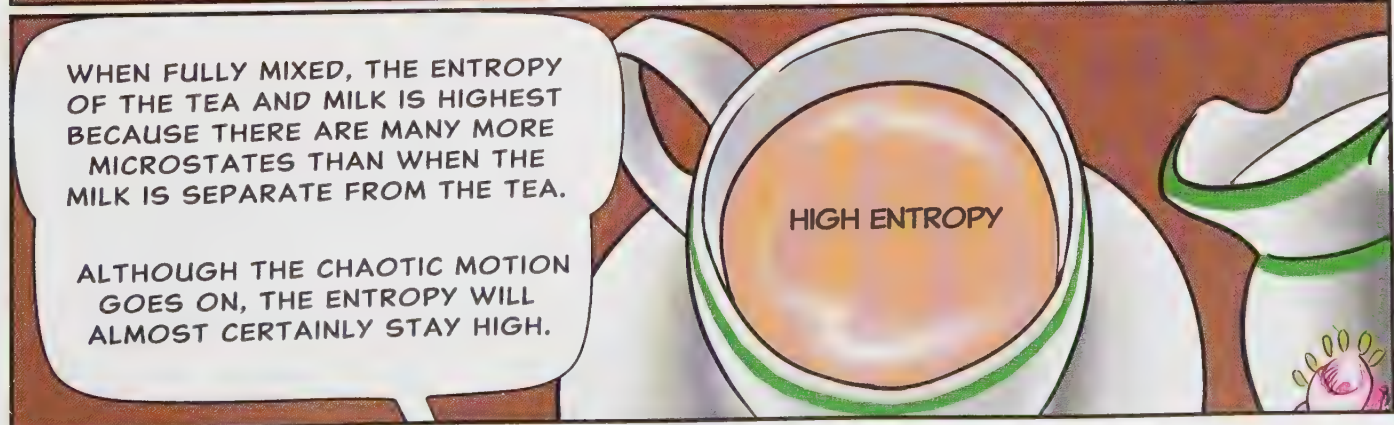
YES, THE CUP HAS LIQUIDS AT DIFFERENT TEMPERATURES - THERE IS *MORE KINETIC ENERGY PER ATOM* IN THE HOT LIQUID THAN IN THE COLD LIQUID.

LET'S SAY THAT HEAT CANNOT ESCAPE FROM THE CUP AND ENERGY IS EXCHANGED BETWEEN THE TWO LIQUIDS.

IF WE COUNT THE POSSIBLE WAYS TO DIVIDE THE KINETIC ENERGY BETWEEN THE ATOMS, WE'LL SEE THAT THE HIGHEST ENTROPY IS FOR MICROSTATES CLOSE TO *EQUIPARTITION OF ENERGY*.

SO TEMPERATURES IN DIFFERENT PARTS TEND TO *EQUALIZE* BY HEAT FLOWING FROM THE HOT TO THE COLD - AS CARNOT SAID.

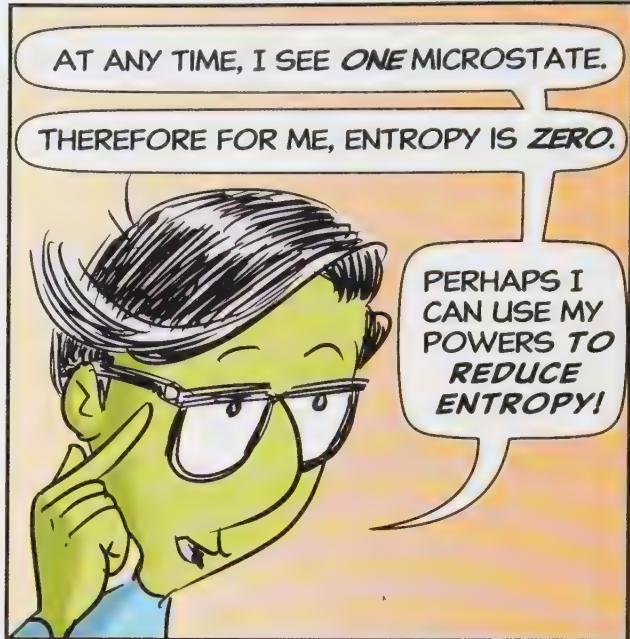






HMM... I THINK I KNOW HOW TO GO ABOUT SIR BIO'S MISSION.

HOW?

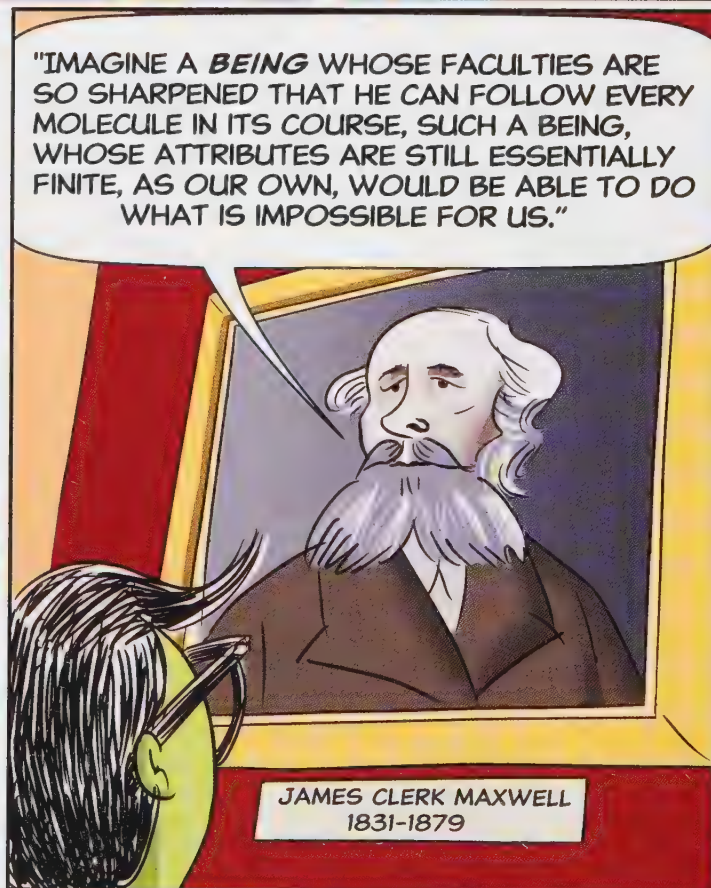


AT ANY TIME, I SEE *ONE* MICROSTATE. THEREFORE FOR ME, ENTROPY IS ZERO.

PERHAPS I CAN USE MY POWERS TO REDUCE ENTROPY!



THIS REMINDS ME OF WHAT MY COLLEAGUE, JAMES CLERK MAXWELL, SAID ABOUT YOU.

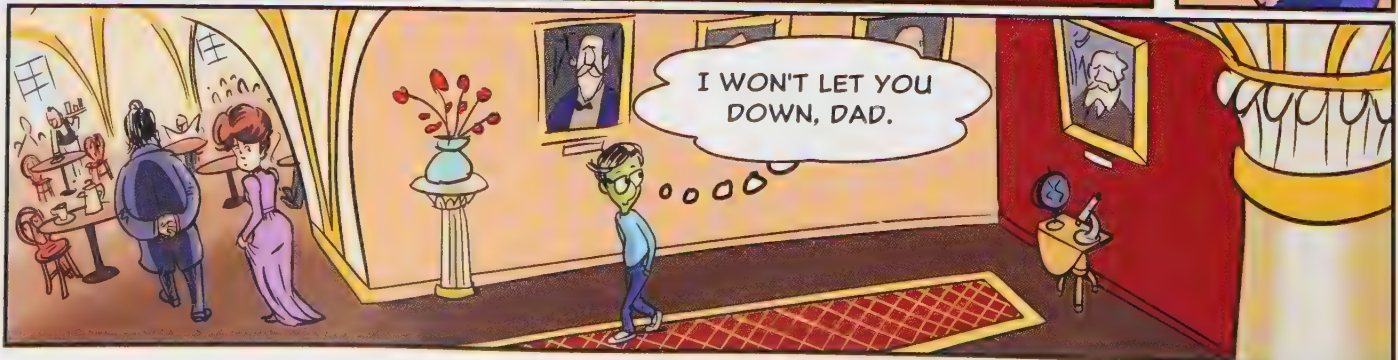


"IMAGINE A *BEING* WHOSE FACULTIES ARE SO SHARPENED THAT HE CAN FOLLOW EVERY MOLECULE IN ITS COURSE, SUCH A BEING, WHOSE ATTRIBUTES ARE STILL ESSENTIALLY FINITE, AS OUR OWN, WOULD BE ABLE TO DO WHAT IS IMPOSSIBLE FOR US."

JAMES CLERK MAXWELL
1831-1879



WHAT A GREAT MAN. HE INVENTED ME!



I WON'T LET YOU DOWN, DAD.



MORALLY, SHOULD ENTROPY BE DECREASED?

YES!

NO!

BAD QUESTION!

VIENNA CIRCLE OF LOGICAL POSITIVISTS

DECREASED! MY PEOPLE SHOULD CONGREGATE IN ONE COUNTRY!

INCREASED! CAPITAL SHOULD BE REDISTRIBUTED!

DECREASED! WE DON'T WANT ANARCHY!

DO WE MEAN CONSCIOUS OR SUBCONSCIOUS ENTROPY?

COME ALONG, MAX. YOUR TUTORING IS DONE. YOU ARE READY FOR WORK.

CAN WE USE A MORE COMFORTABLE TIME MACHINE THIS TIME?

BACK TO BOSTON



I'M SORRY WE'RE LEAVING,
PROFESSOR BOLTZMANN.

VIENNA
TO
BOSTON
SPACE-TIME
TRAIN

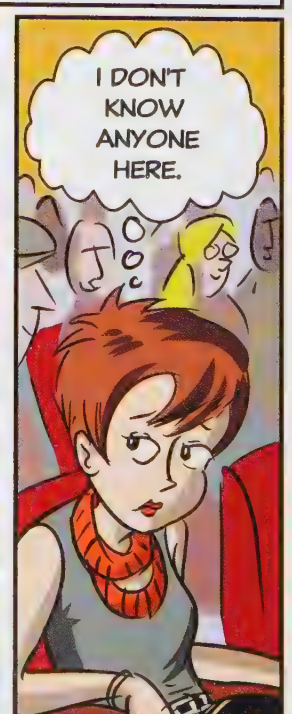
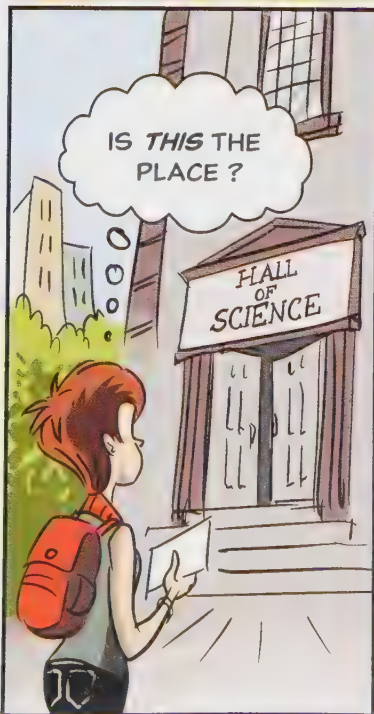
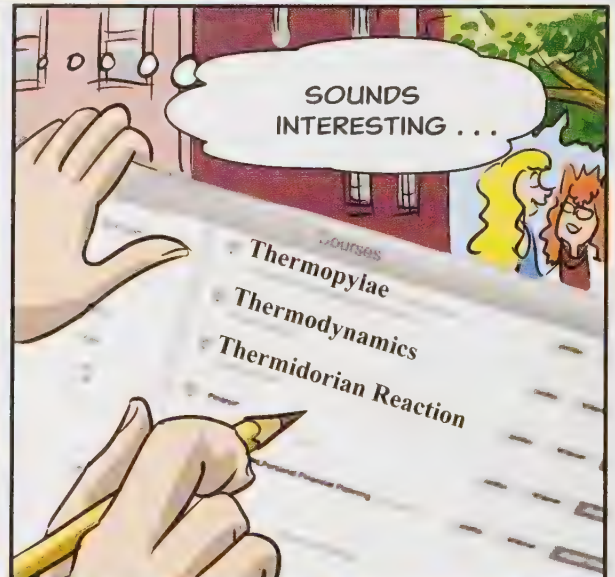
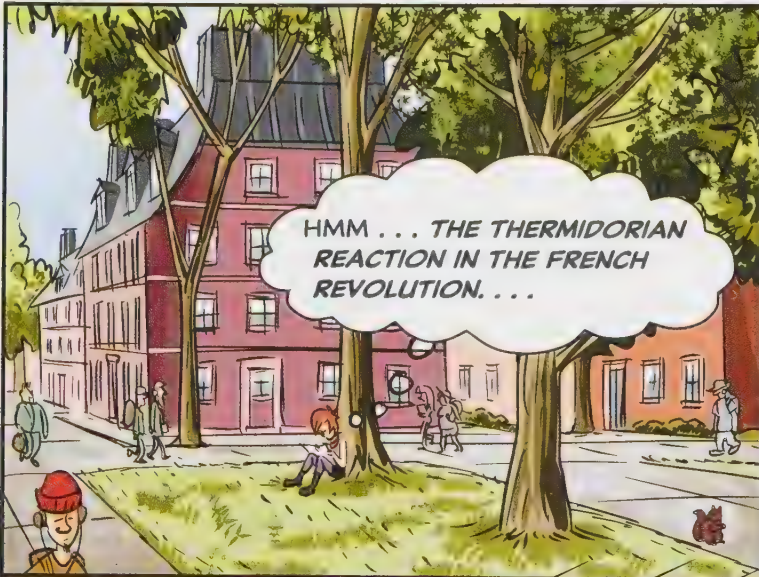
YOU'LL SEE HIM
AGAIN IN ALL
OUR TEXTBOOKS.

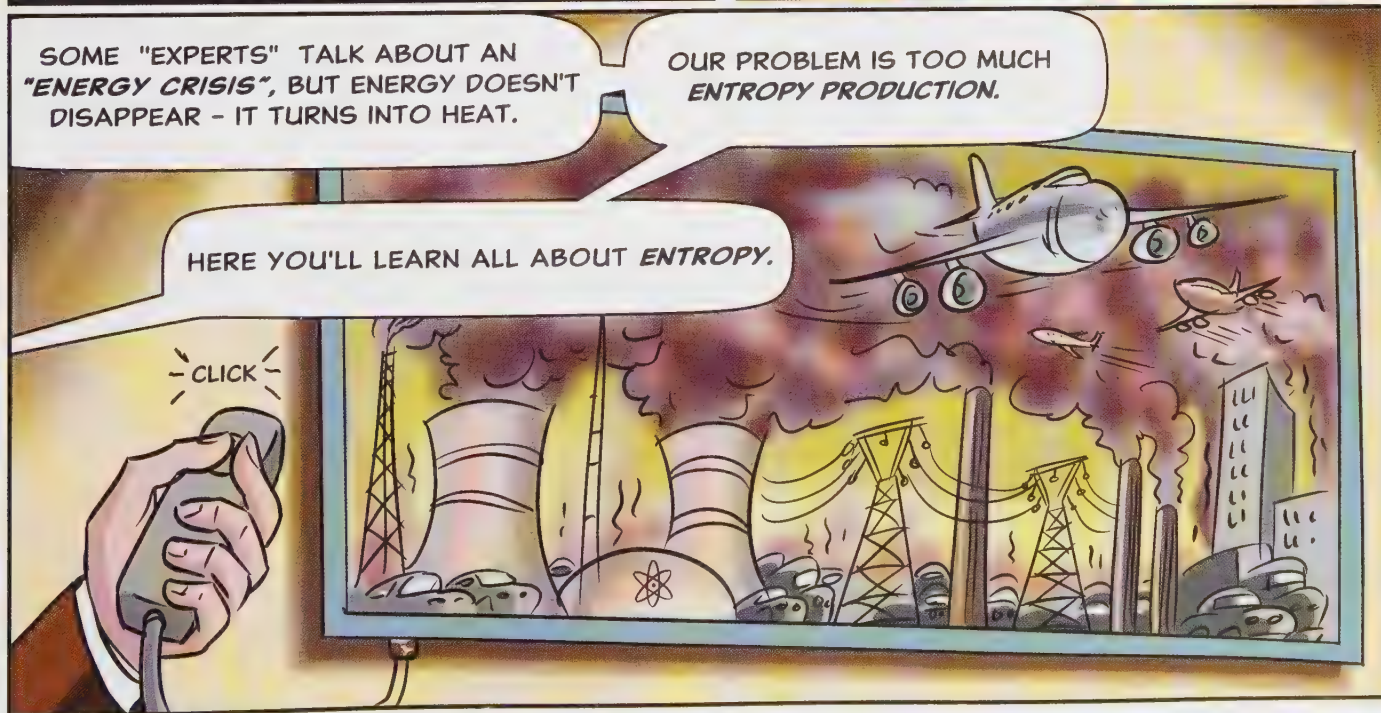
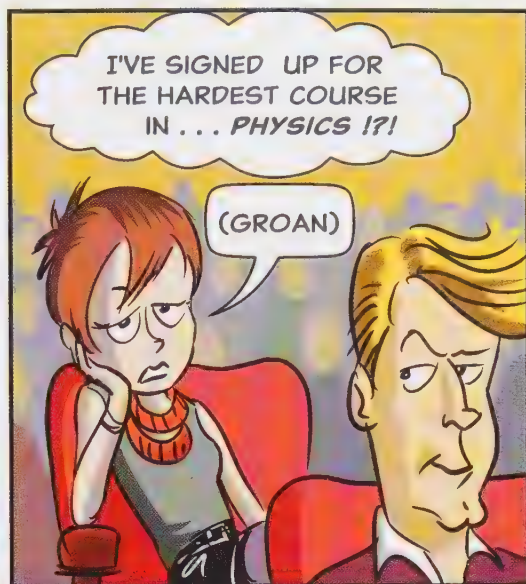
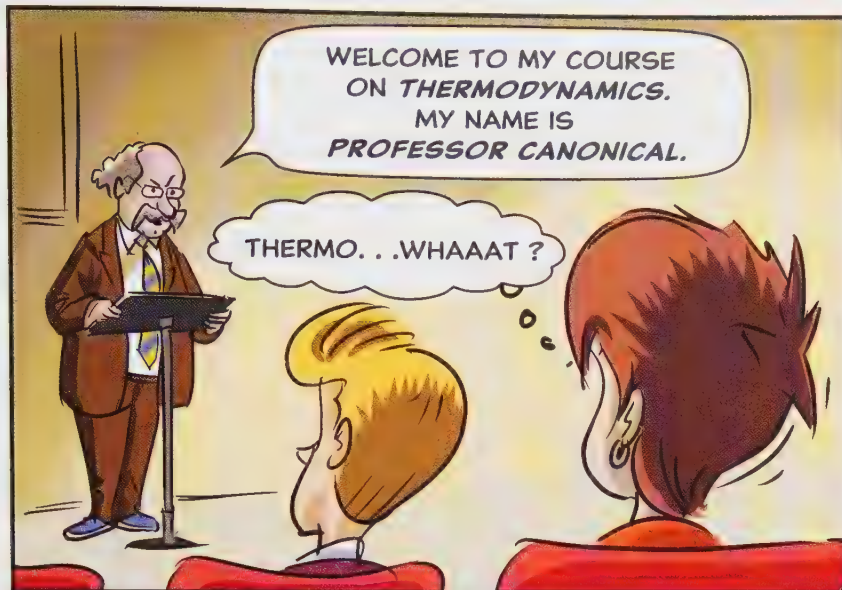
CHAPTER V

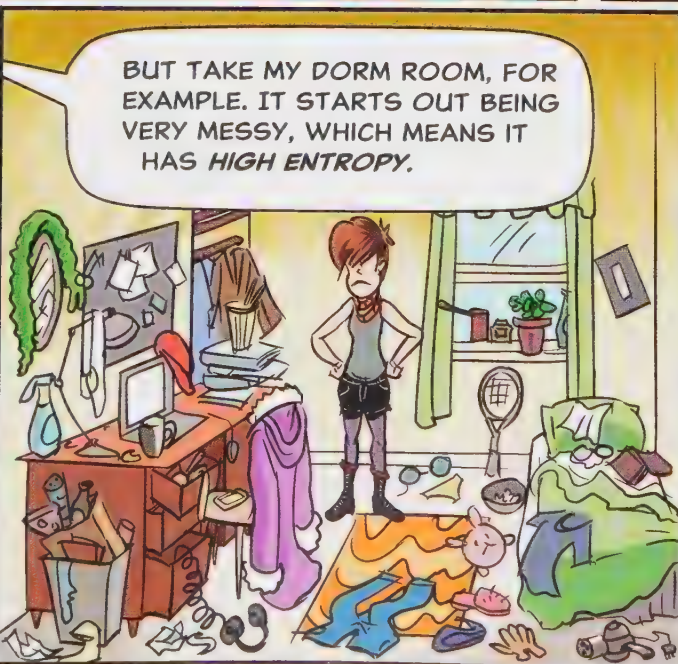
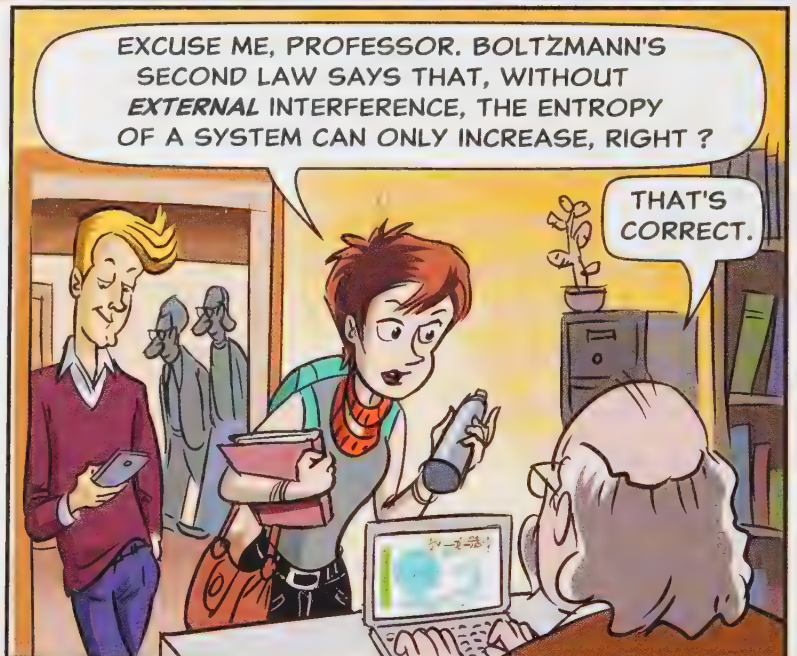
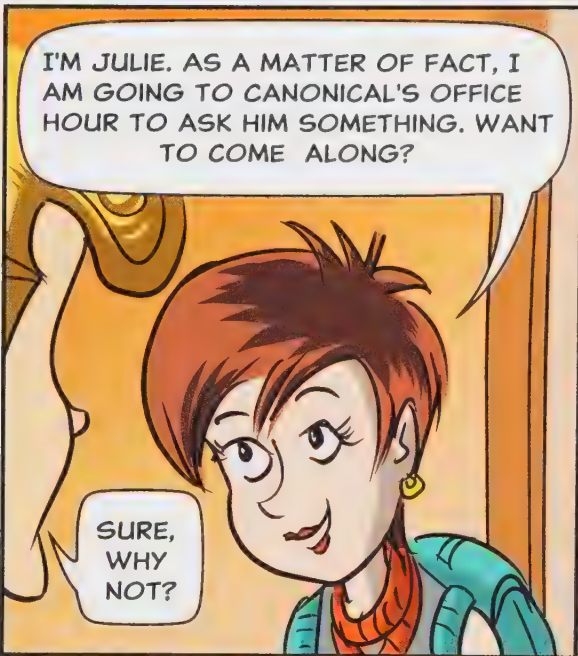
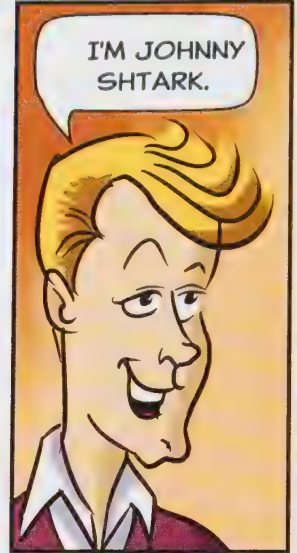
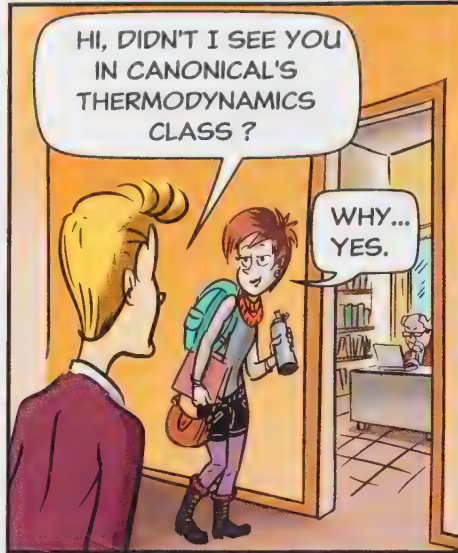
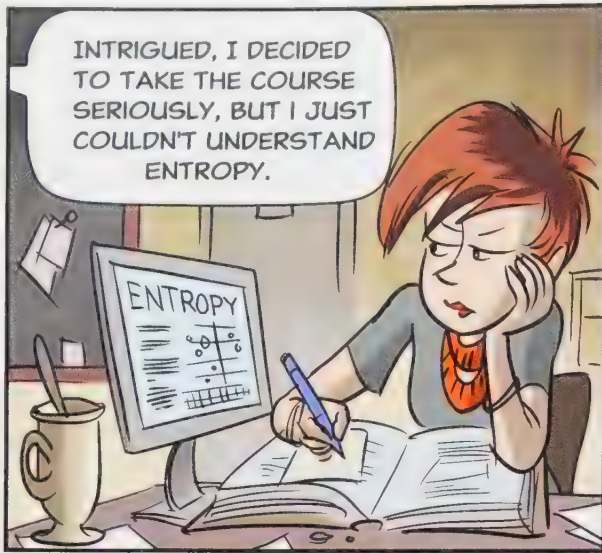
JOURNEY TO THE PRESENT

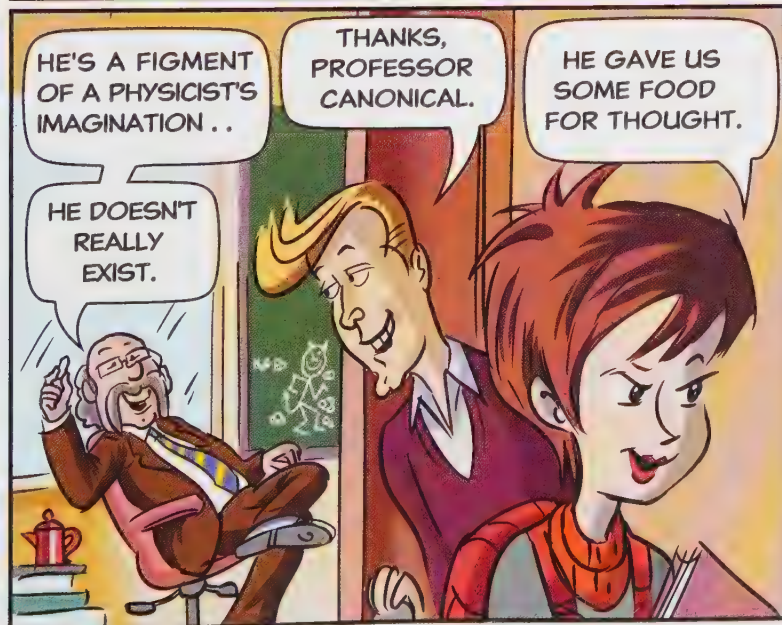
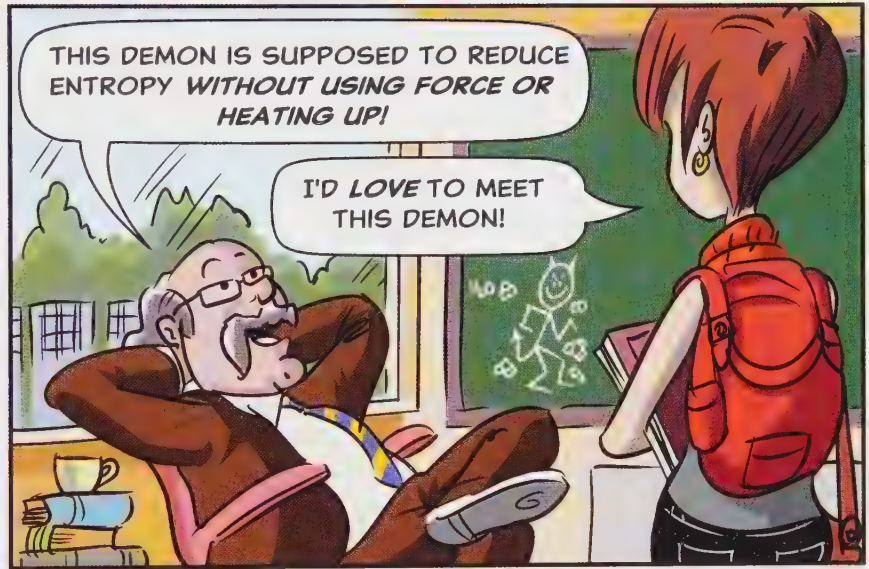
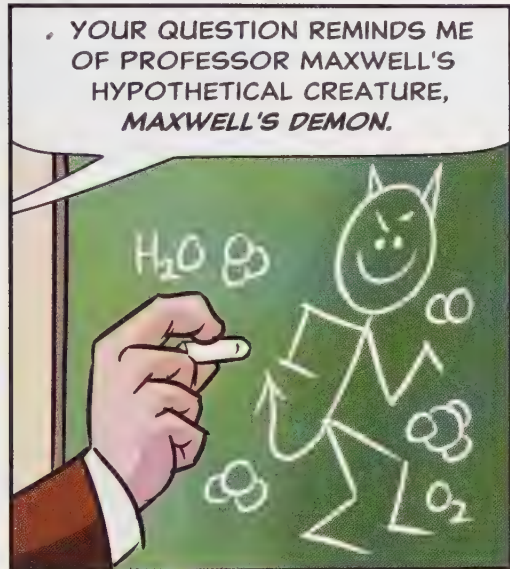
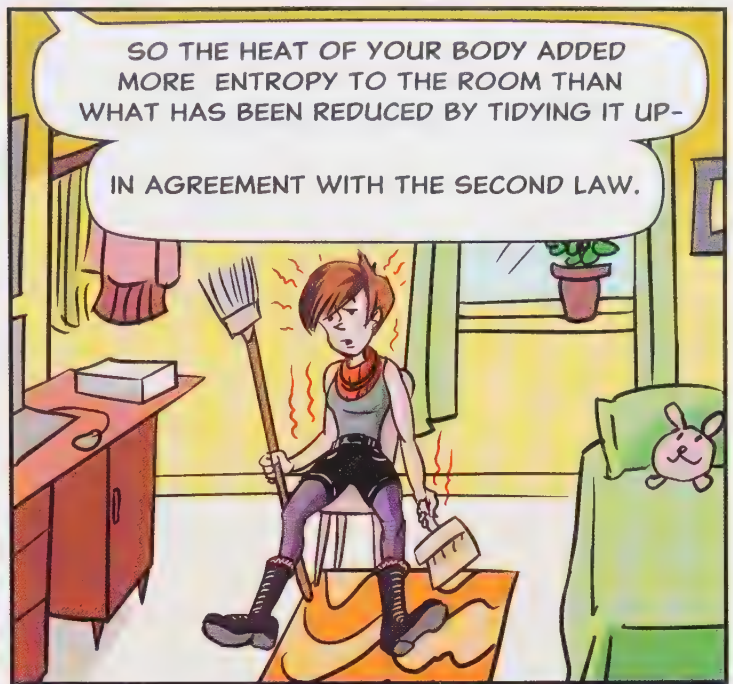
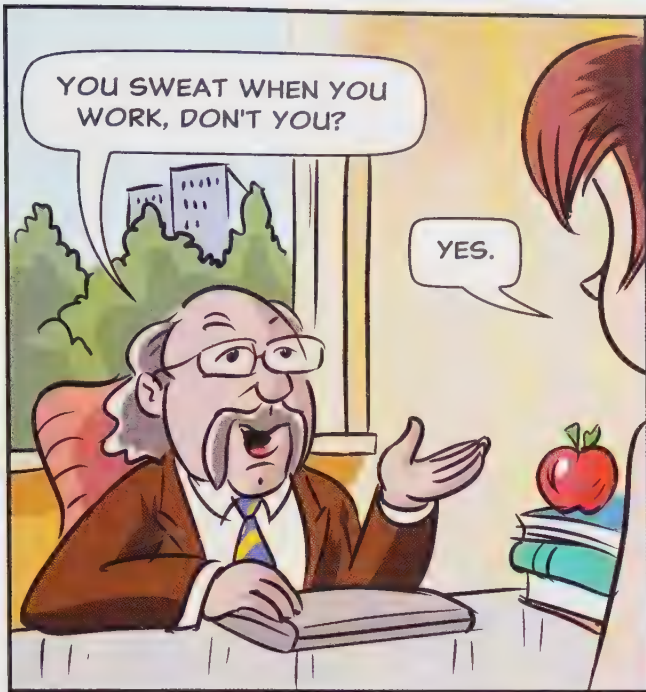


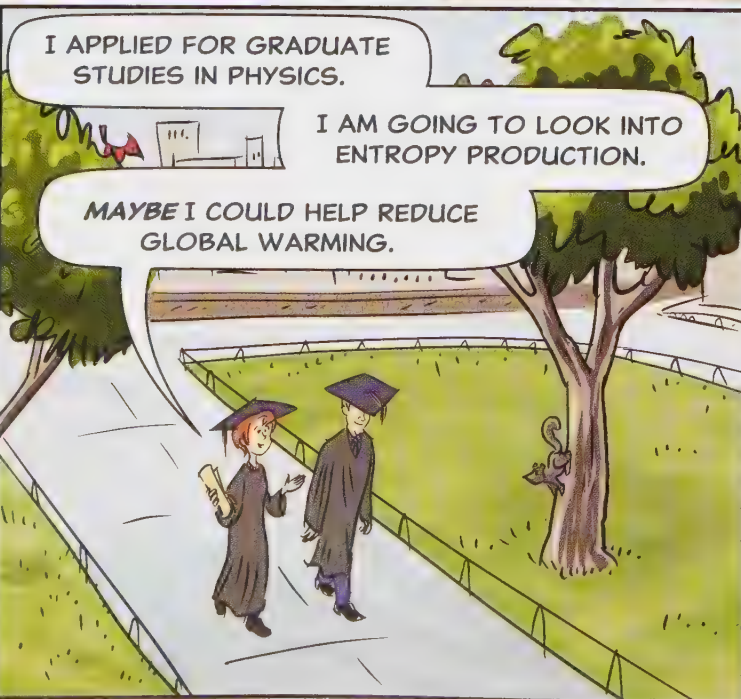
JULIE'S STORY

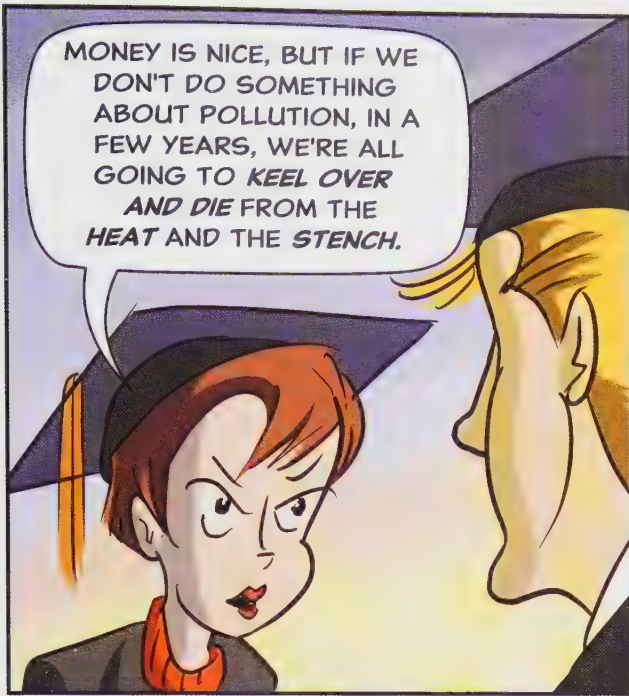












MONEY IS NICE, BUT IF WE DON'T DO SOMETHING ABOUT POLLUTION, IN A FEW YEARS, WE'RE ALL GOING TO *KEEL OVER AND DIE* FROM THE HEAT AND THE STENCH.



DON'T WORRY YOUR PRETTY LITTLE HEAD ABOUT IT. WE'LL JUST ESCAPE IN MY PRIVATE JET TO MY PERSONAL PARADISE ISLAND IN THE SOUTH PACIFIC.



AND LEAVE EVERYONE ELSE TO *CHOK*E AND ROT? HOW FREAKIN' SELFISH IS *THAT*!?

ON A SCALE OF ONE TO TEN?

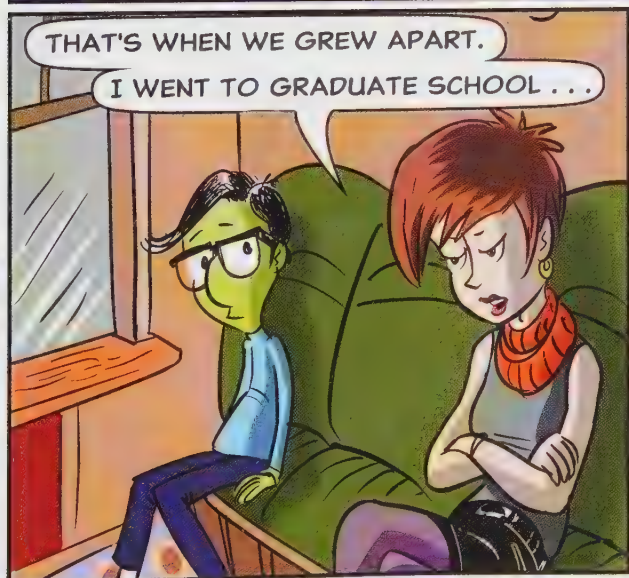


GOOD LUCK IN YOUR CAREER CHOICE.

I THINK I'LL WALK HOME BY MYSELF.

BYE!

YEAH, SEE YOU LATER.



THAT'S WHEN WE GREW APART. I WENT TO GRADUATE SCHOOL . . .



AND GOT INTO SERIOUS RESEARCH ON CLEAN ENERGY TECHNOLOGIES.

ONE EVENING, AS I WAS SURFING THE WEB, A STRANGE WINDOW POPPED UP ON MY SCREEN. . .

MAXWELL'S DEMON
THE "2ND LAW"
ENTROPY REDUCTION



DON'T BE ALARMED, JULIE.

I AM NOT A TROLL, A
TROJAN HORSE OR A
SCHIZOPHRENIC EPISODE.



SO YOU'RE A PERVERT.
GET LOST, OR I'LL CALL
SECURITY!



I AM AN EXTRA TERRESTRIAL
BEING WITH AN IMPORTANT
MESSAGE FOR YOU.

IT BETTER NOT
BE ABOUT MY
UNDERWEAR.
LOG OFF, CREEP!

NO, NO.
LOOK
OUT
YOUR
WINDOW.



YOU WILL NOW SEE THREE
FLASHES FROM THE STAR
ABOVE POLARIS.

THAT'S MY VALIDATION
MESSAGE.

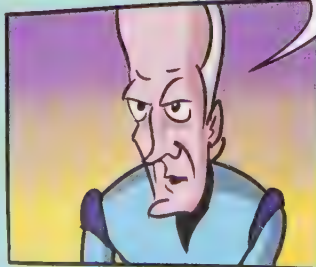
BLINK
BLINK
BLINK



AMAZING.

WHO ARE YOU?

I AM SIR BIO FROM
TACHYONIA GALACTIC
HEADQUARTERS AND
WE ARE VERY WORRIED
ABOUT OVER PRODUCTION
OF ENTROPY ON EARTH.

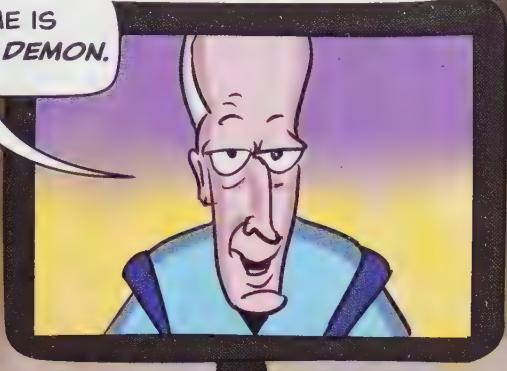


WHAT CAN I
DO ABOUT IT?

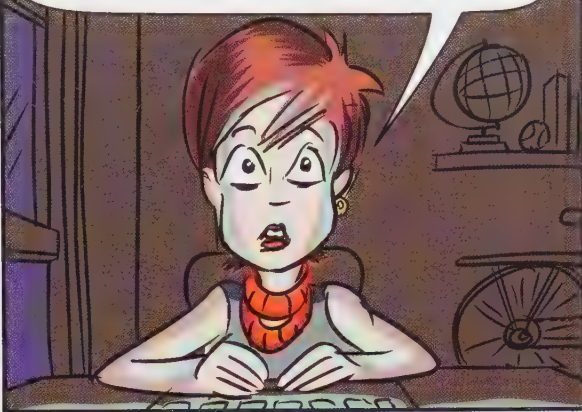


SOON, WE WILL BE SENDING A SUPERHERO TO EARTH TO DEAL WITH YOUR ENTROPY CRISIS AND YOU, JULIE, WILL BE HIS HOST.

HIS NAME IS **MAX THE DEMON.**

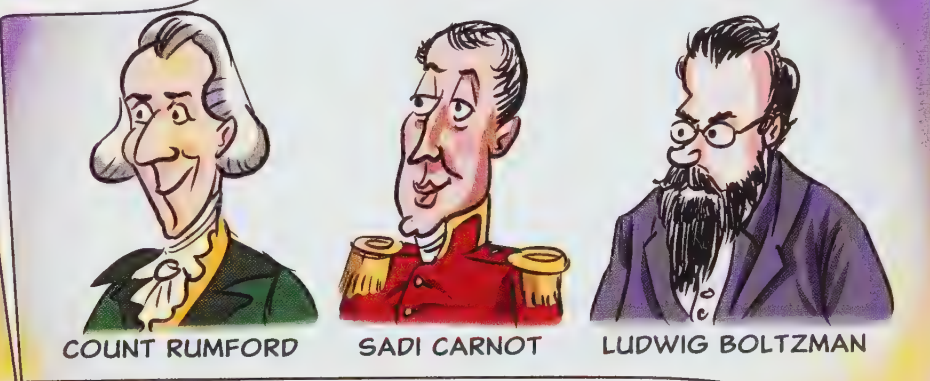


THE DEMON INVENTED BY MAXWELL? WHAT AM I SUPPOSED TO DO WITH HIM?



MAX WILL NEED SOME BASIC EDUCATION ABOUT ENTROPY. YOU SEE, FOR HIM, ENTROPY IS JUST ZERO.

YOU WILL TAKE HIM TO VISIT SOME OF THE GREATEST PHYSICISTS OF THE PAST.



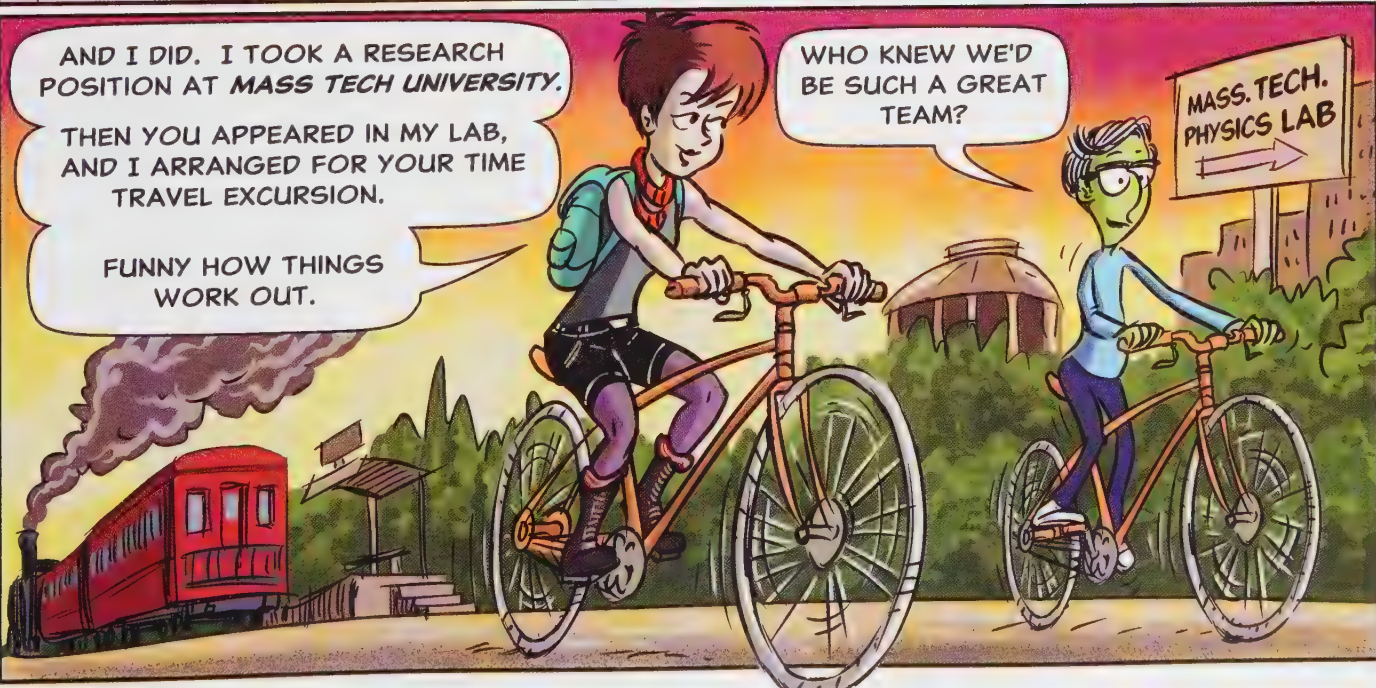
COUNT RUMFORD SADI CARNOT LUDWIG BOLTZMAN

AFTERWARDS, YOU WILL HELP MAX WITH WHATEVER HE NEEDS TO REDUCE ENTROPY PRODUCTION ON EARTH.

DO YOU ACCEPT THIS MISSION?

AND I DID. I TOOK A RESEARCH POSITION AT MASS TECH UNIVERSITY. THEN YOU APPEARED IN MY LAB, AND I ARRANGED FOR YOUR TIME TRAVEL EXCURSION. FUNNY HOW THINGS WORK OUT.

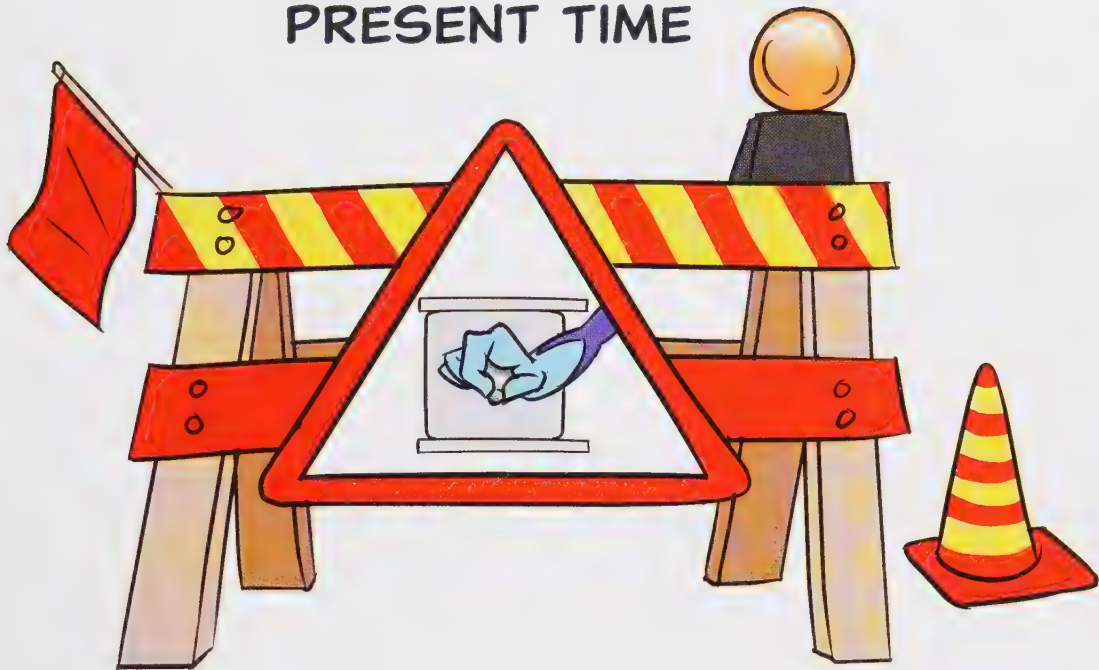
WHO KNEW WE'D BE SUCH A GREAT TEAM?



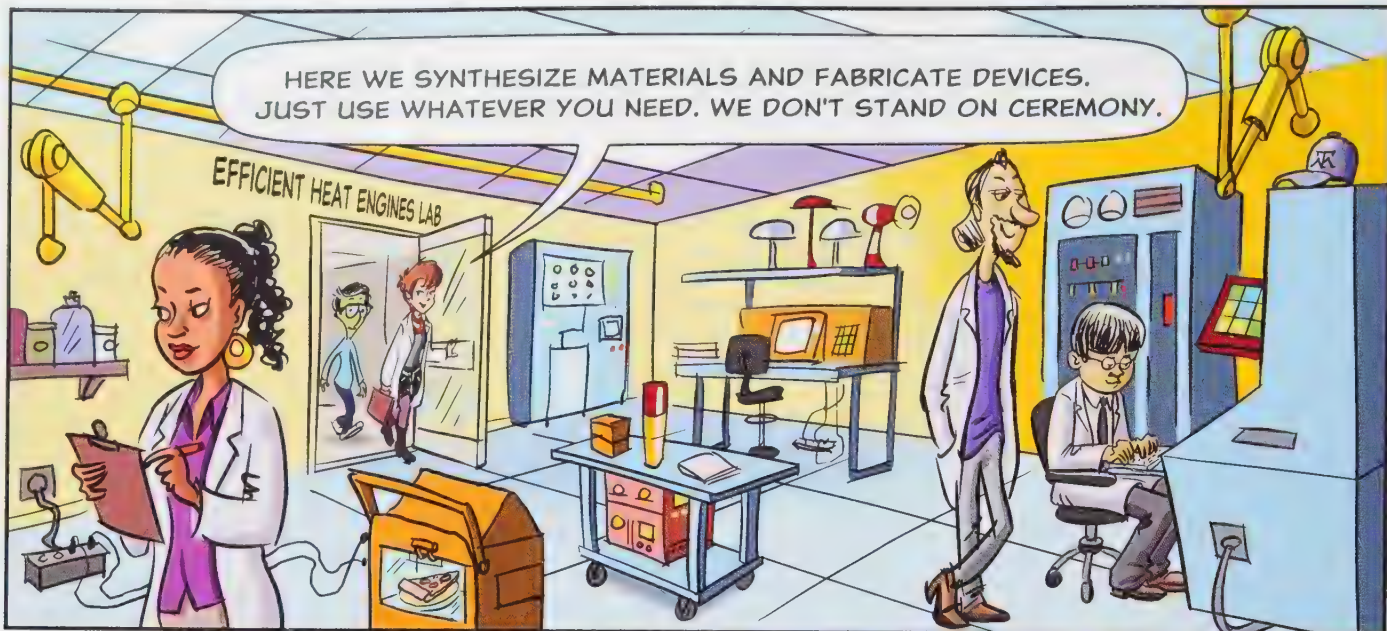


CHAPTER VI

PRESENT TIME



DEMON AT WORK

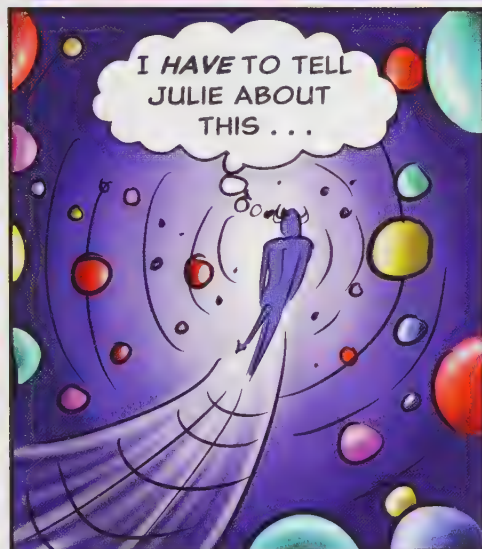




HOW COOL IS THIS!

I SEE EVERYTHING!

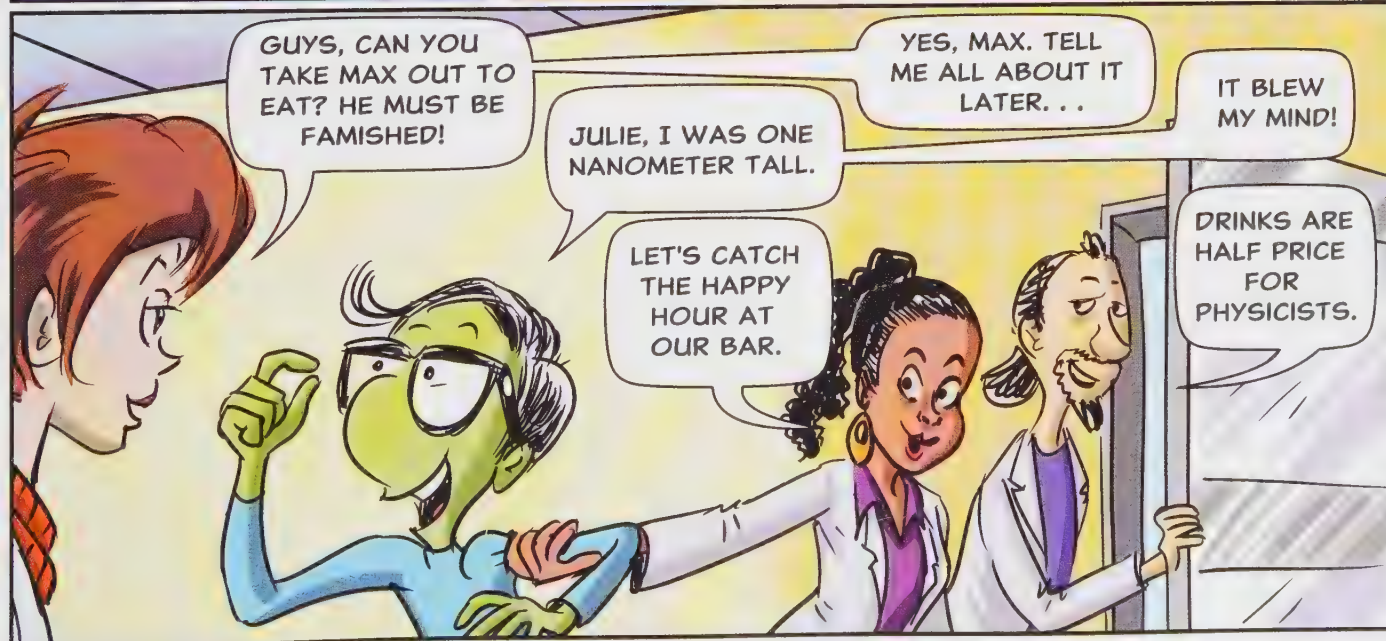
I'M IN THE COMPANY OF ATOMS AND MOLECULES.



I HAVE TO TELL JULIE ABOUT THIS...



HE'S BACK!



GUYS, CAN YOU TAKE MAX OUT TO EAT? HE MUST BE FAMISHED!

JULIE, I WAS ONE NANOMETER TALL.

LET'S CATCH THE HAPPY HOUR AT OUR BAR.

YES, MAX. TELL ME ALL ABOUT IT LATER...

IT BLEW MY MIND!

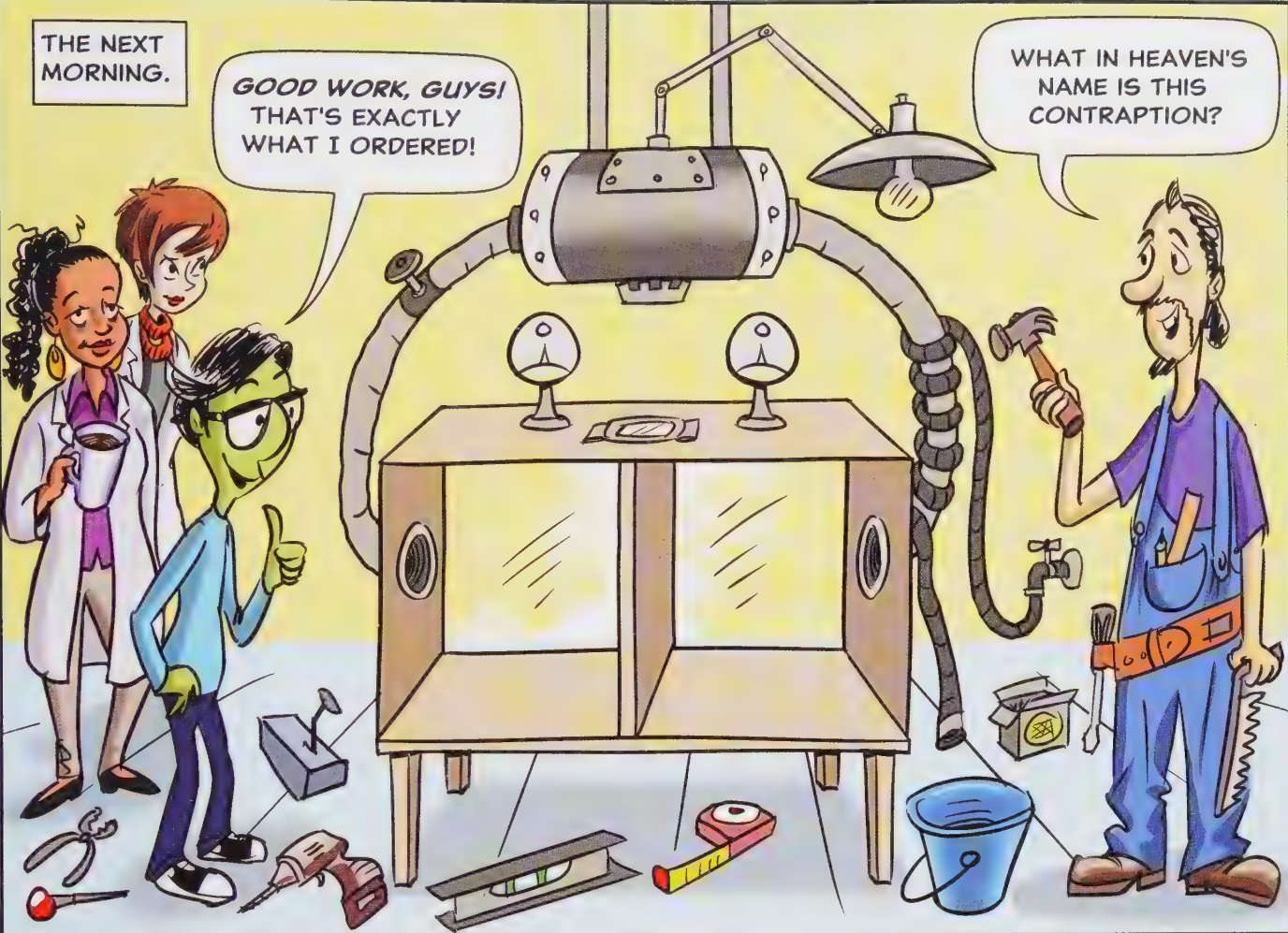
DRINKS ARE HALF PRICE FOR PHYSICISTS.



THE NEXT MORNING.

GOOD WORK, GUYS!
THAT'S EXACTLY
WHAT I ORDERED!

WHAT IN HEAVEN'S
NAME IS THIS
CONTRAPTION?



WITH THIS DEVICE I CAN PRODUCE
UNLIMITED ELECTRIC POWER
WITHOUT INVESTING ANY WORK
OR BURNING ANY FUEL!



YOU'RE KIDDING!?



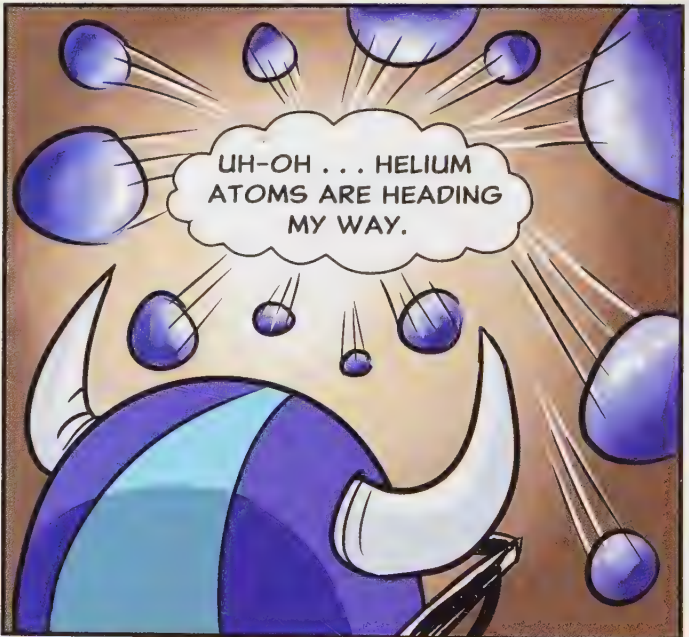
WATCH ME!
I'M GOING IN...



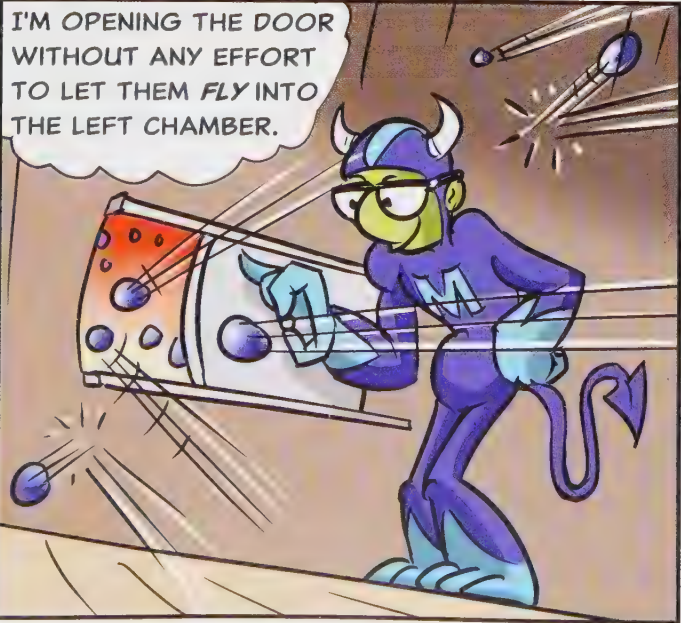
THERE'S THE SHUTTER
I ASKED THEM TO BUILD.
I HOPE IT WORKS THE
WAY IT'S SUPPOSED TO.



IT'S LIGHTWEIGHT,
AND FRICTIONLESS
... PERFECT!



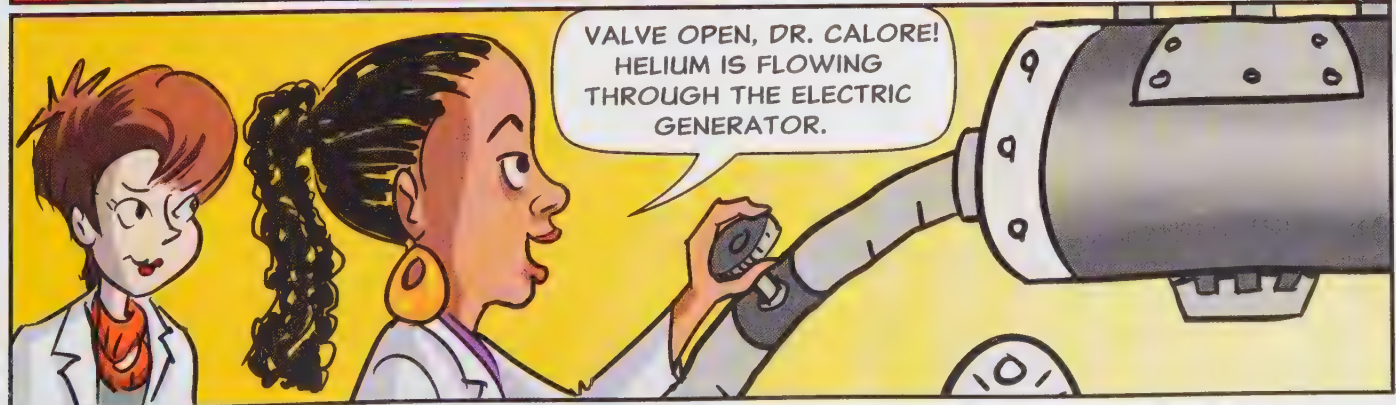
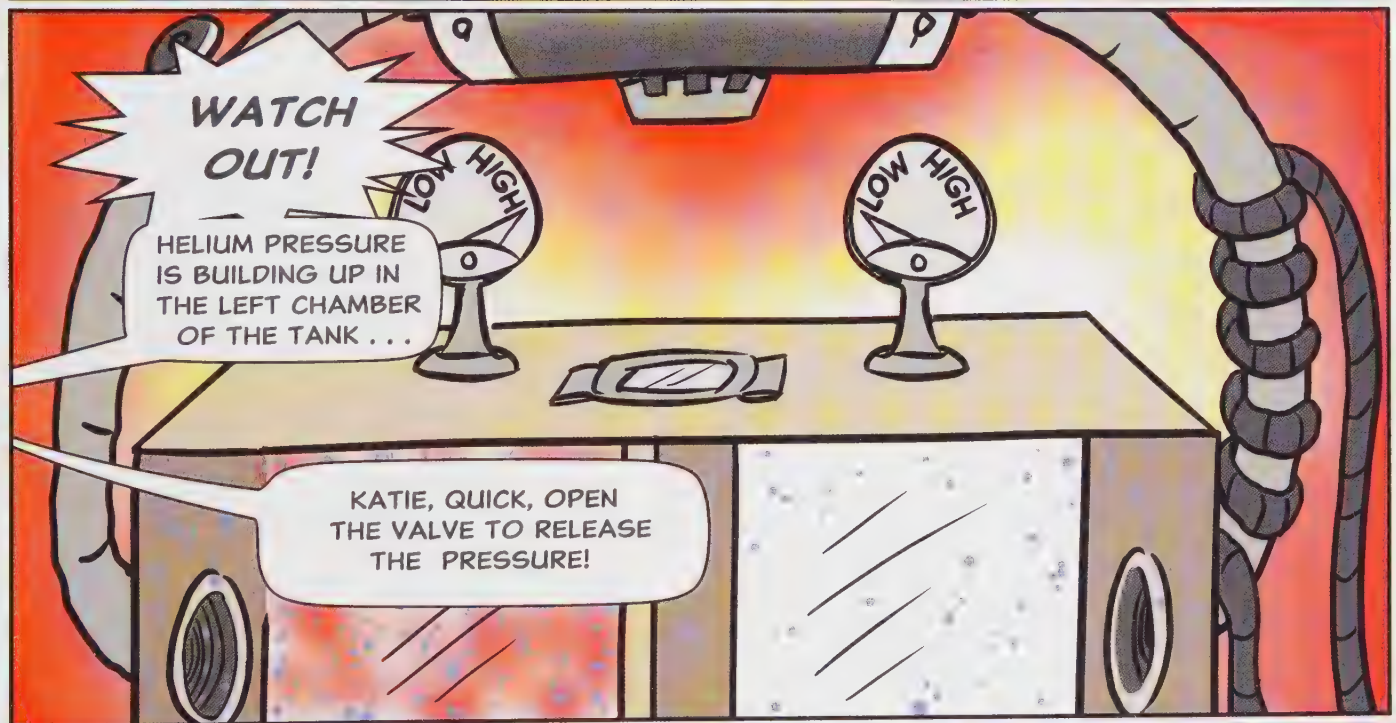
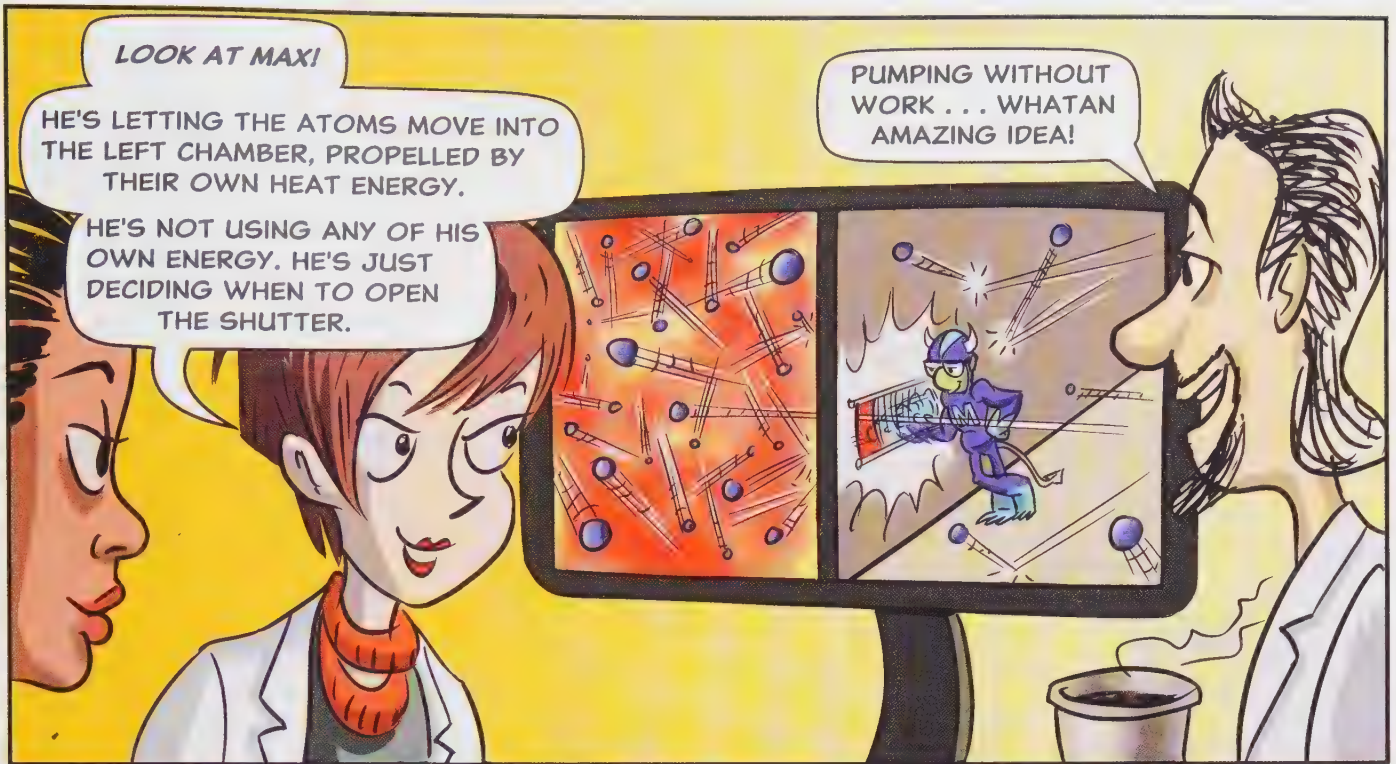
UH-OH ... HELIUM
ATOMS ARE HEADING
MY WAY.

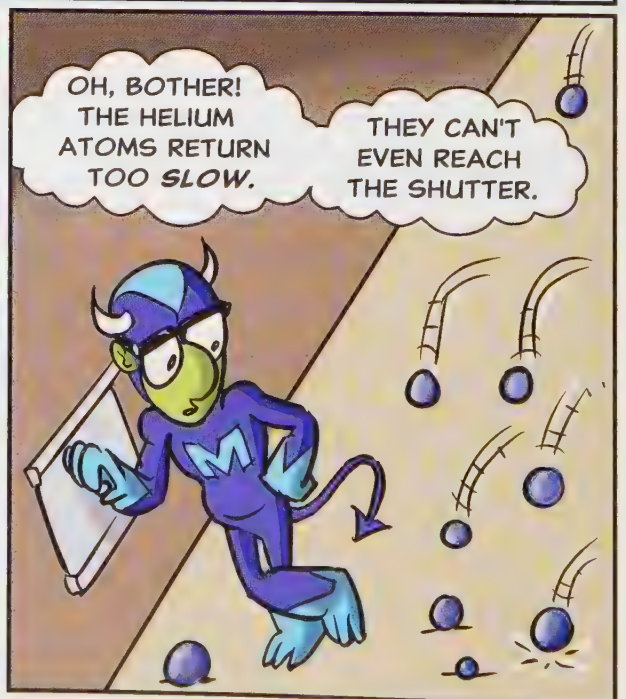
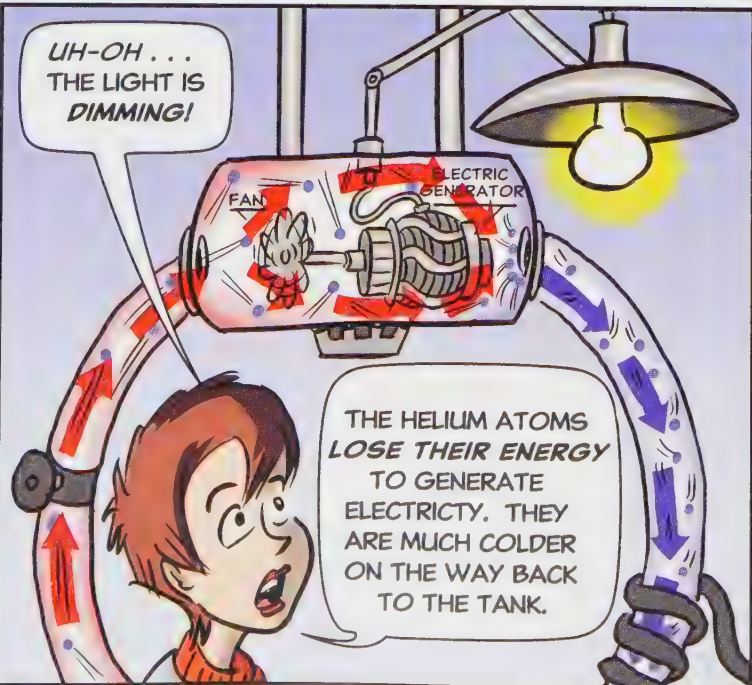


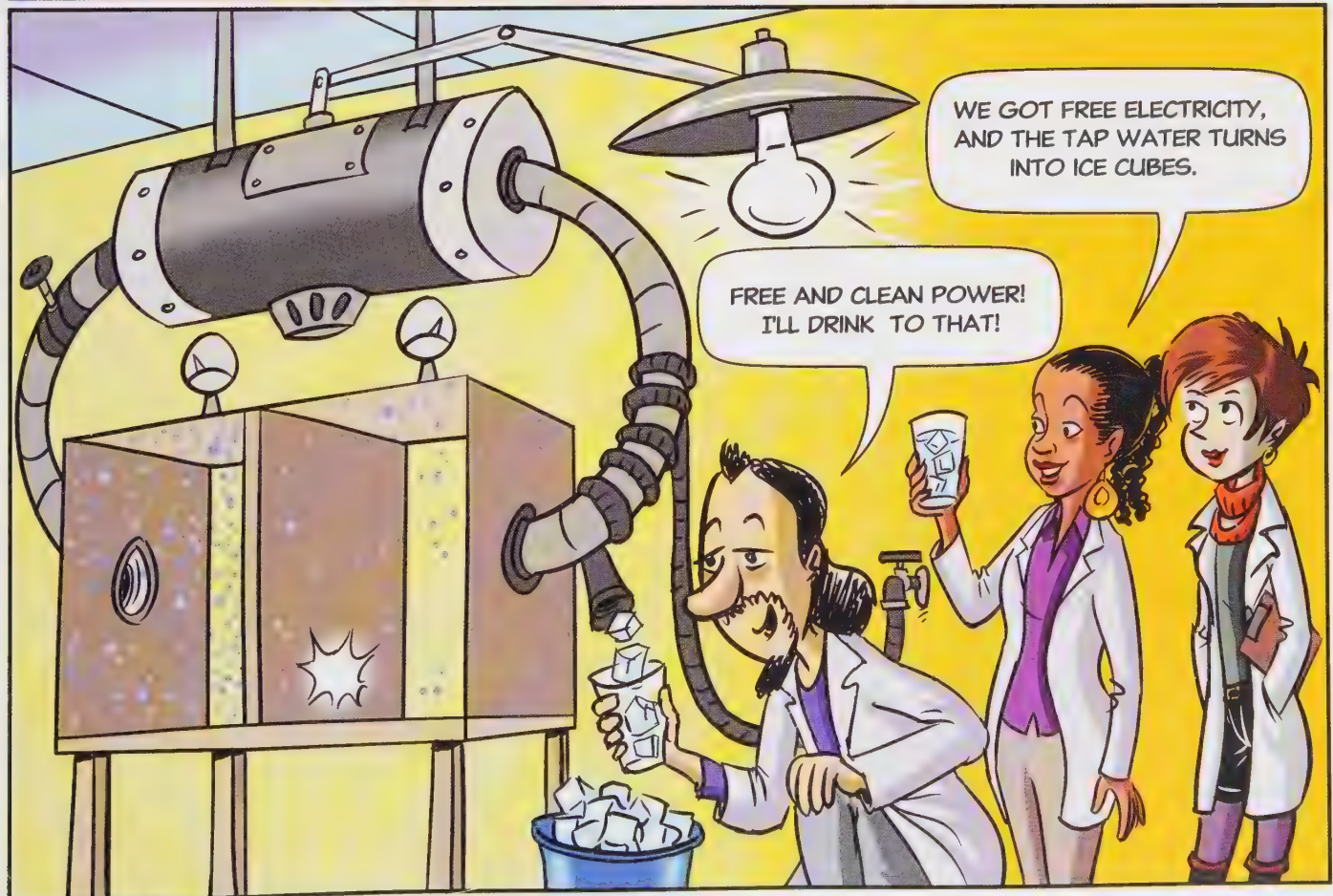
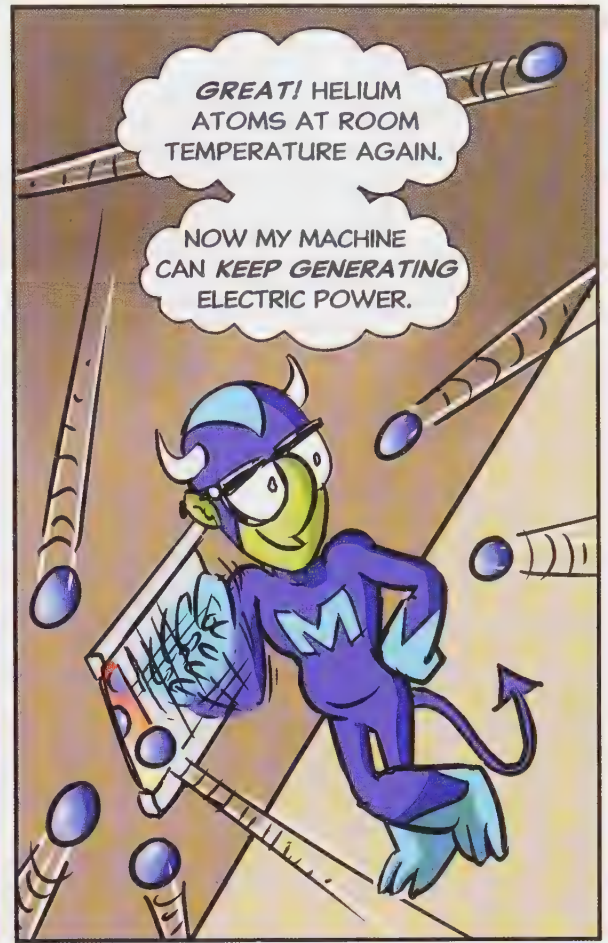
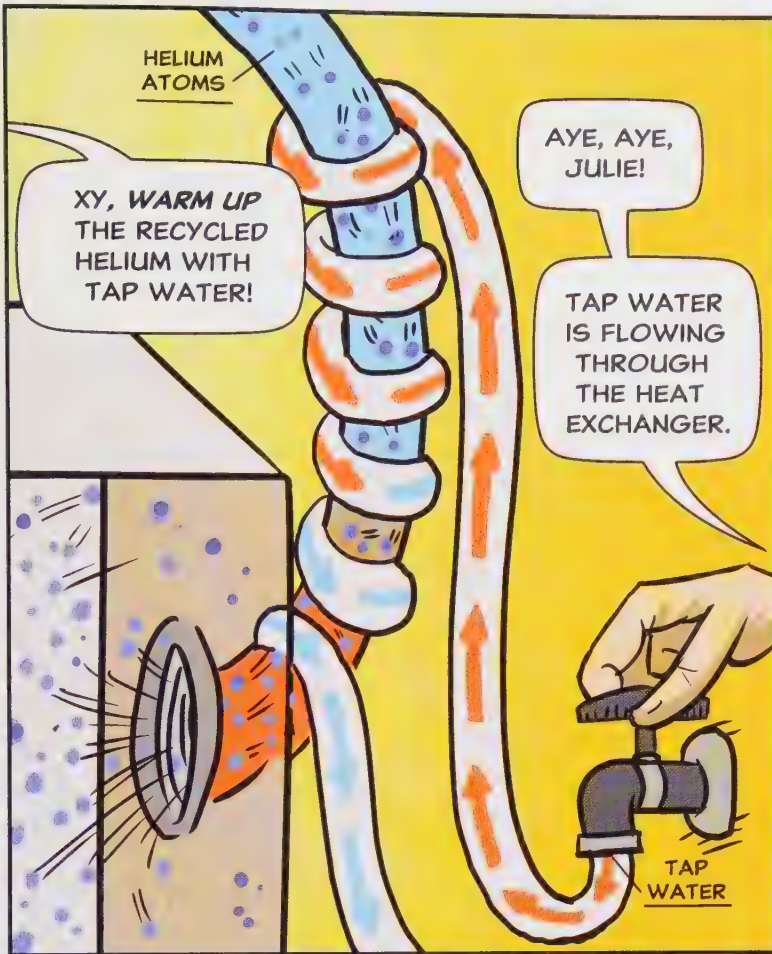
I'M OPENING THE DOOR
WITHOUT ANY EFFORT
TO LET THEM FLY INTO
THE LEFT CHAMBER.



AND I'M *NOT*
LETTING ANY ATOMS
RETURN FROM THE
LEFT CHAMBER.







CHECK THIS OUT: ENERGY IS FLOWING FROM LUKEWARM TAP WATER TO A BRIGHT HOT LIGHT BULB. ISN'T THAT A DOWNRIGHT VIOLATION OF THE SECOND LAW?

YOU'RE RIGHT!

I BET CARNOT WOULD NOT BE AMUSED, IF HE WERE HERE ...

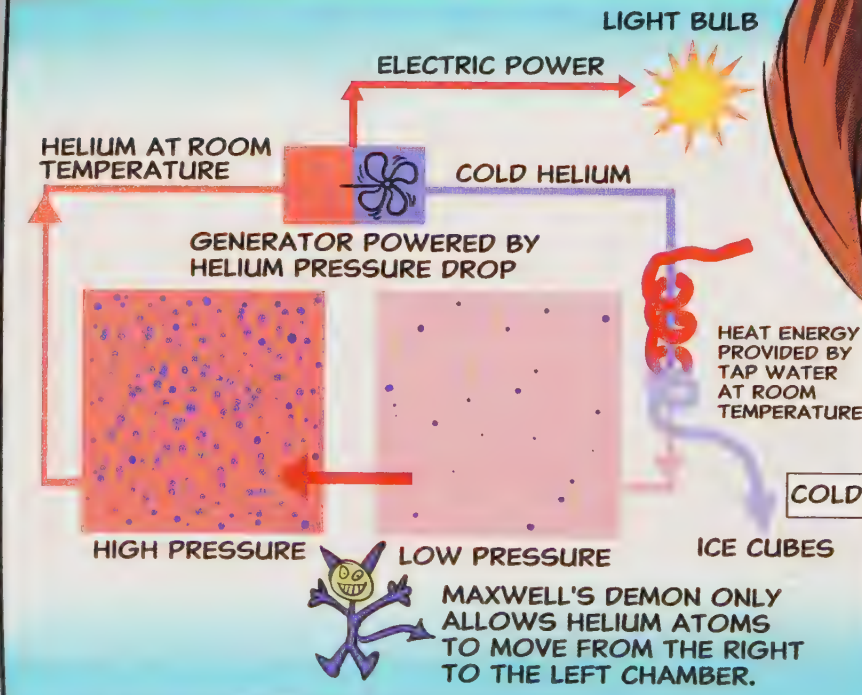


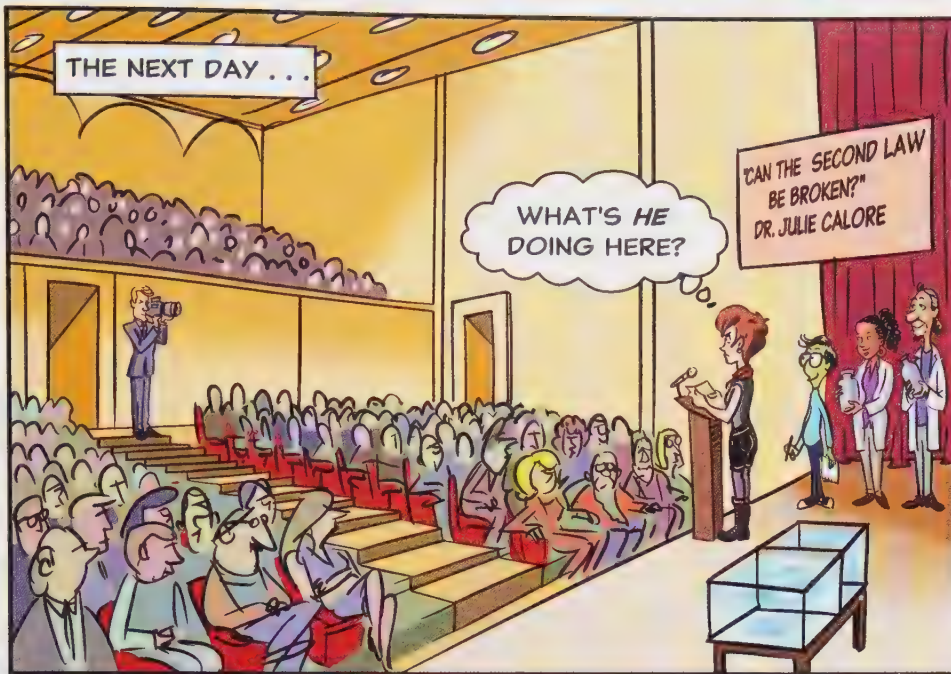
INDEED. MAX SELECTS WHICH ATOMS CAN PASS THROUGH HIS SHUTTER.

HE CHOOSES *IMPROBABLE MICROSTATES*, WITH MORE ATOMS IN THE LEFT CHAMBER THAN IN THE RIGHT ONE.

THAT'S HOW MAX REDUCES THE ENTROPY.

TOMORROW I'LL GIVE A SEMINAR ABOUT THIS. IT'LL BE SENSATIONAL!

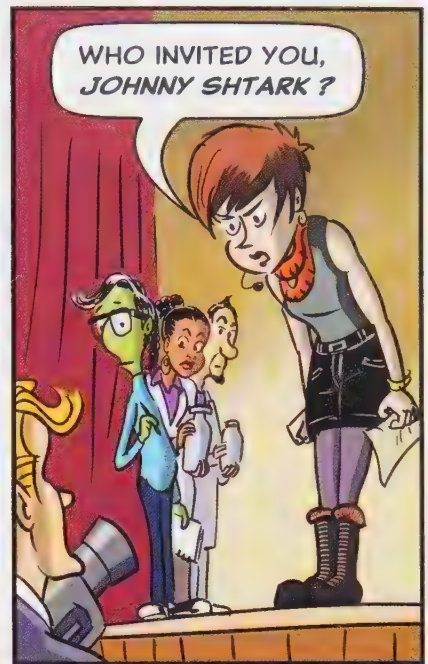




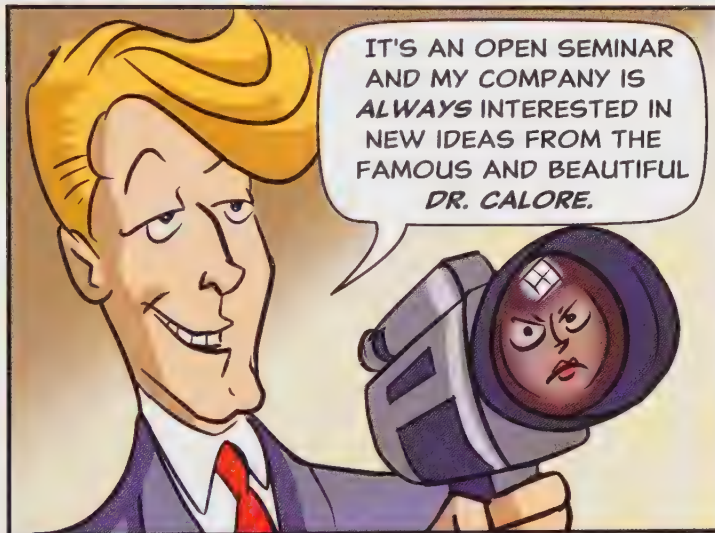
THE NEXT DAY ...

WHAT'S HE DOING HERE?

"CAN THE SECOND LAW BE BROKEN?"
DR. JULIE CALORE



WHO INVITED YOU,
JOHNNY SHTARK?



IT'S AN OPEN SEMINAR
AND MY COMPANY IS
ALWAYS INTERESTED IN
NEW IDEAS FROM THE
FAMOUS AND BEAUTIFUL
DR. CALORE.



FINE, BUT KEEP AWAY
FROM MY EQUIPMENT,
MY ASSISTANTS AND ME.



MAXWELL'S DEMON
WILL DESALINATE
SALTY WATER
WITHOUT ANY
POWER SUPPLY. ...

MAX, GET READY...
MINIATURIZE!

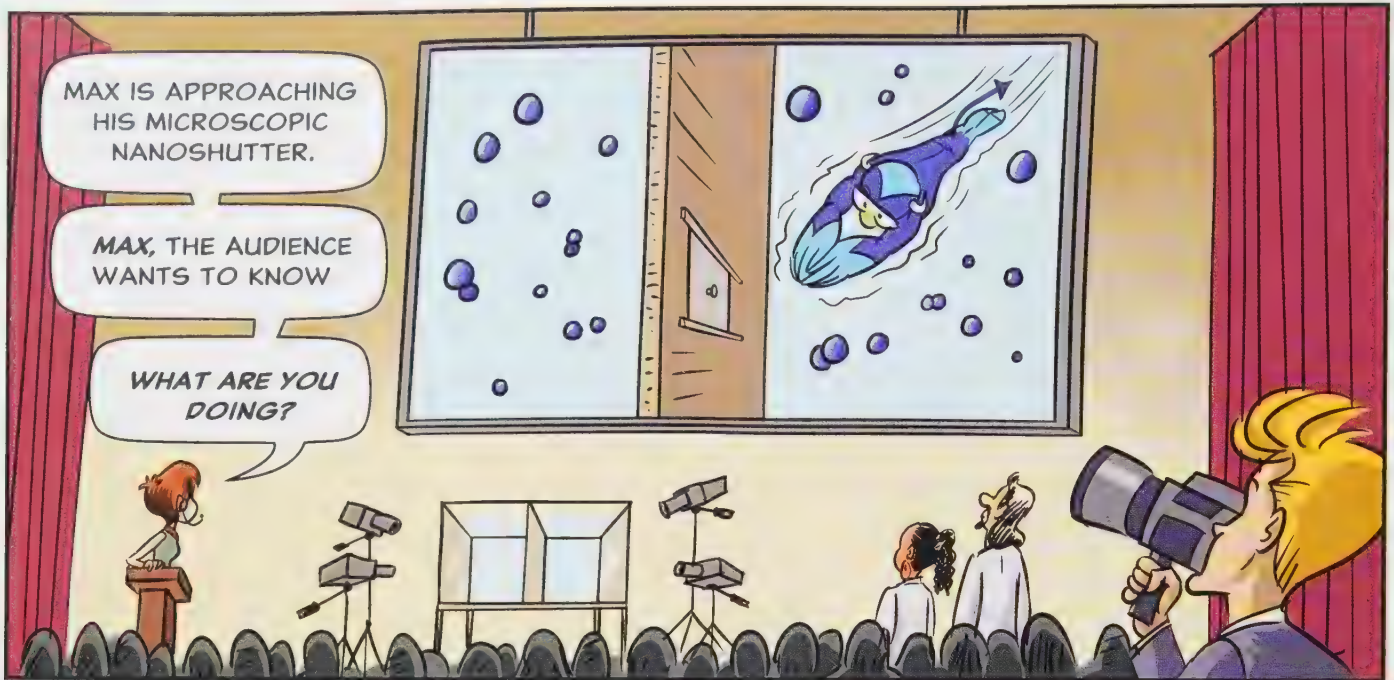
KATIE AND XY:
POUR IN THE SALT.

ABSOLUTE
IMPOSSIBILITY!

HE CAN'T BREAK
THE SECOND LAW!

PREPOSTEROUS!

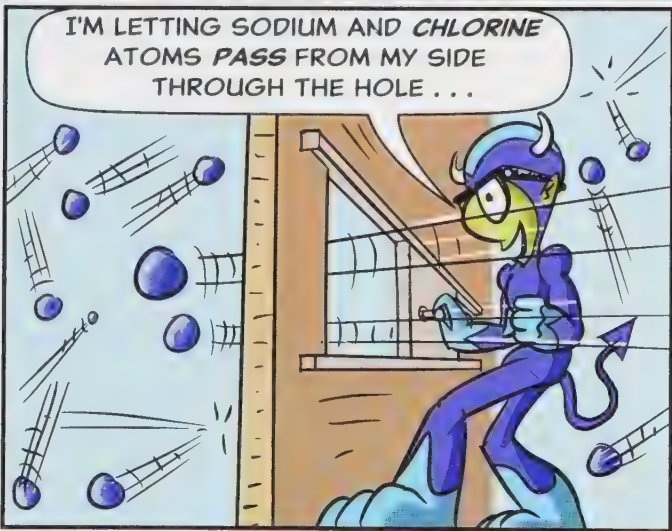
CHARLATANS!



MAX IS APPROACHING HIS MICROSCOPIC NANOSHUTTER.

MAX, THE AUDIENCE WANTS TO KNOW

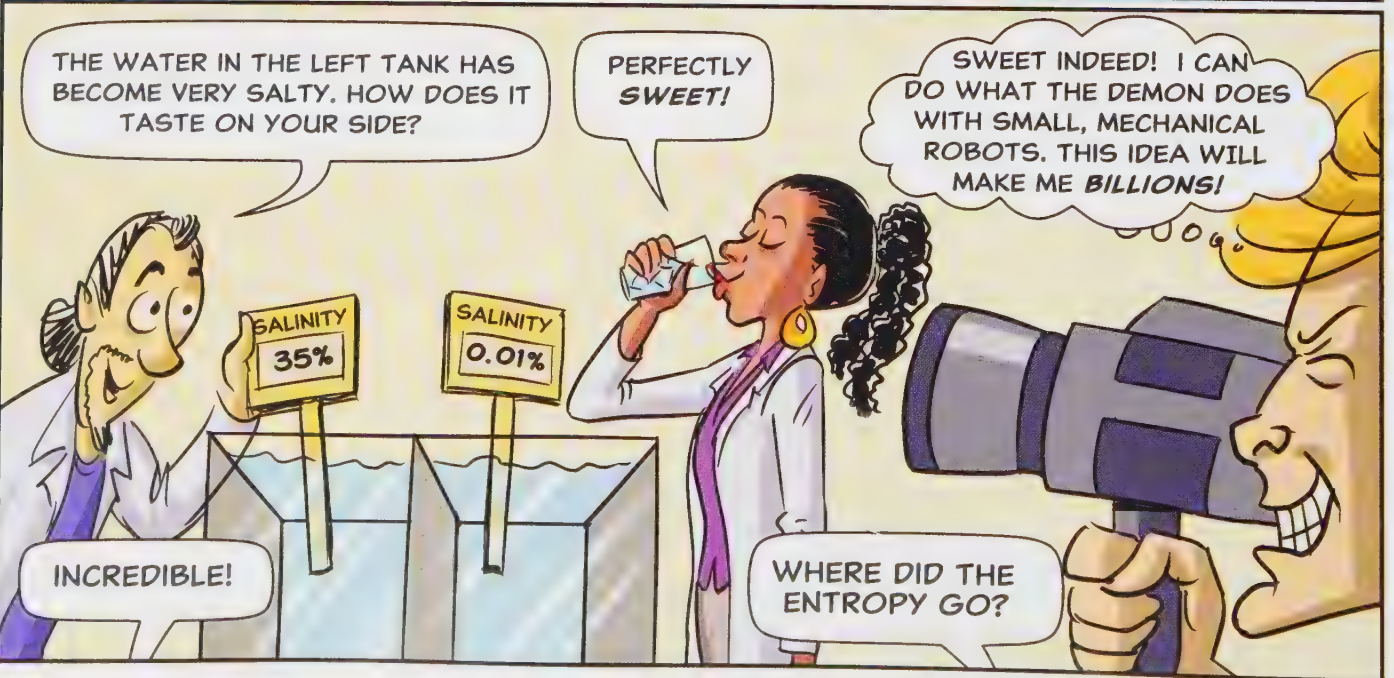
WHAT ARE YOU DOING?



I'M LETTING SODIUM AND CHLORINE ATOMS PASS FROM MY SIDE THROUGH THE HOLE . . .



AND I'M BLOCKING THEM FROM RETURNING FROM THE OTHER SIDE!



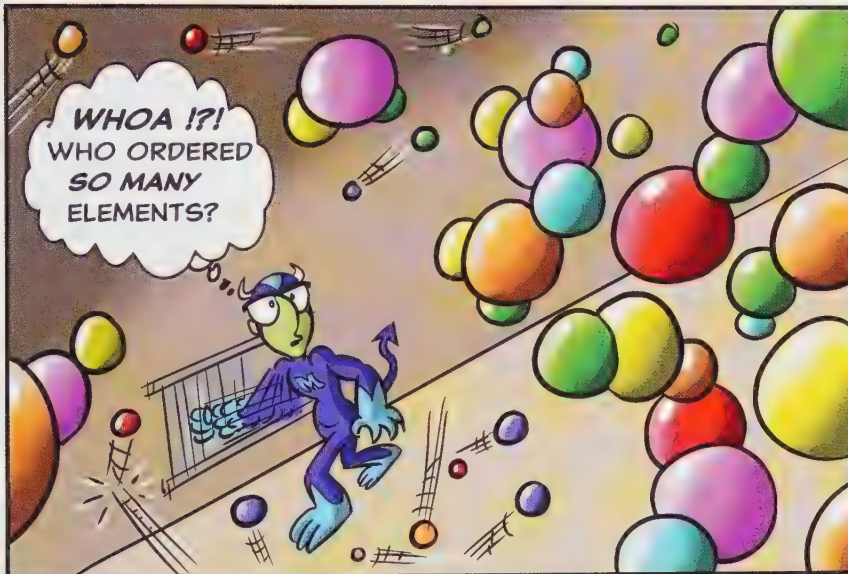
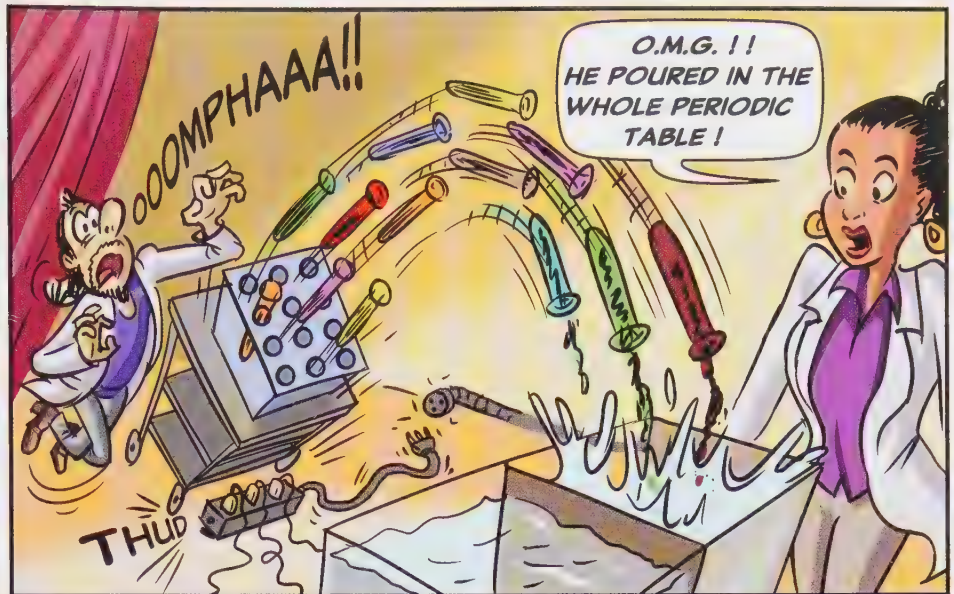
THE WATER IN THE LEFT TANK HAS BECOME VERY SALTY. HOW DOES IT TASTE ON YOUR SIDE?

PERFECTLY SWEET!

SWEET INDEED! I CAN DO WHAT THE DEMON DOES WITH SMALL, MECHANICAL ROBOTS. THIS IDEA WILL MAKE ME BILLIONS!

INCREDIBLE!

WHERE DID THE ENTROPY GO?



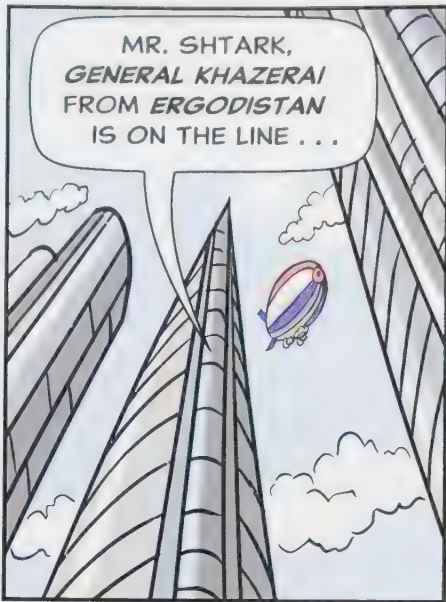


CHAPTER VII

6 MONTHS LATER



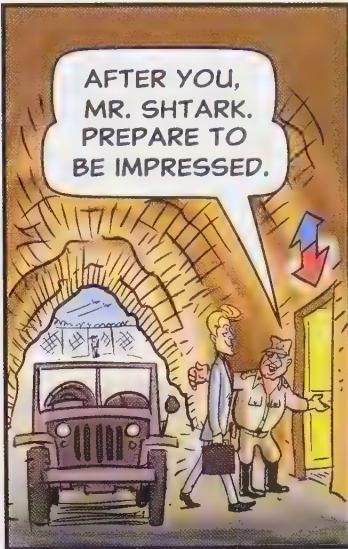
THE MECHANICAL DEMONS' DEBACLE



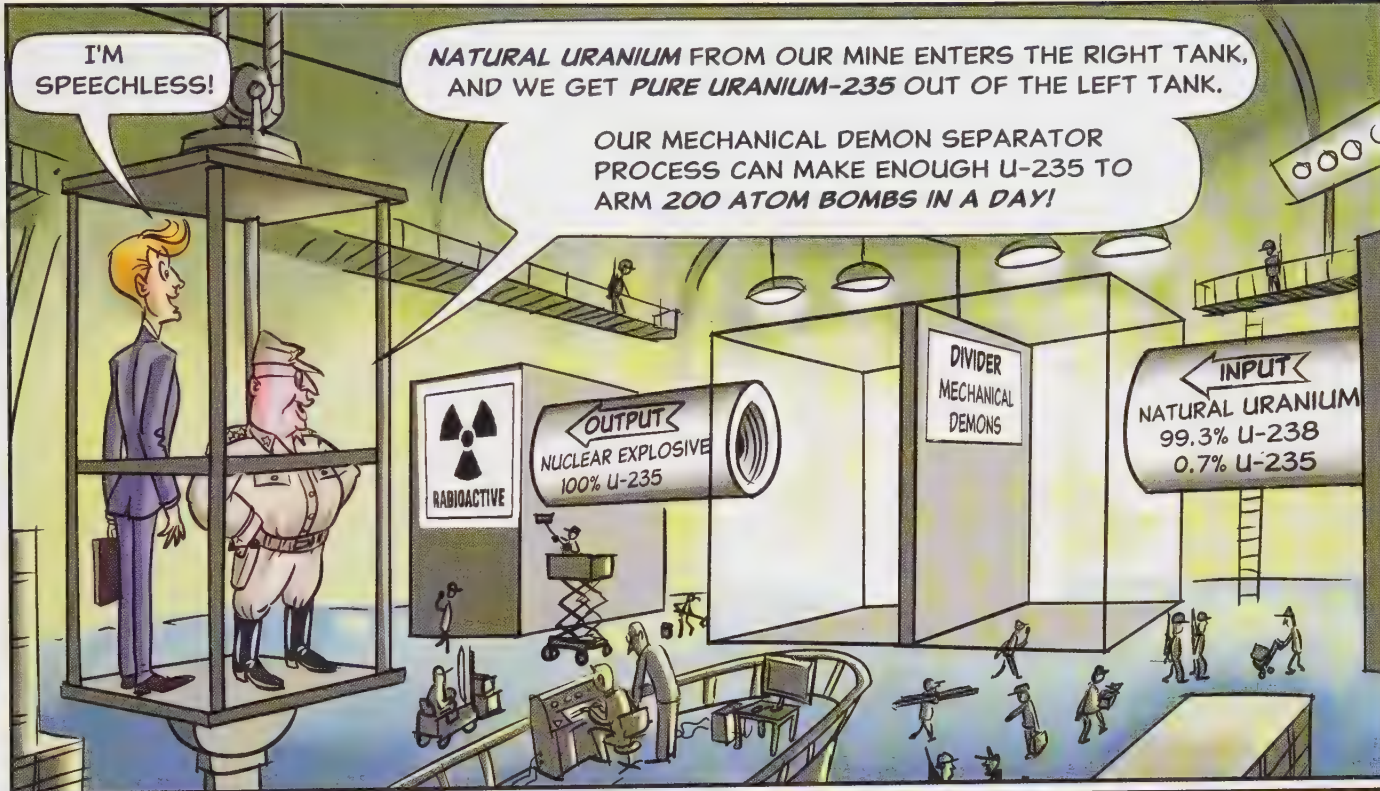
TWO WEEKS LATER

THIS INSTALLATION IS TOP SECRET. NOBODY, OUTSIDE ERGODISTAN, KNOWS ANYTHING ABOUT IT AND WE INTEND TO KEEP IT THAT WAY-UNDERSTOOD?

YOU CAN TRUST ME, GENERAL.



AFTER YOU, MR. SHTARK. PREPARE TO BE IMPRESSED.



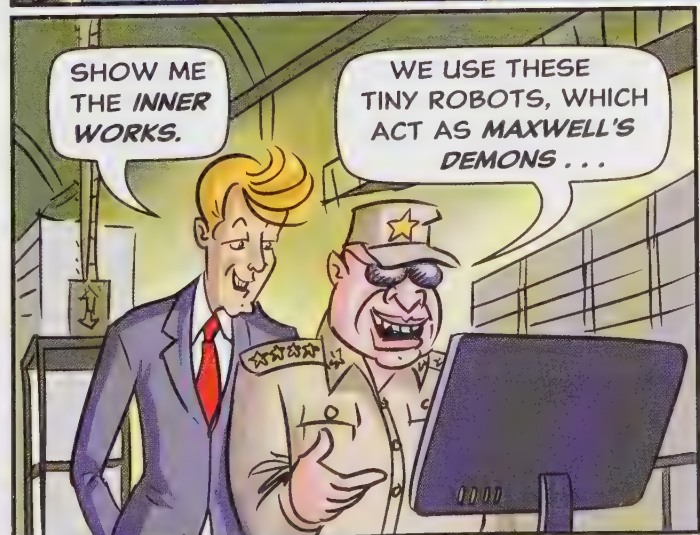
I'M SPEECHLESS!

NATURAL URANIUM FROM OUR MINE ENTERS THE RIGHT TANK, AND WE GET PURE URANIUM-235 OUT OF THE LEFT TANK.

OUR MECHANICAL DEMON SEPARATOR PROCESS CAN MAKE ENOUGH U-235 TO ARM 200 ATOM BOMBS IN A DAY!

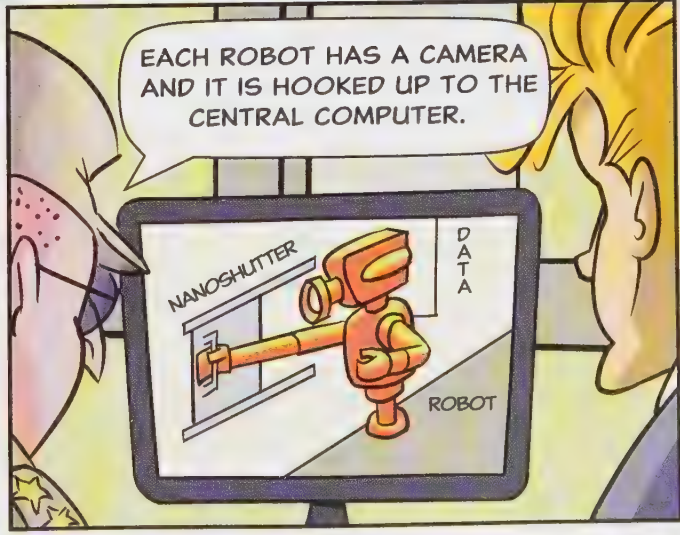
OUTPUT
NUCLEAR EXPLOSIVE
100% U-235

INPUT
NATURAL URANIUM
99.3% U-238
0.7% U-235



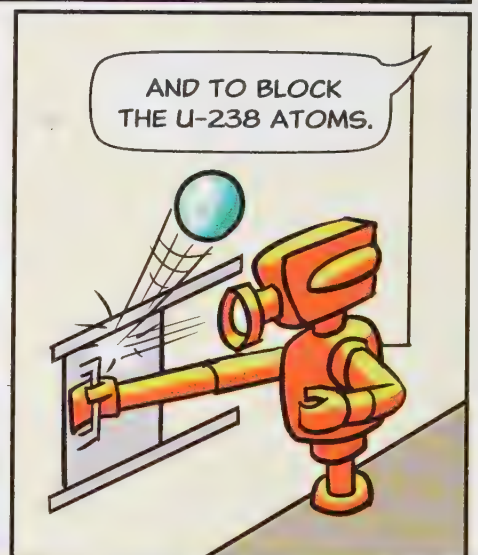
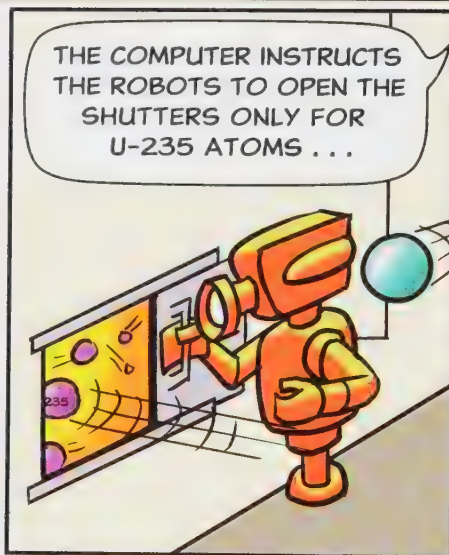
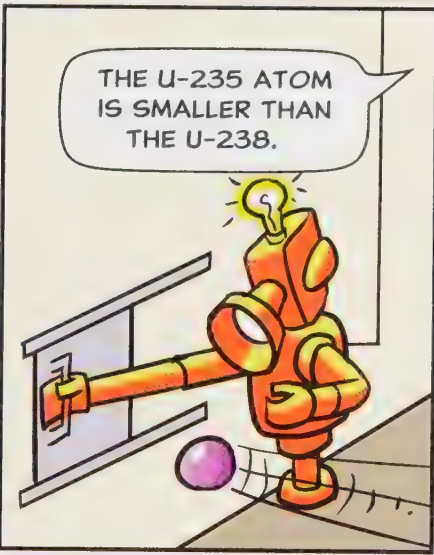
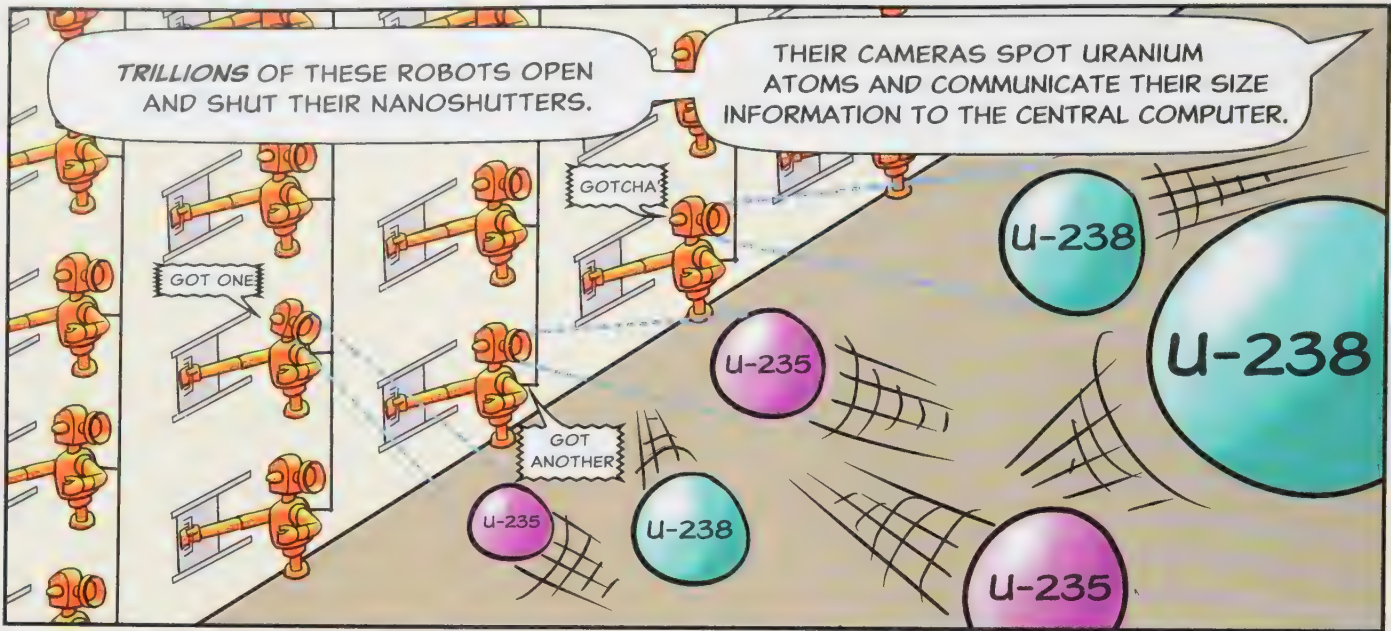
SHOW ME THE INNER WORKS.

WE USE THESE TINY ROBOTS, WHICH ACT AS MAXWELL'S DEMONS...



EACH ROBOT HAS A CAMERA AND IT IS HOOKED UP TO THE CENTRAL COMPUTER.

NANOSHUTTER
DATA
ROBOT





TRUSTED OFFICERS, LOYAL CITIZENS
AND SNIVELING SYCOPHANTS!
TODAY IS A GLORIOUS DAY
FOR ERGODISTAN!



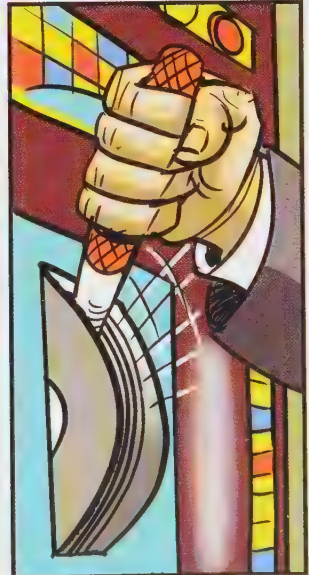
FOR MANY YEARS, WE HAVE SUFFERED THE
DISRESPECT OF OUR NEIGHBORS AND
RIDICULE FROM THE REST OF THE WORLD ..

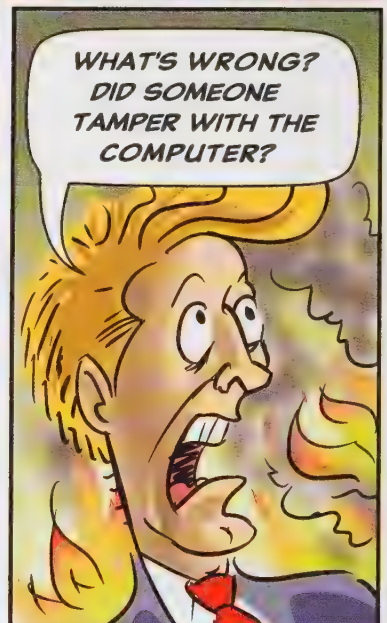
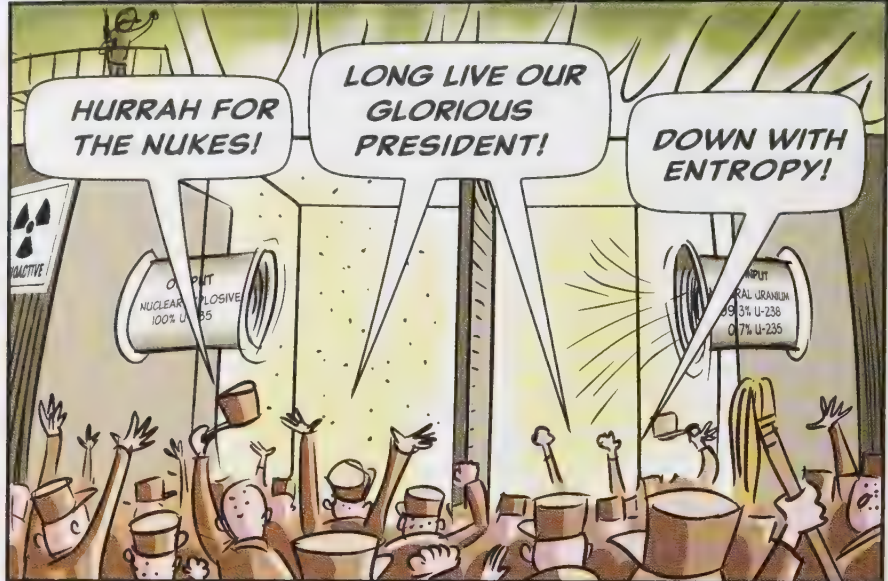
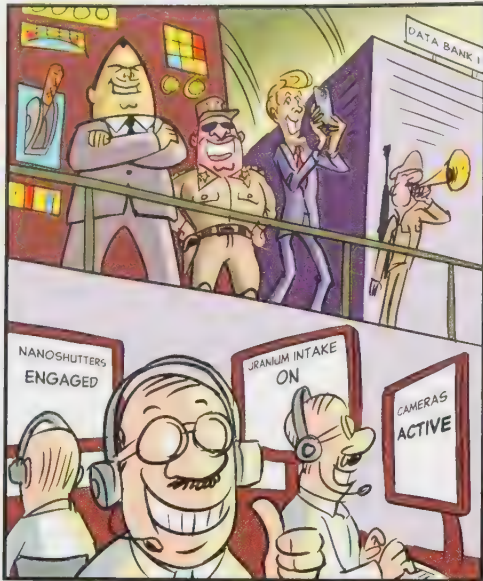
BUT I AM ABOUT TO CHANGE ALL THAT!

OUR *MECHANICAL DEMONS*
WILL IGNOMINIOUSLY THWART THE
SECOND LAW OF THERMODYNAMICS
AND MAKE US MANY MAGNIFICENT
NUCLEAR WEAPONS!

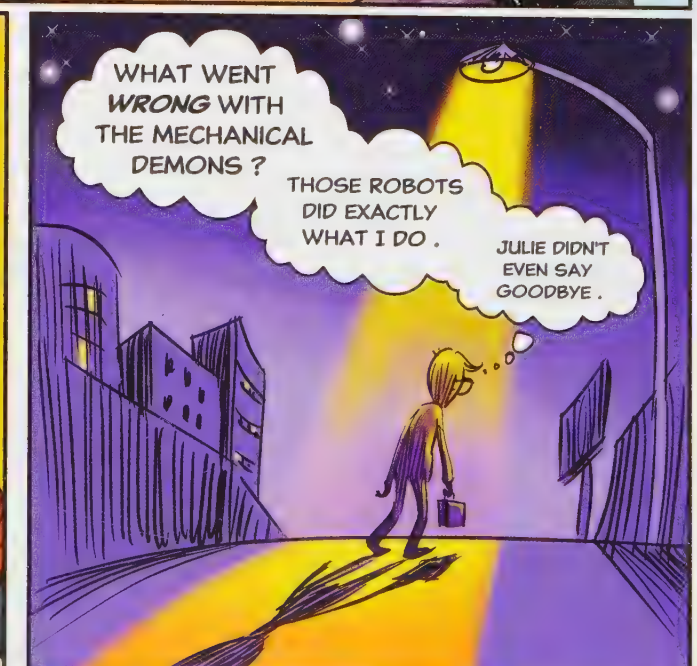
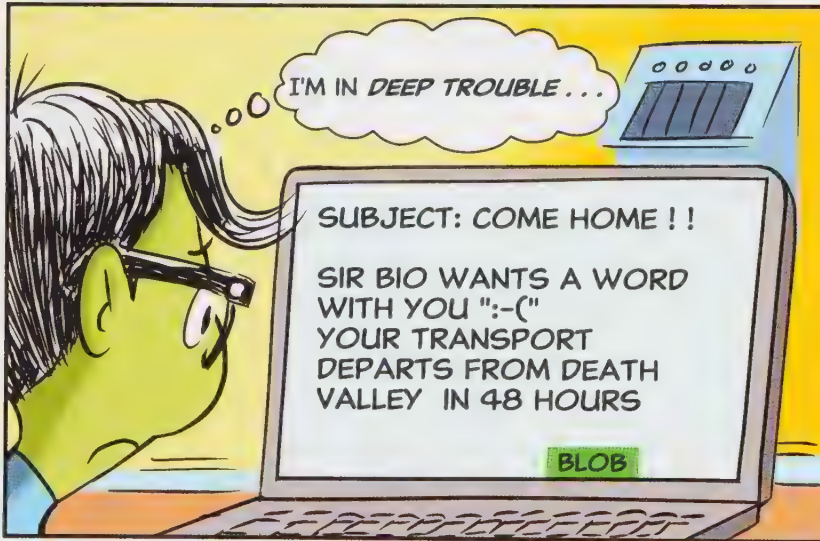
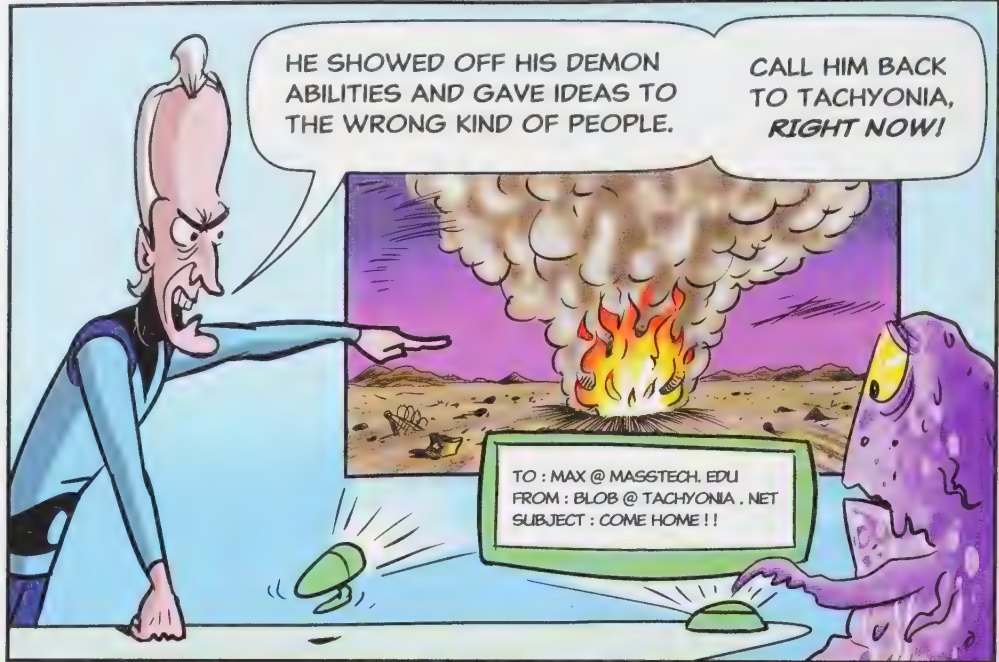


AS WE PLAY OUR BEAUTIFUL AND *INSPIRING*
NATIONAL ANTHEM, PLEASE FOLLOW ME IN
AN *ENTHUSIASTIC CHEER*, WHILE I INITIATE
OUR FIRST, PROUD STEPS INTO A
MAGNIFICENT AND EVER *BRIGHTER* FUTURE.



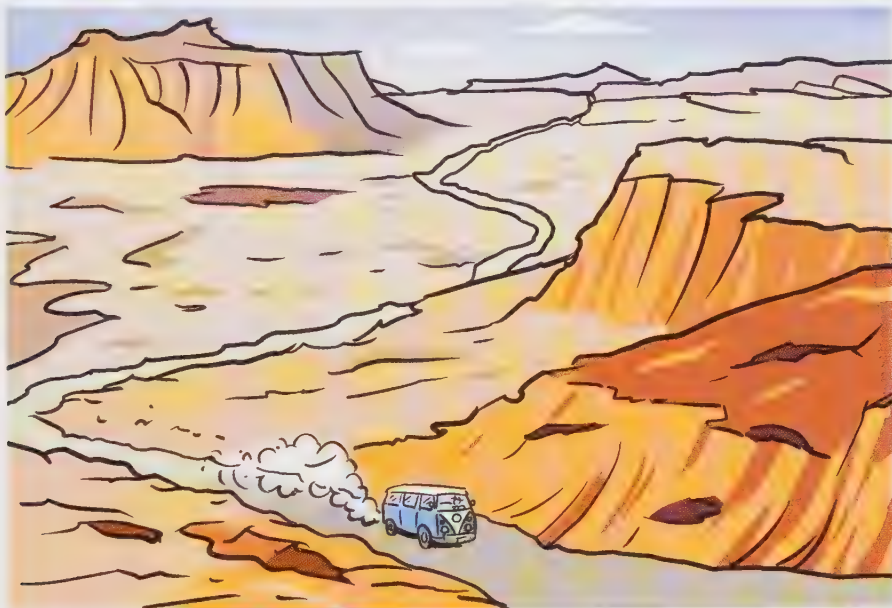




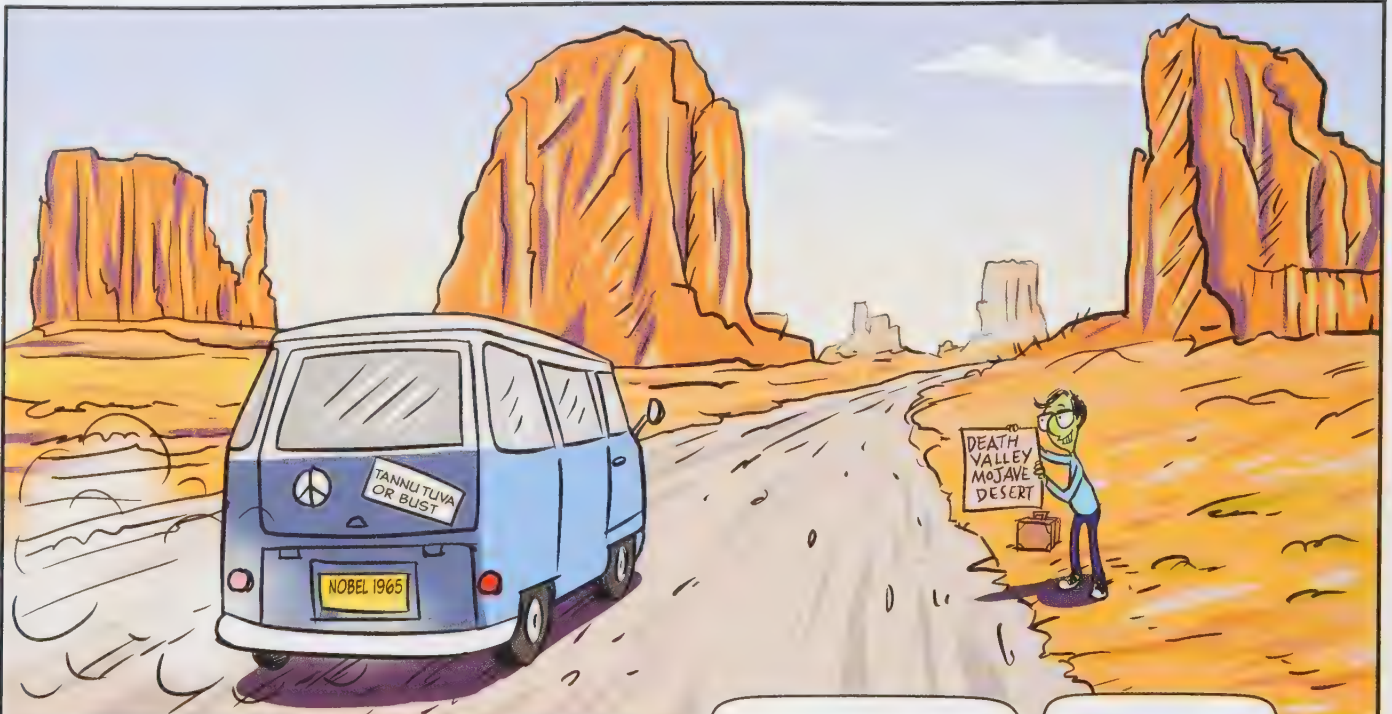


CHAPTER VIII

MOJAVE DESERT, THE NEXT DAY



ENTROPY AND INFORMATION



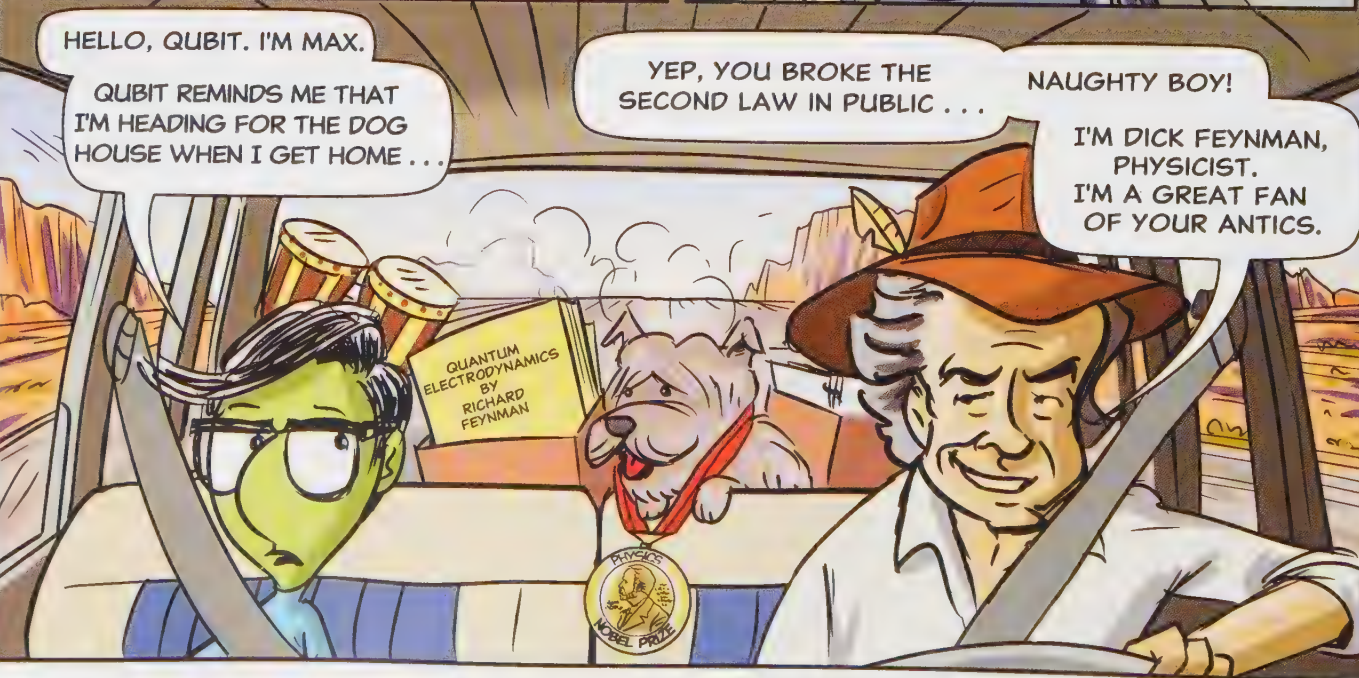
HELLO, CAN I GET A RIDE WITH YOU?

SURE, HOP RIGHT IN.



THERE'S COLD BEER IN THE BACK.

SAY HI TO MY DOG, QUBIT.



HELLO, QUBIT. I'M MAX.
QUBIT REMINDS ME THAT I'M HEADING FOR THE DOG HOUSE WHEN I GET HOME...

YEP, YOU BROKE THE SECOND LAW IN PUBLIC...

NAUGHTY BOY!
I'M DICK FEYNMAN, PHYSICIST. I'M A GREAT FAN OF YOUR ANTICS.

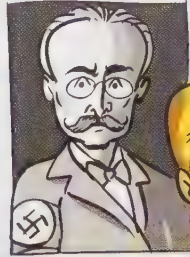


I DIDN'T EXPECT JOHNNY SHTARK TO PUT MY METHODS TO BAD USE.

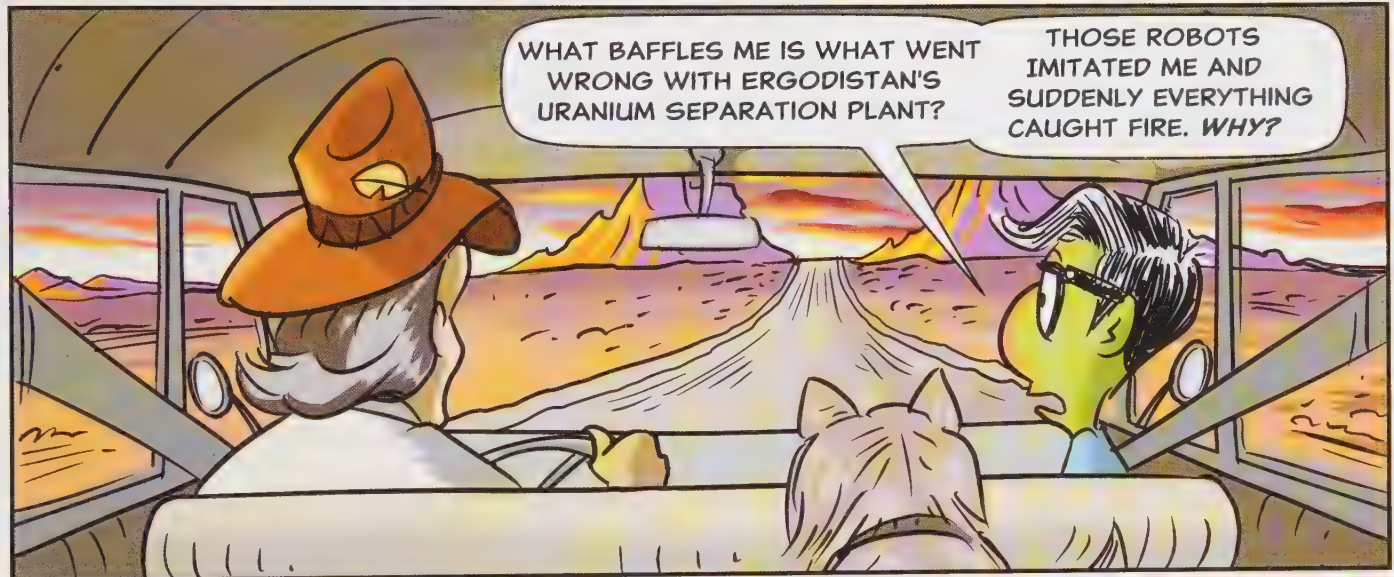


I'M NOT SURPRISED.

HE TOOK AFTER HIS GREAT GRANDFATHER, A PHYSICIST WHO MORPHED INTO A RAVING NAZI.

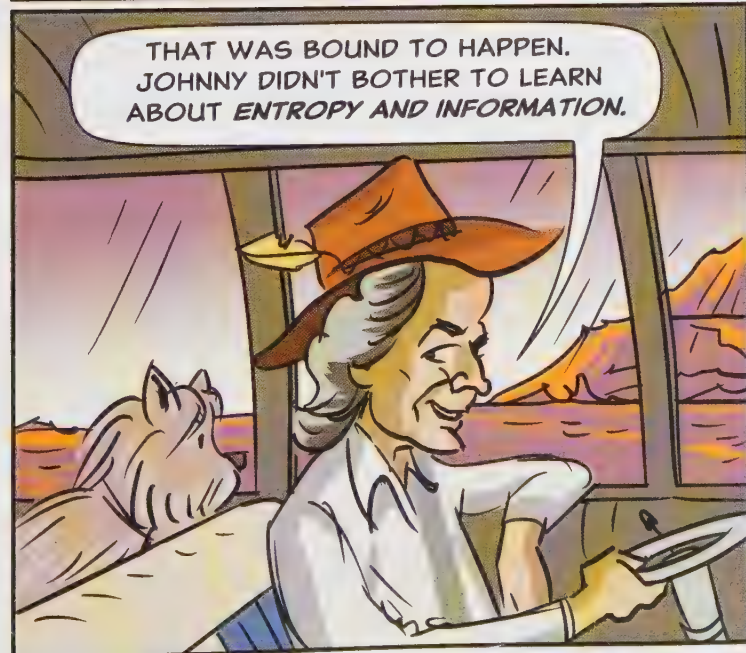


JOHANNES STARK
1874-1957



WHAT Baffles ME IS WHAT WENT WRONG WITH ERGODISTAN'S URANIUM SEPARATION PLANT?

THOSE ROBOTS IMITATED ME AND SUDDENLY EVERYTHING CAUGHT FIRE. WHY?



THAT WAS BOUND TO HAPPEN. JOHNNY DIDN'T BOTHER TO LEARN ABOUT ENTROPY AND INFORMATION.



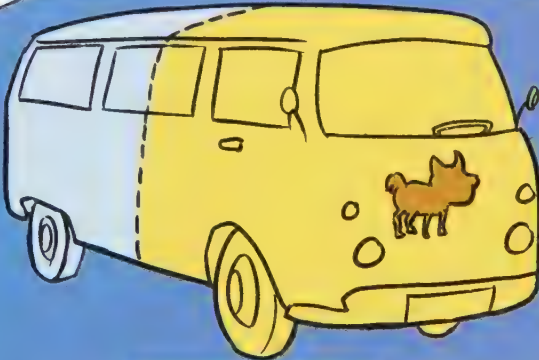
INFORMATION? WHAT DO YOU MEAN BY INFORMATION?

INFORMATION IN PHYSICS QUANTIFIES WHAT WE LEARN ABOUT A SYSTEM WHEN WE MEASURE IT. FOR EXAMPLE: WE LEFT QUBIT IN THE VAN, BUT WE DON'T KNOW PRECISELY WHERE.

HE CAN BE IN TWO POSSIBLE MICROSTATES.

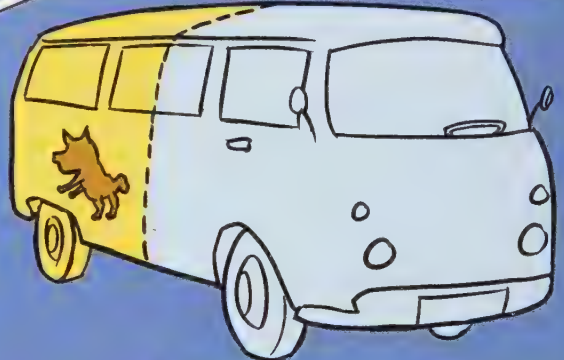


EITHER QUBIT IS IN THE FRONT END, SITTING ON MY DRIVER'S SEAT ...



MICROSTATE 1

OR HE IS IN THE BACK END, GOING THROUGH MY COOLER.



MICROSTATE 2

SINCE WE HAVEN'T A CLUE WHICH ANSWER IS TRUE, WE HAVE ZERO INFORMATION. YET BOLTZMANN SAYS THAT WITH TWO EQUALLY POSSIBLE MICROSTATES, WE'VE GOT $k \log(2)$ WORTH OF ENTROPY.

QUBIT, "THE ENTROPIC DOG"

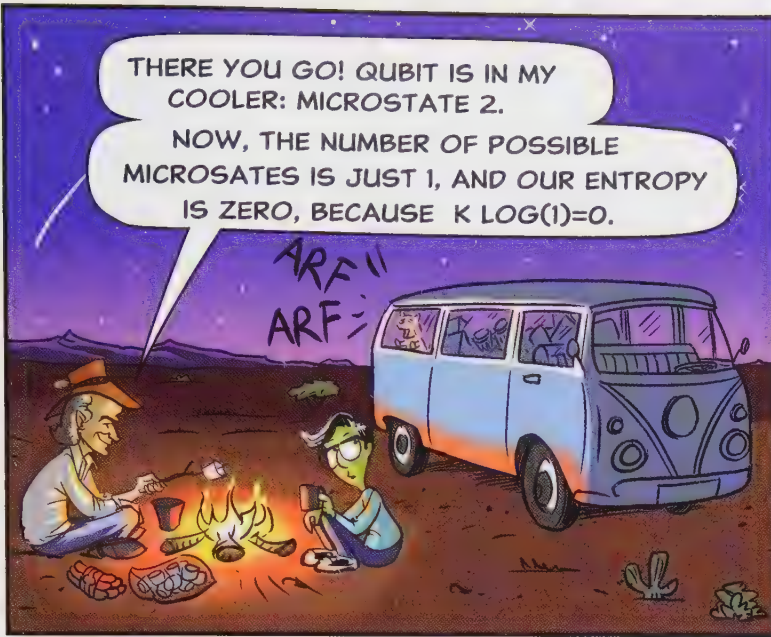


NOW LET'S FIND OUT WHICH MICROSTATE QUBIT IS IN.

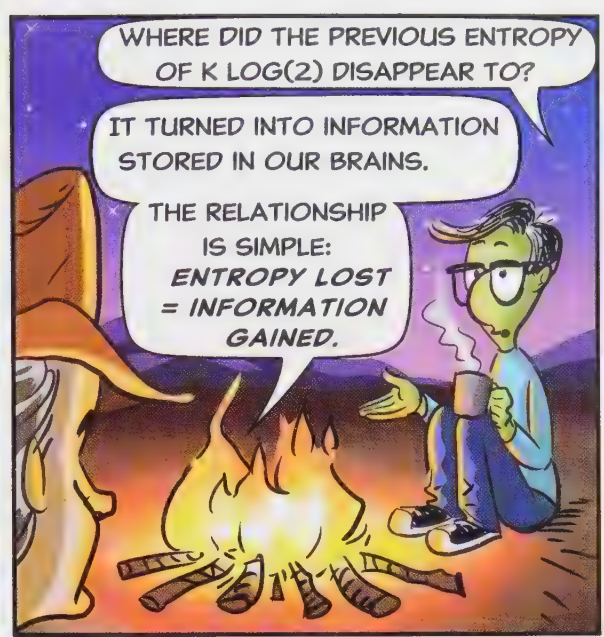
QUBIT! YOUR HOT DOG IS READY!!

CLAP CLAP

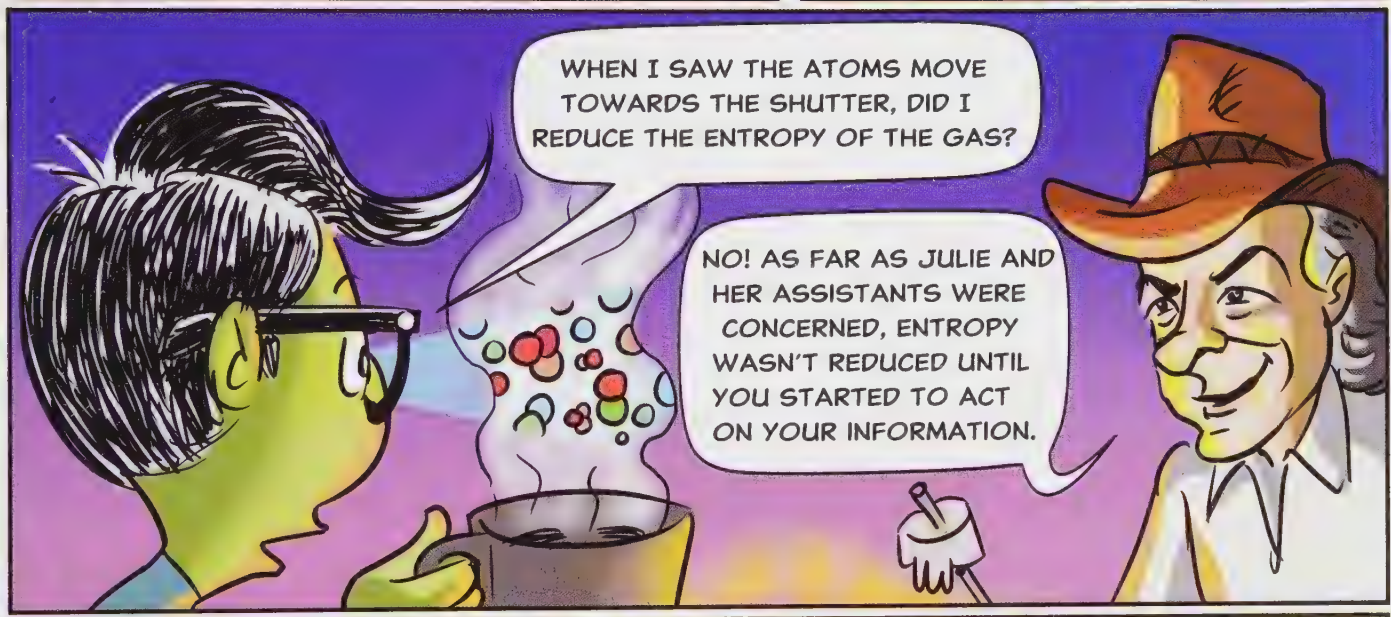




THERE YOU GO! QUBIT IS IN MY COOLER: MICROSTATE 2.
 NOW, THE NUMBER OF POSSIBLE MICROSTATES IS JUST 1, AND OUR ENTROPY IS ZERO, BECAUSE $K \log(1)=0$.



WHERE DID THE PREVIOUS ENTROPY OF $K \log(2)$ DISAPPEAR TO?
 IT TURNED INTO INFORMATION STORED IN OUR BRAINS.
 THE RELATIONSHIP IS SIMPLE:
ENTROPY LOST = INFORMATION GAINED.

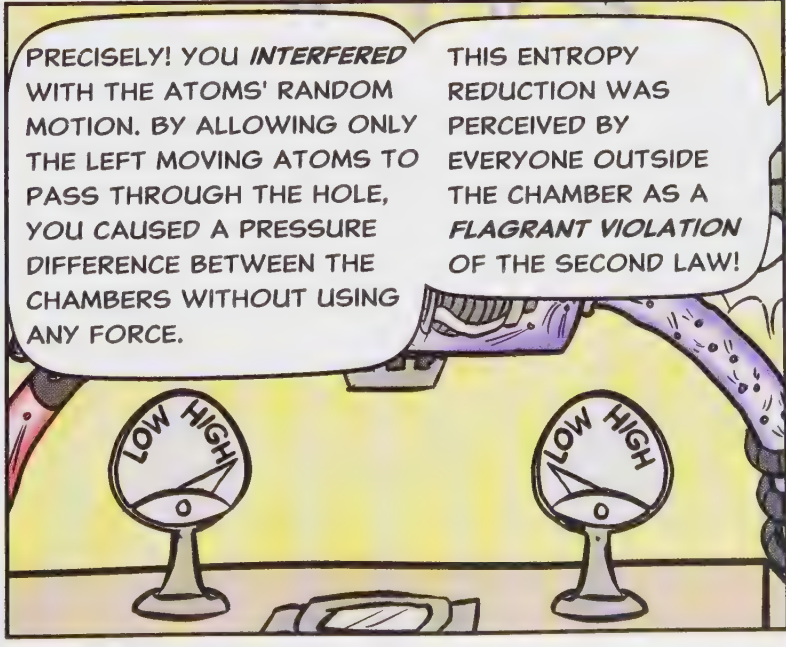


WHEN I SAW THE ATOMS MOVE TOWARDS THE SHUTTER, DID I REDUCE THE ENTROPY OF THE GAS?

NO! AS FAR AS JULIE AND HER ASSISTANTS WERE CONCERNED, ENTROPY WASN'T REDUCED UNTIL YOU STARTED TO ACT ON YOUR INFORMATION.

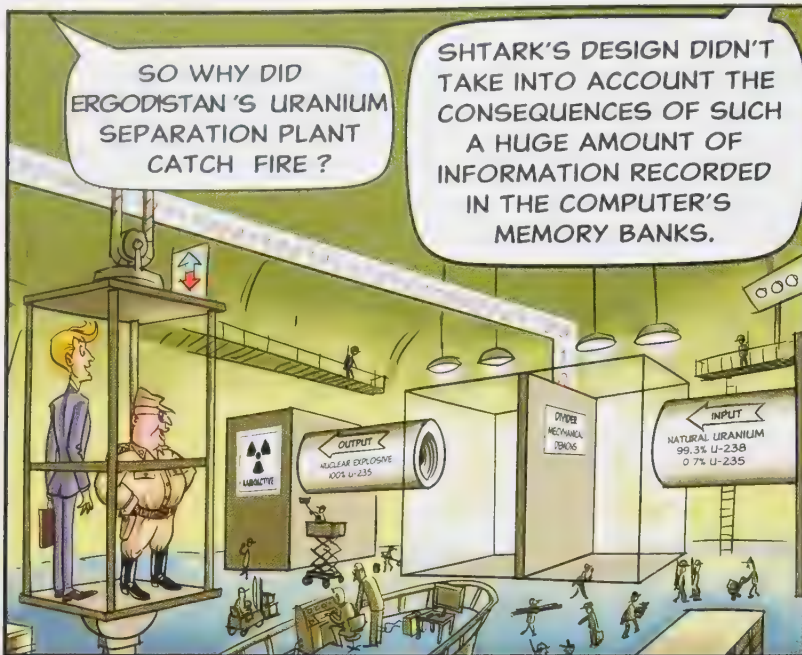


BUT I JUST OPENED AND SHUT MY SHUTTER!



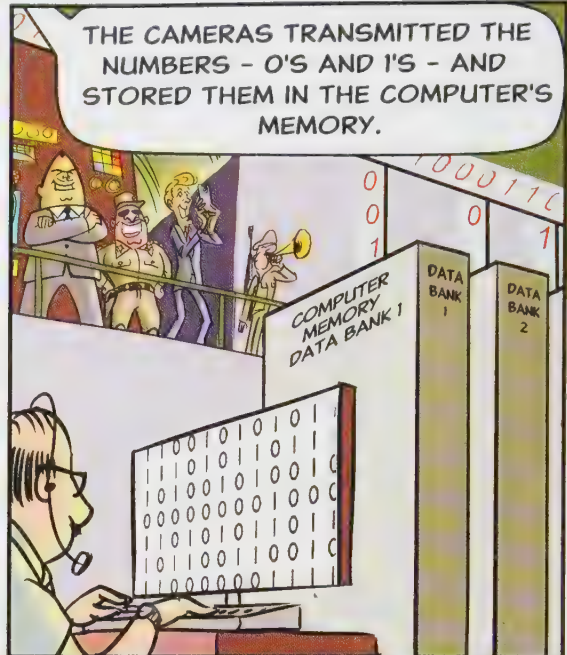
PRECISELY! YOU *INTERFERED* WITH THE ATOMS' RANDOM MOTION. BY ALLOWING ONLY THE LEFT MOVING ATOMS TO PASS THROUGH THE HOLE, YOU CAUSED A PRESSURE DIFFERENCE BETWEEN THE CHAMBERS WITHOUT USING ANY FORCE.

THIS ENTROPY REDUCTION WAS PERCEIVED BY EVERYONE OUTSIDE THE CHAMBER AS A *FLAGRANT VIOLATION* OF THE SECOND LAW!

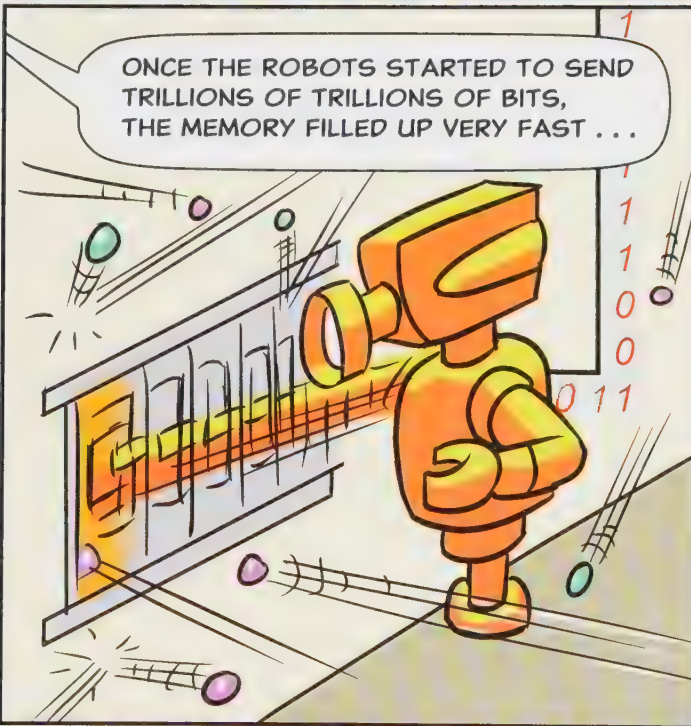


SO WHY DID ERGODISTAN'S URANIUM SEPARATION PLANT CATCH FIRE?

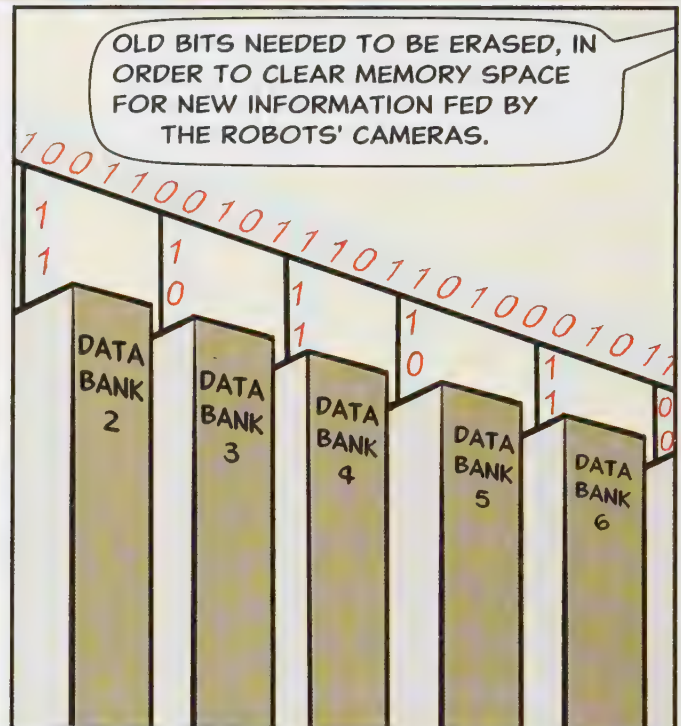
SHTARK'S DESIGN DIDN'T TAKE INTO ACCOUNT THE CONSEQUENCES OF SUCH A HUGE AMOUNT OF INFORMATION RECORDED IN THE COMPUTER'S MEMORY BANKS.



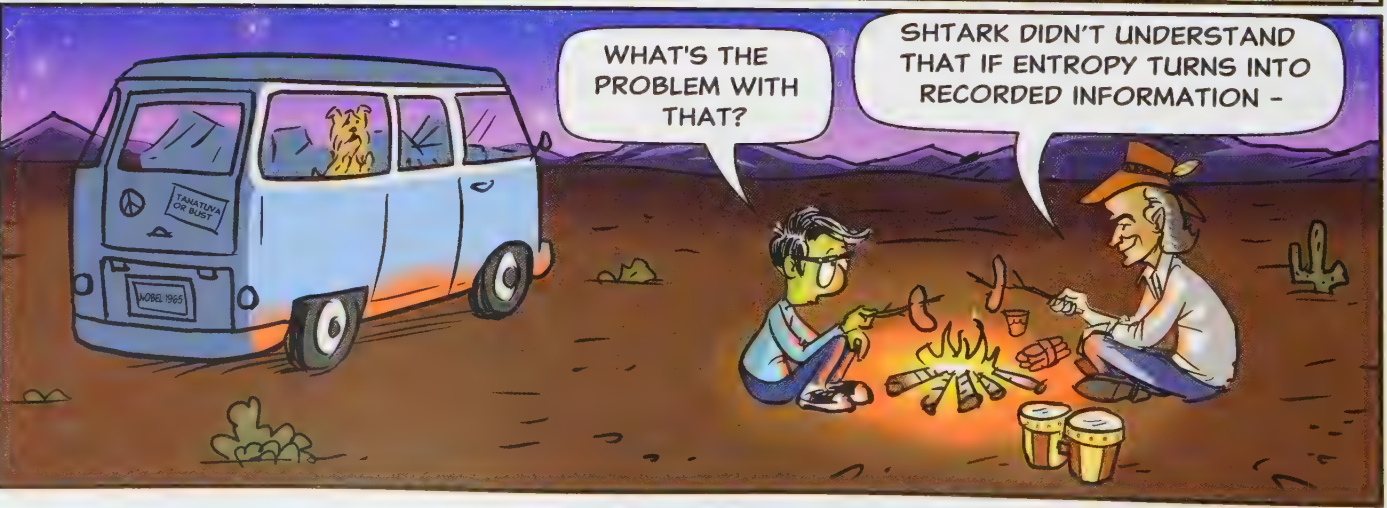
THE CAMERAS TRANSMITTED THE NUMBERS - 0'S AND 1'S - AND STORED THEM IN THE COMPUTER'S MEMORY.



ONCE THE ROBOTS STARTED TO SEND TRILLIONS OF TRILLIONS OF BITS, THE MEMORY FILLED UP VERY FAST ...



OLD BITS NEEDED TO BE ERASED, IN ORDER TO CLEAR MEMORY SPACE FOR NEW INFORMATION FED BY THE ROBOTS' CAMERAS.

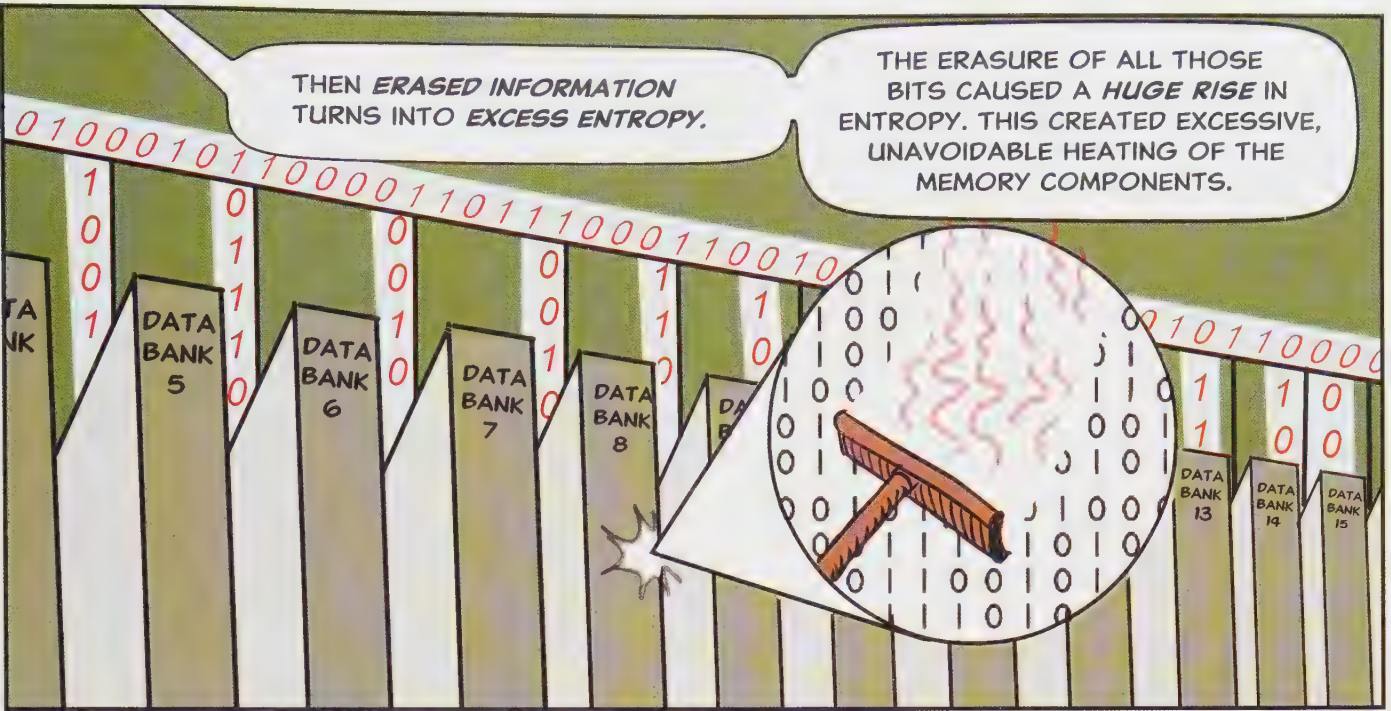


WHAT'S THE PROBLEM WITH THAT?

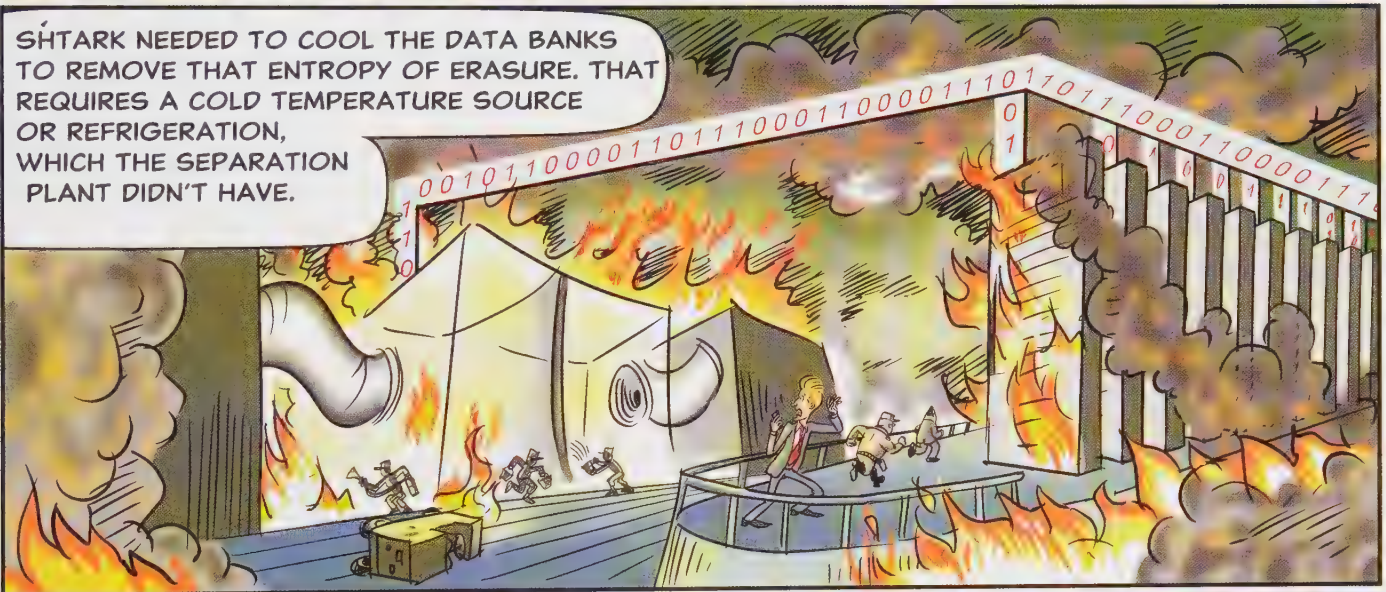
SHTARK DIDN'T UNDERSTAND THAT IF ENTROPY TURNS INTO RECORDED INFORMATION -

THEN *ERASED INFORMATION* TURNS INTO *EXCESS ENTROPY*.

THE ERASURE OF ALL THOSE BITS CAUSED A *HUGE RISE* IN ENTROPY. THIS CREATED EXCESSIVE, UNAVOIDABLE HEATING OF THE MEMORY COMPONENTS.



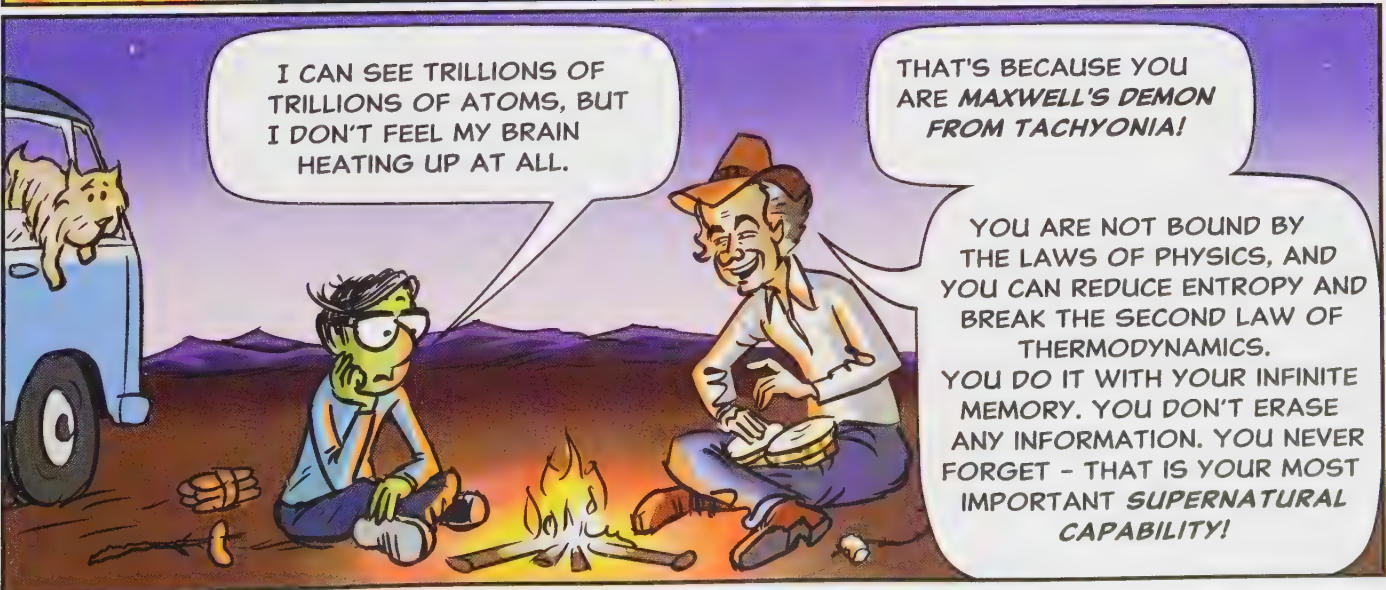
SHTARK NEEDED TO COOL THE DATA BANKS TO REMOVE THAT ENTROPY OF ERASURE. THAT REQUIRES A COLD TEMPERATURE SOURCE OR REFRIGERATION, WHICH THE SEPARATION PLANT DIDN'T HAVE.

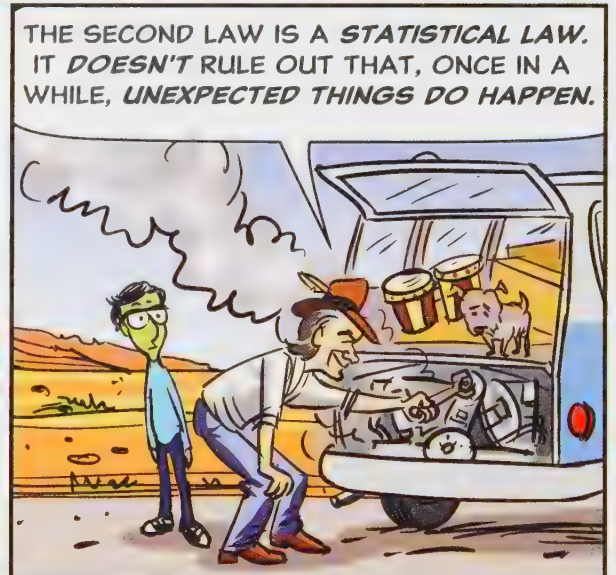
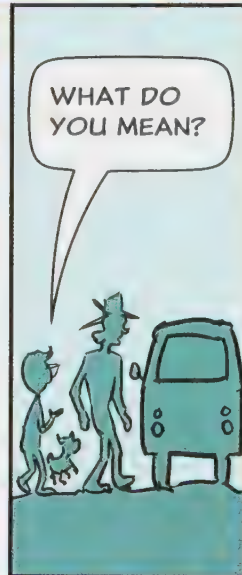


I CAN SEE TRILLIONS OF TRILLIONS OF ATOMS, BUT I DON'T FEEL MY BRAIN HEATING UP AT ALL.

THAT'S BECAUSE YOU ARE *MAXWELL'S DEMON* FROM *TACHYONIA!*

YOU ARE NOT BOUND BY THE LAWS OF PHYSICS, AND YOU CAN REDUCE ENTROPY AND BREAK THE SECOND LAW OF THERMODYNAMICS. YOU DO IT WITH YOUR INFINITE MEMORY. YOU DON'T ERASE ANY INFORMATION. YOU NEVER FORGET - THAT IS YOUR MOST IMPORTANT *SUPERNATURAL CAPABILITY!*



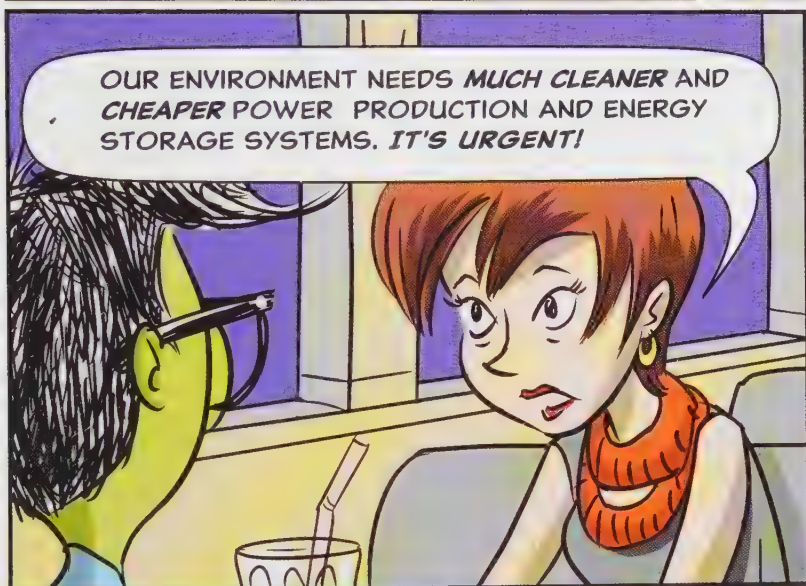
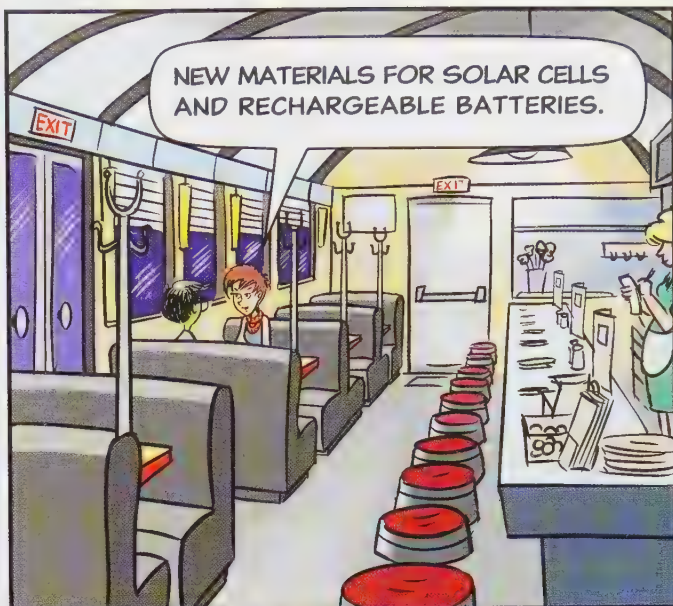


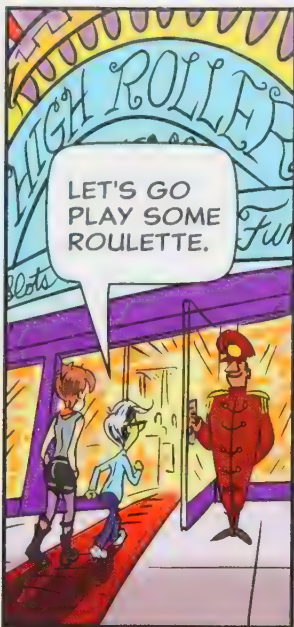
CHAPTER IX



ONE LAST THING . . .







LET'S GO PLAY SOME ROULETTE.

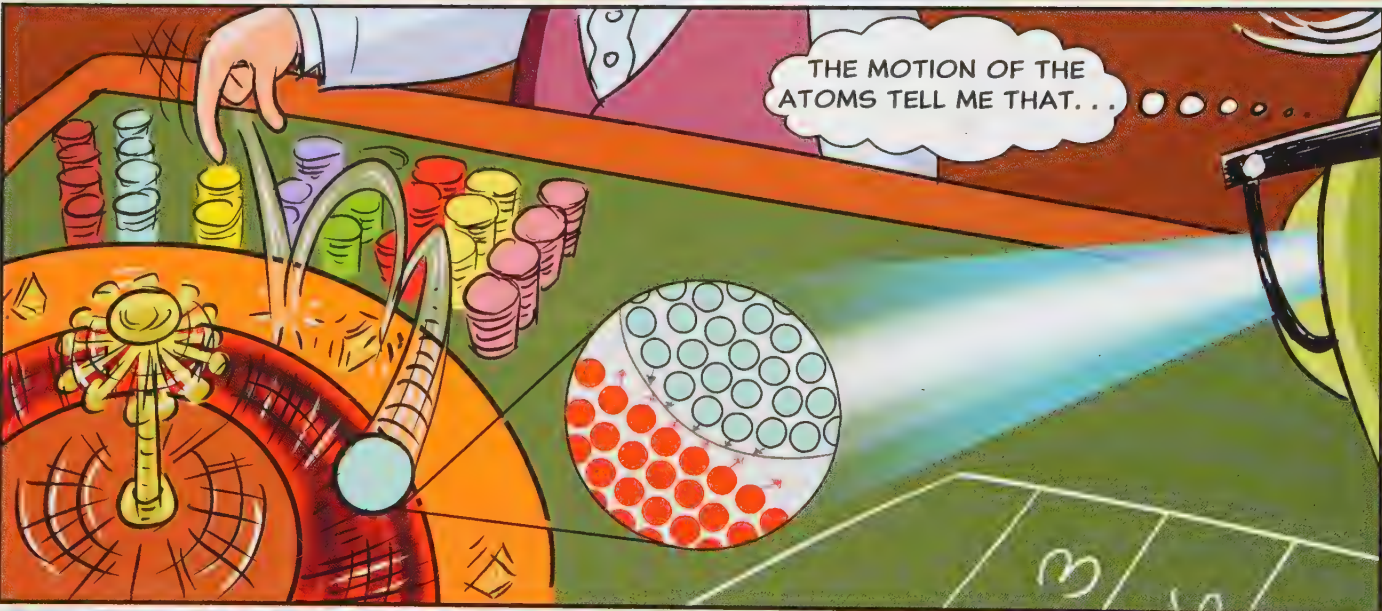


YOU - A GAMBLER?

NOT AT ALL.



IT'S NOT GAMBLING WHEN I CAN COMPUTE PRECISELY WHERE THE BALL WILL LAND.



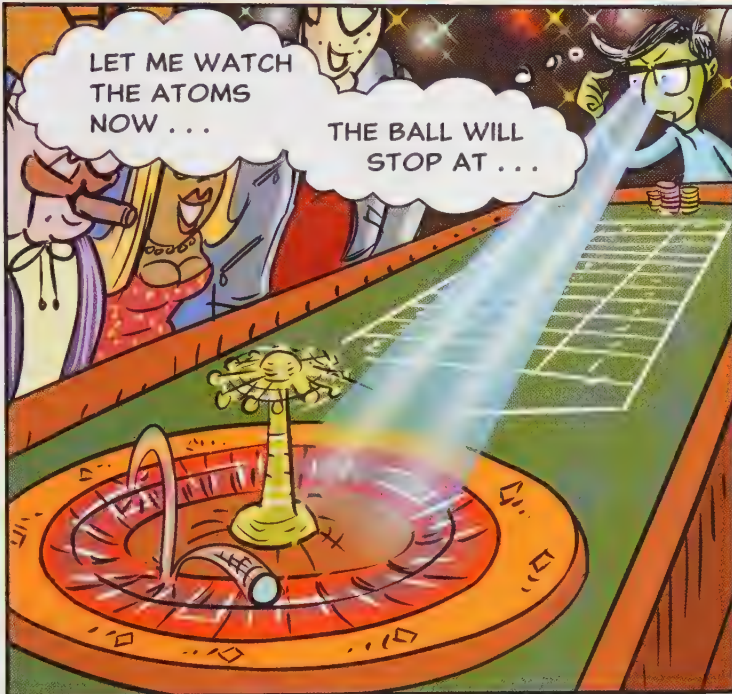
THE MOTION OF THE ATOMS TELL ME THAT...



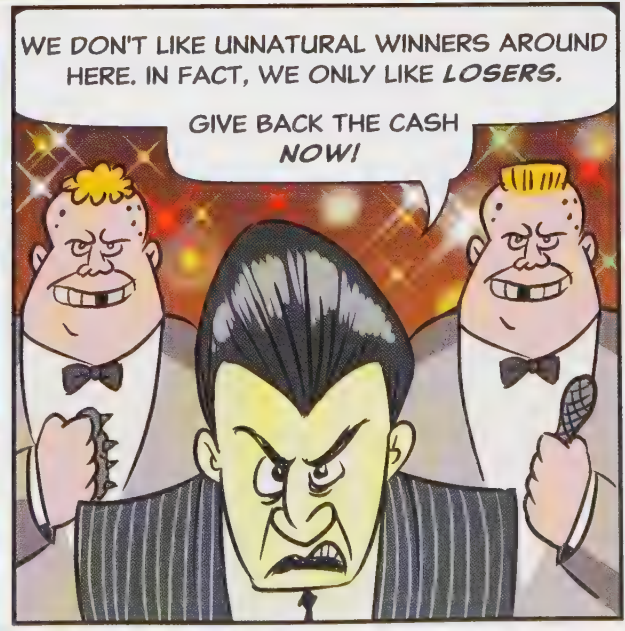
THE BALL WILL KEEP ROLLING UNTIL IT WILL STOP AT...



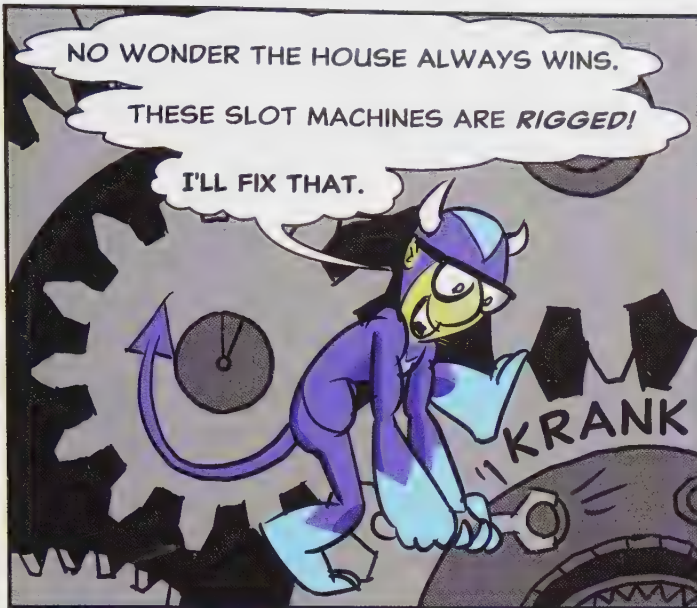
28!

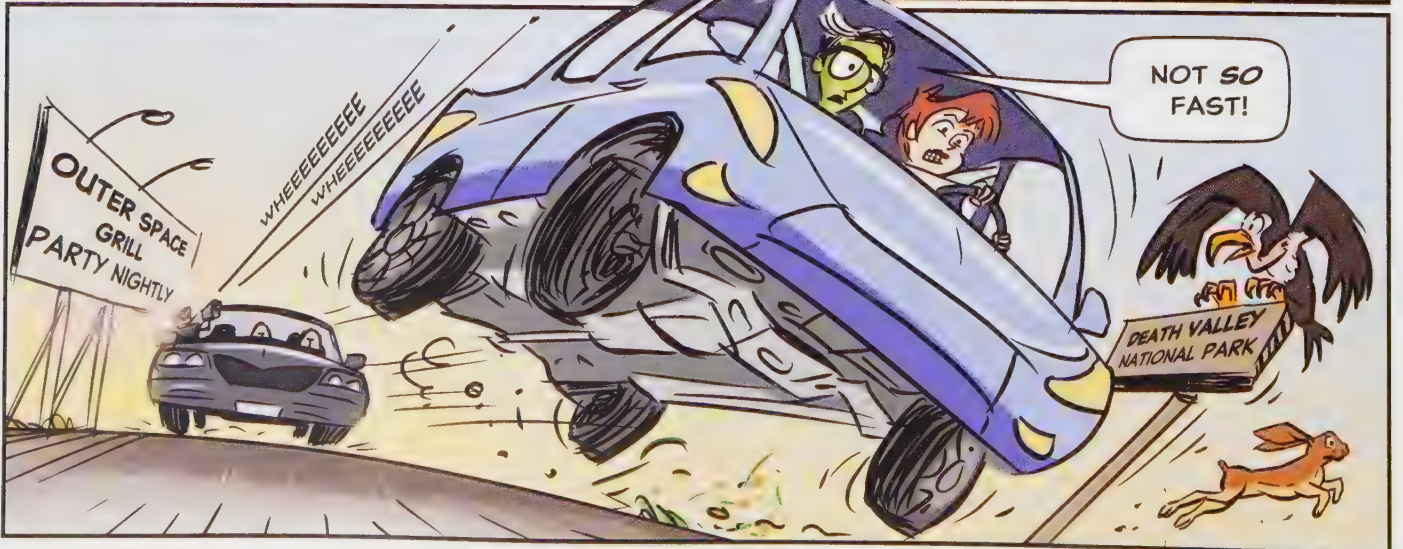
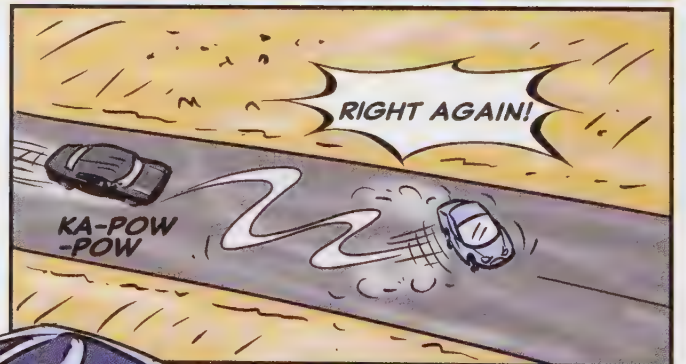


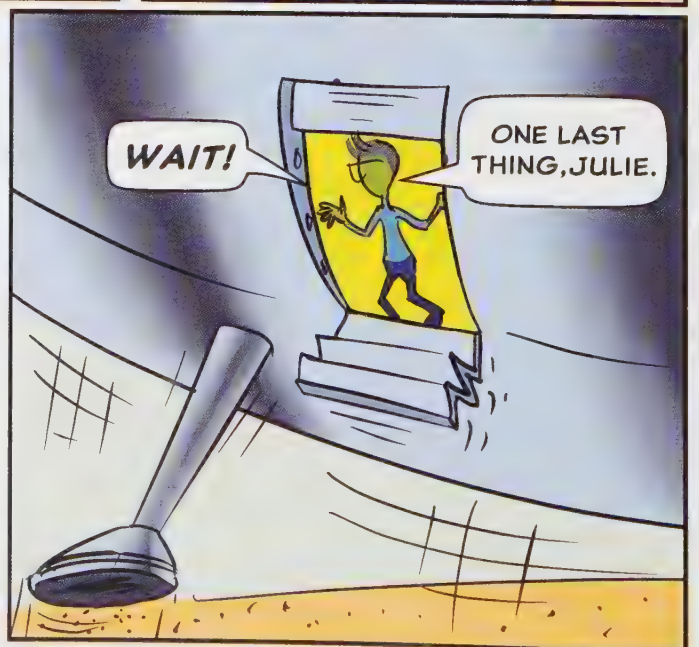


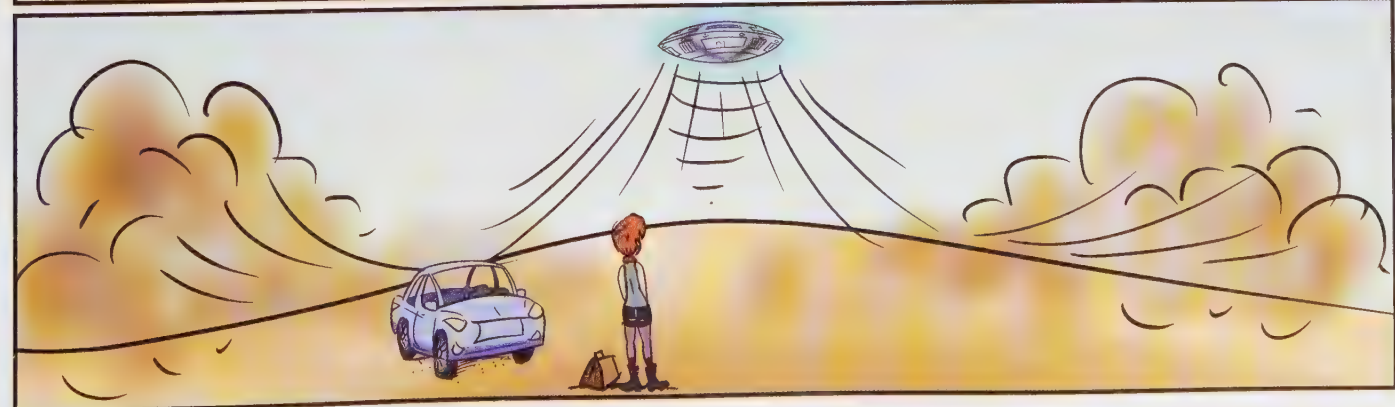
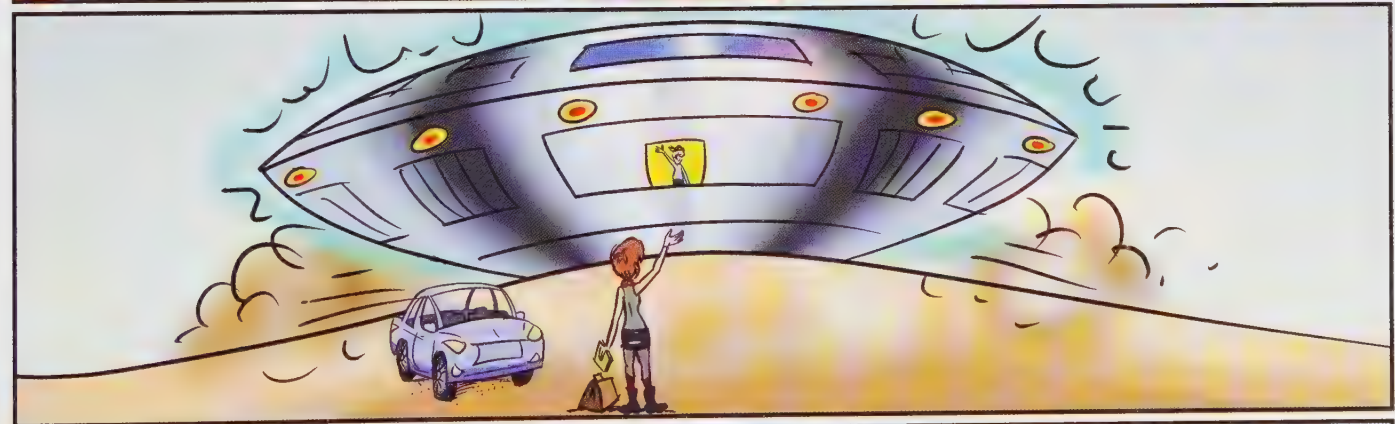
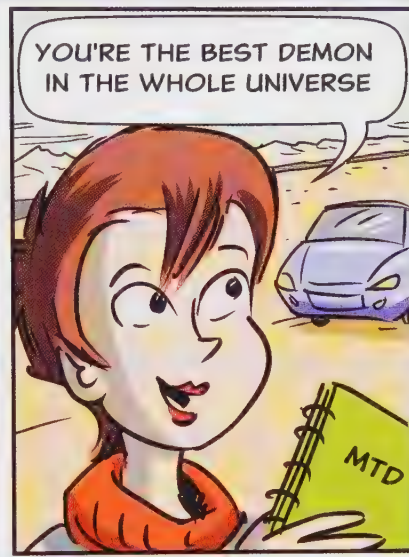
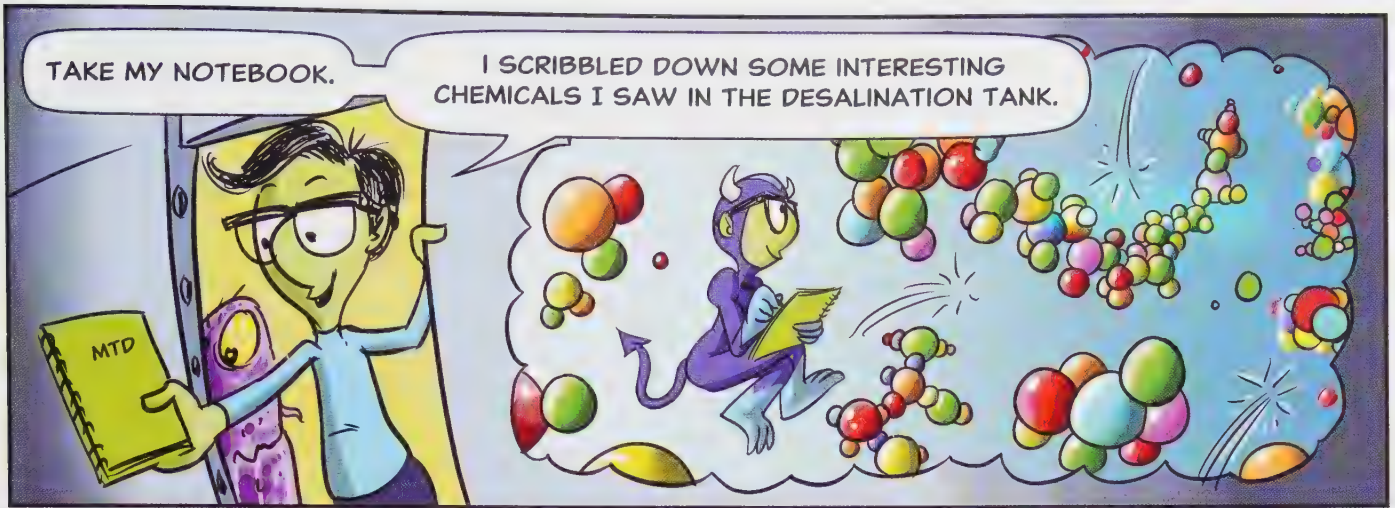








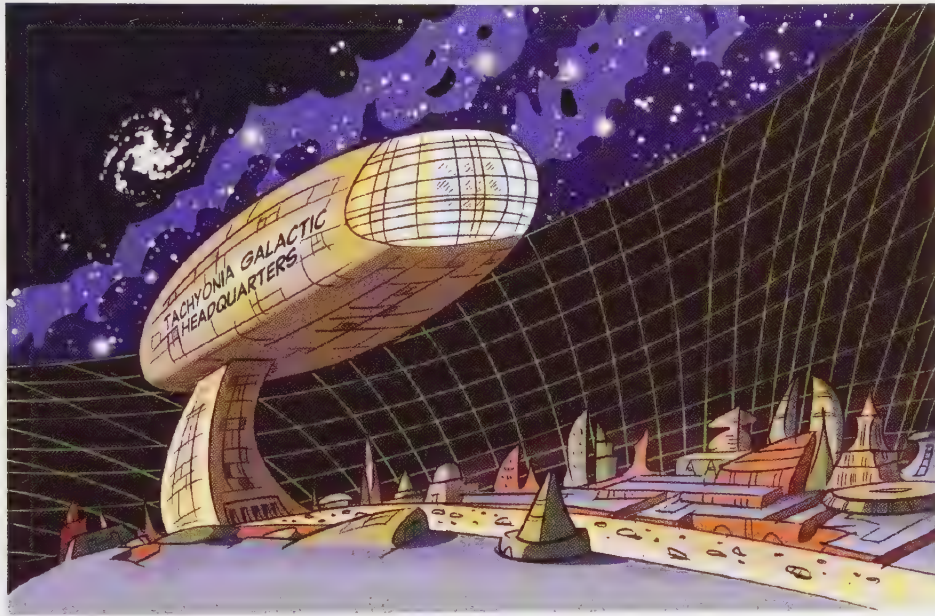






EPILOGUE

IN THE NOT TOO DISTANT FUTURE



MAX ON TRIAL

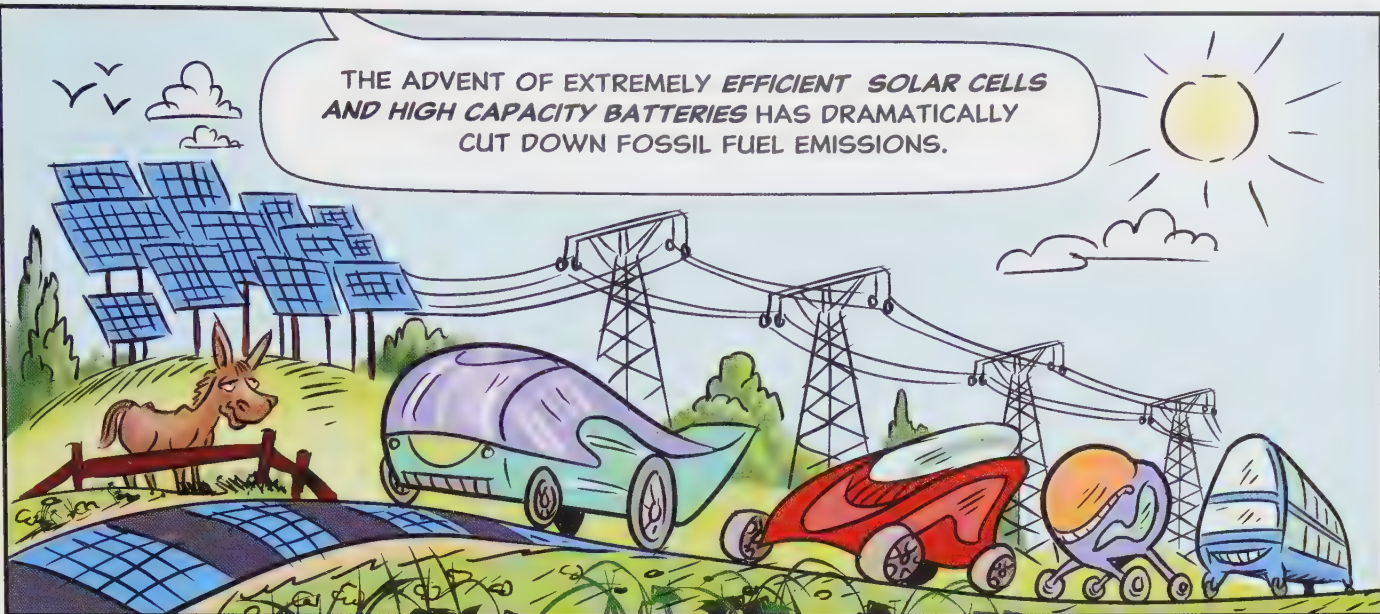
TODAY, THE FEDERAL CLIMATE BUREAU
ANNOUNCED A DRAMATIC DROP IN POLLUTION.

GLOBAL WARMING HAS BEEN
SIGNIFICANTLY REDUCED.

THE ECOLOGICAL STATE OF EMERGENCY
IS LIFTED.



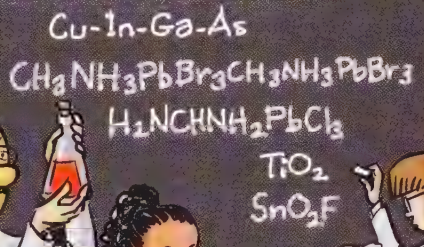
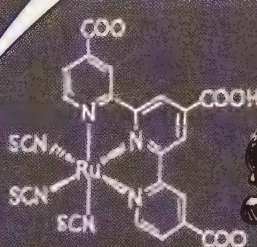
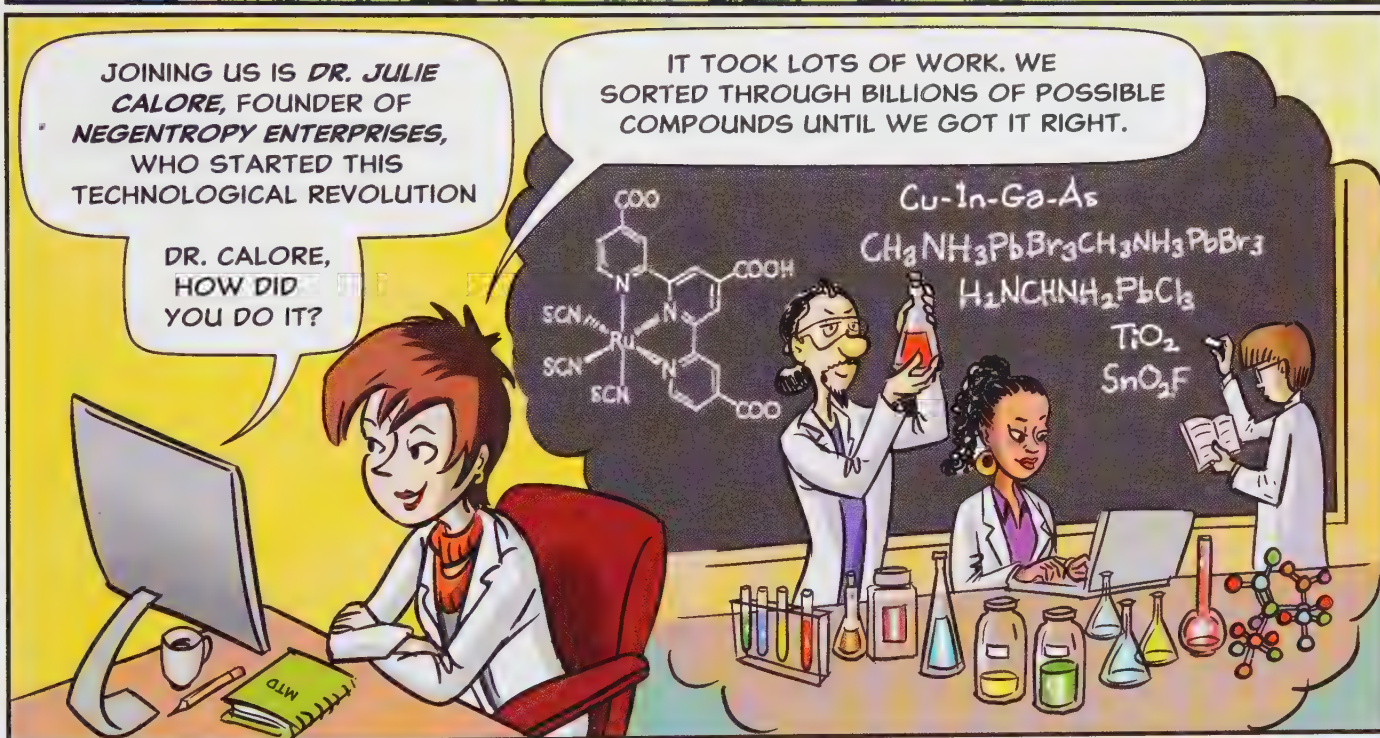
THE ADVENT OF EXTREMELY EFFICIENT SOLAR CELLS AND HIGH CAPACITY BATTERIES HAS DRAMATICALLY CUT DOWN FOSSIL FUEL EMISSIONS.



JOINING US IS DR. JULIE CALORE, FOUNDER OF NEGENTROPY ENTERPRISES, WHO STARTED THIS TECHNOLOGICAL REVOLUTION

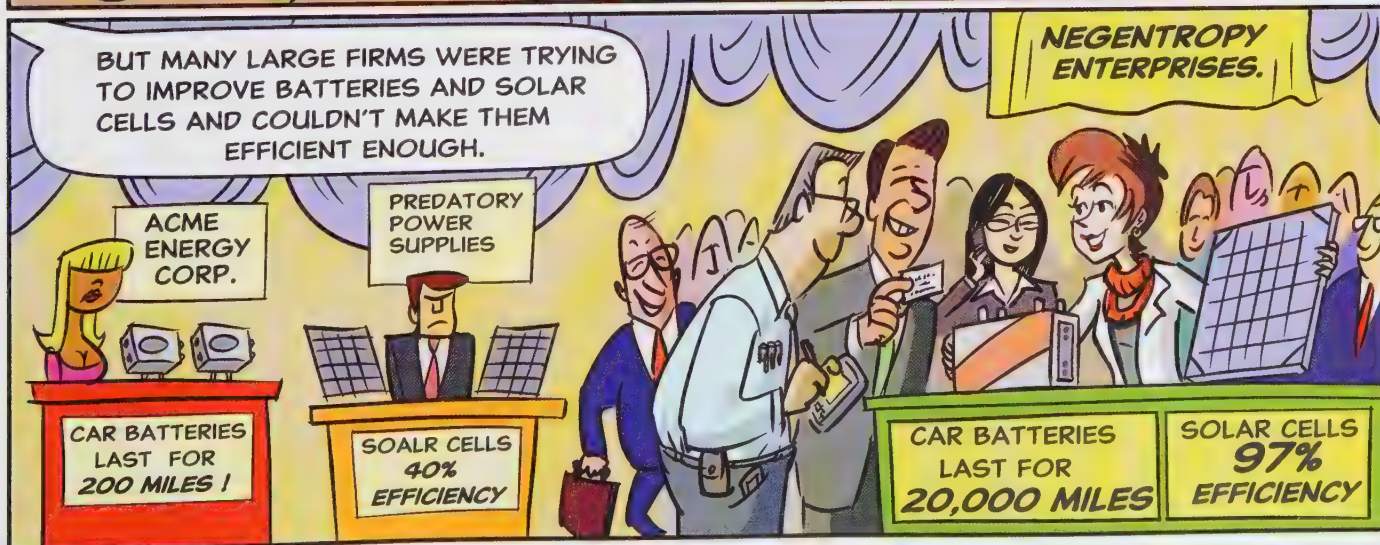
DR. CALORE, HOW DID YOU DO IT?

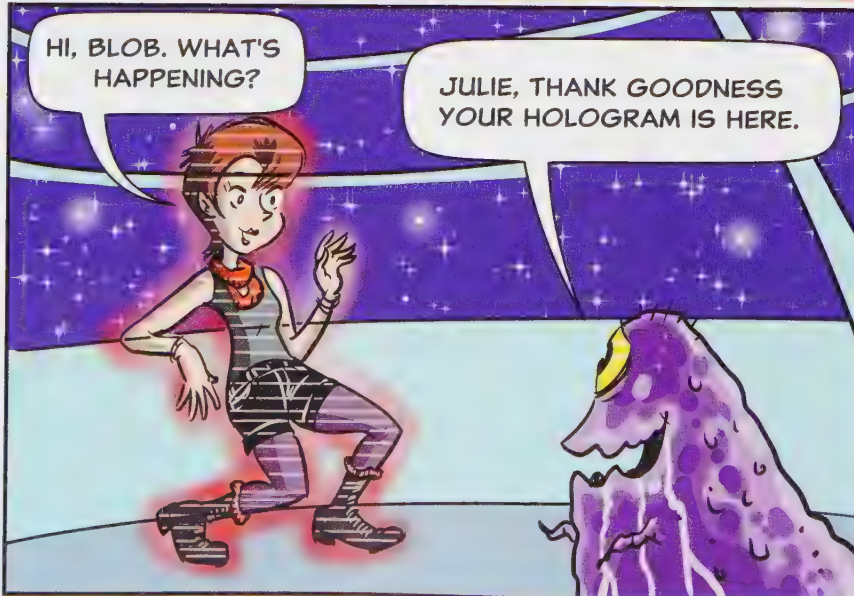
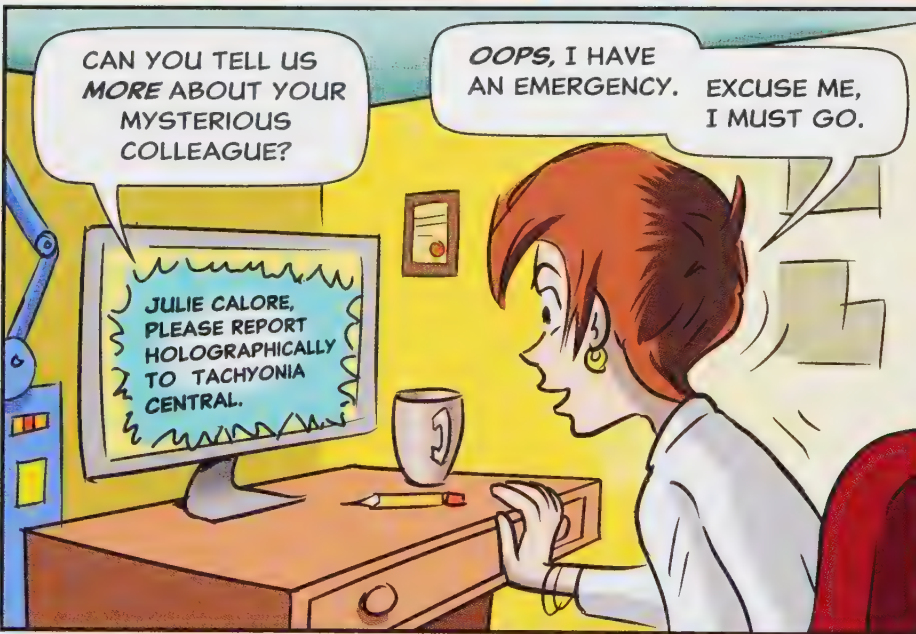
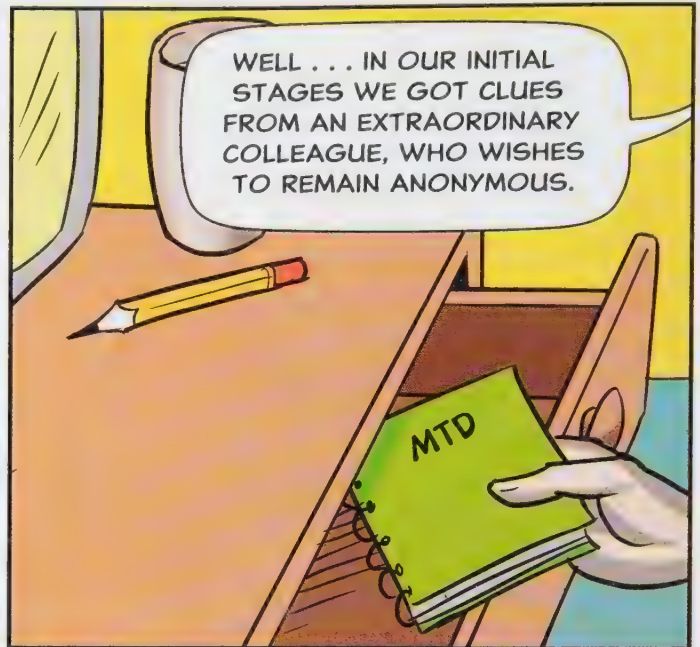
IT TOOK LOTS OF WORK. WE SORTED THROUGH BILLIONS OF POSSIBLE COMPOUNDS UNTIL WE GOT IT RIGHT.



BUT MANY LARGE FIRMS WERE TRYING TO IMPROVE BATTERIES AND SOLAR CELLS AND COULDN'T MAKE THEM EFFICIENT ENOUGH.

NEGENTROPY ENTERPRISES.







HURRY UP, JULIE!

SAVE MAX,
YOUNG
TERRESTRIAN.

THE TRIAL HAS
ALREADY STARTED.

FASTER!



AFTER MAX HAD INSPIRED THE ERGODISTAN DEBACLE, HE CHEATED AT GAMBLING IN LAS VEGAS AND **BROKE THE SECOND LAW IN PUBLIC VIEW AGAIN!**



MAX, I WARNED YOU AFTER ERGODISTAN. I CAN IGNORE YOUR PETTY GAMBLING TRICKS IN LAS VEGAS, . . .

BUT YOU'LL BE SEVERELY PUNISHED IF YOU HAVE REDUCED GLOBAL WARMING BY BREAKING THE SECOND LAW!



NO, I DID NOT, SIR!

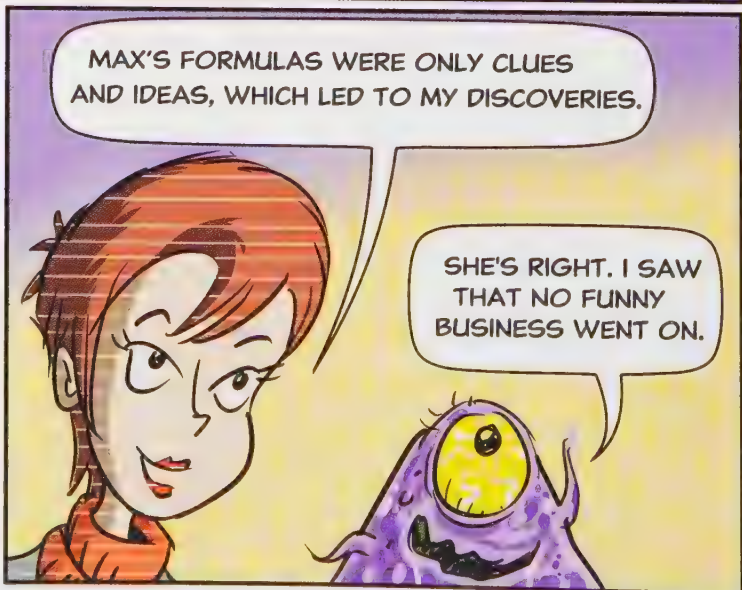


I FOLLOWED SIR BIO'S ORDERS AND HELPED JULIE CALORE REDUCE GLOBAL WARMING WITHOUT BREAKING THE SECOND LAW!

EXPLAIN TO THE COURT: HOW DID YOU DO THAT?



LET ME EXPLAIN.



MAX'S FORMULAS WERE ONLY CLUES AND IDEAS, WHICH LED TO MY DISCOVERIES.

SHE'S RIGHT. I SAW THAT NO FUNNY BUSINESS WENT ON.

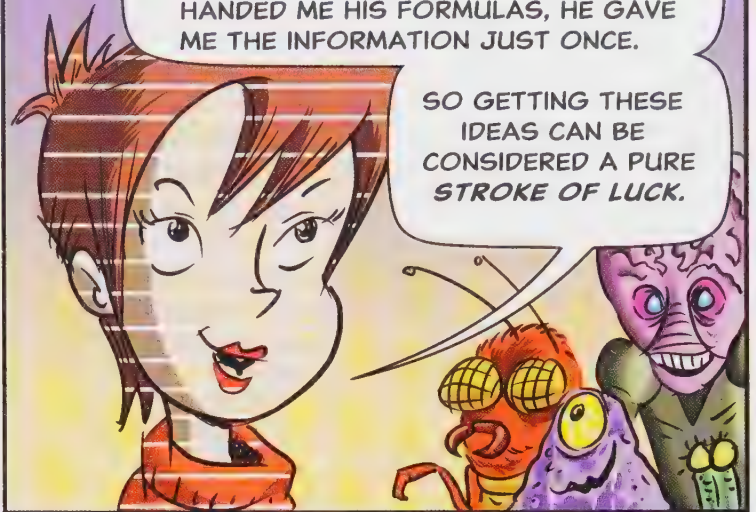
INDEED! MAX GAVE YOU, AND THE REST OF HUMANITY, *USEFUL INFORMATION!* AS FEYNMAN EXPLAINED: *INFORMATION GAINED=ENTROPY LOST.* MAX ACTUALLY REDUCED ENTROPY.

THIS WAS A VIOLATION OF THE SECOND LAW IN PUBLIC!



NOT AT ALL! THE SECOND LAW IS A STATISTICAL LAW. WHEN MAX HANDED ME HIS FORMULAS, HE GAVE ME THE INFORMATION JUST ONCE.

SO GETTING THESE IDEAS CAN BE CONSIDERED A PURE STROKE OF LUCK.



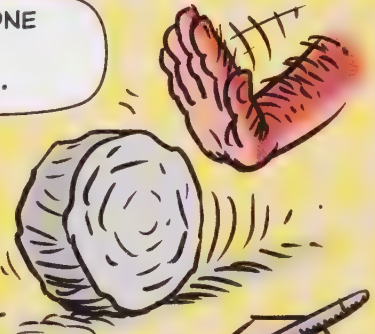
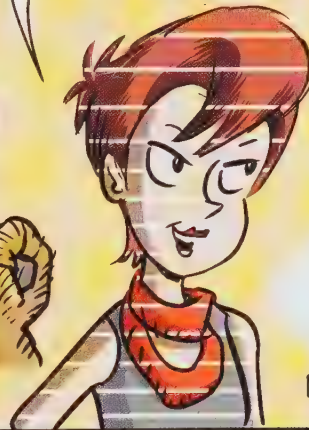
COME TO THINK OF IT, THAT'S WHAT ONE USUALLY SAYS ABOUT ALL GREAT INVENTIONS IN HUMAN HISTORY ...



FIRE



ALPHABET



WHEEL

$$S = k \text{Log} W$$

BOLTZMANN ENTROPY

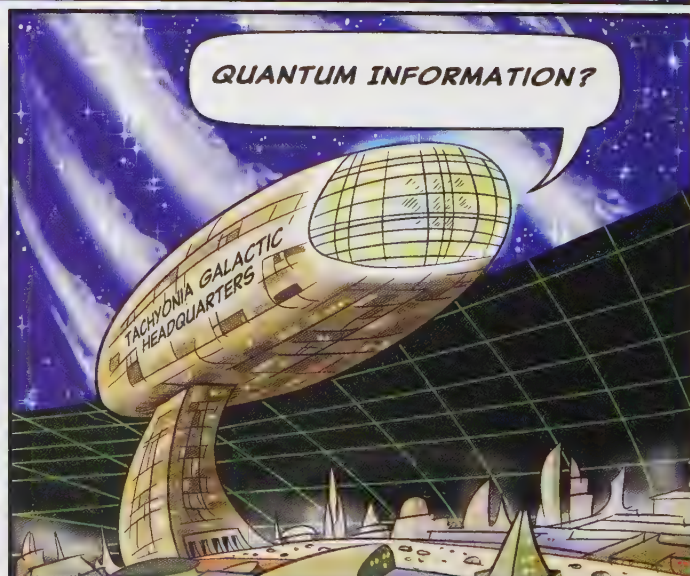
MAX'S GIFT INSPIRED JULIE AND THE HUMAN RACE TO COME TOGETHER AND SAVE THEIR ENVIRONMENT BY THEMSELVES!

I FIND MAX THE DEMON - NOT GUILTY!



HOORAY !!





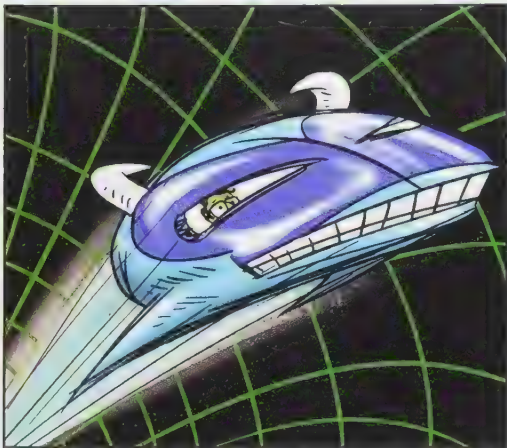


PLEASE?

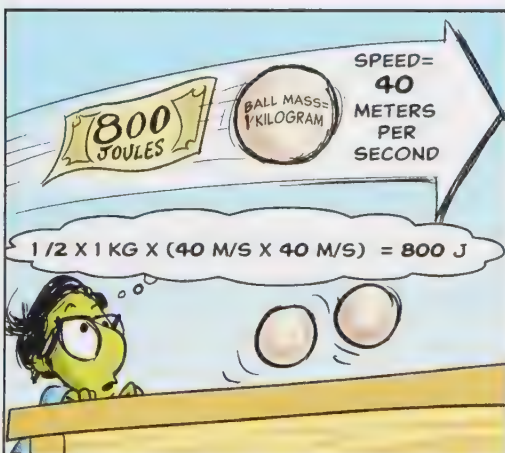
TACHYONIA

EARTH

What's Fiction and What's Physics?



Fiction: The story is pure fiction. Any resemblance of Julie Calore, Johnny Shtark, Katie, XY or Blob, to real characters is coincidental. Tachyonia and its inhabitants may exist inside a black hole, but laws of physics prevent them from communicating with the outside universe or leaving the black hole. Max the Demon, his time travel machine, his Microstate Determinator glasses and his miniaturizing suit are figments of our imagination.



Physics: The laws of physics explained to Max are correct, although not precisely formulated. For simplicity, the reader is spared the mathematically rigorous definitions of energy, heat, temperature, pressure and entropy, which can be found in physics textbooks. The laws of Quantum Mechanics and Relativity are not mentioned, since they are not crucial for the physics explained in the story.



A Little Bit of Both: Max's miniaturization and his ability to sort enormous numbers of atoms without having his brain burn up, are unphysical. However, the frictionless nanoshutter in his power plant device is theoretically possible using a levitating superconductor or superfluid lubrication.

Glossary

Black Hole. A region of space-time with such a strong gravitational force that particles or electromagnetic waves cannot escape its boundary. That boundary is known as the event horizon.

Caloric Theory. A theory that describes heat transfer as the flow of a massless fluid, called caloric, from hotter bodies to colder bodies. Count Rumford showed that he could generate endless amount of heat by boring a cannon, which cannot be explained by a finite amount of "caloric fluid".

Calorie. A unit of energy. 1 Calorie = 4.184 Joules. One Food Calorie (called Calories when discussing food energy content), is a thousand times larger: 1 Food Calorie = 4184 Joules.

Conservation of Energy. A fundamental law of classical and quantum physics. The sum of kinetic and potential energies in an isolated system of bodies is constant in time.

Desalination. Removing dissolved salts from water. According to the Second Law of Thermodynamics, desalination requires investment of external energy in order to decrease the entropy of the salty water.

Entropy. Measures the number of possible microstates in a system, each of which has the same macroscopic properties, like total energy, volume, and number of particles. Each microscopic configuration is described by the positions and velocities of all its particles.

Entropy of Erasure. In 1972, Rolf Landauer applied the Second Law of Thermodynamics to a computer and showed that a small amount of entropy is generated by erasing one bit of information. (A bit is a binary number: 0 or 1). In 1982, Charles Bennet used Landauer's limit to show that a computerized Maxwell's Demon cannot break the second law because it must generate more entropy than it reduces, when erasing the acquired information from its memory.

Equipartition. Equipartition is the most likely state of a thermodynamic system, and therefore has the highest possible entropy. In this state, on average, energy is shared equally among all the components of the system.

Greenhouse Effect. Gases in the atmosphere reflect radiation back onto the earth's surface, causing an increase in surface temperature.

Heat. Energy transferred into a body or system of particles, without changing any of its macroscopic variables, such as volume, shape, or number of particles. The input of heat into a gas increases the random velocities of the particles.

Heat Engine. An engine that converts heat energy into mechanical work. A heat engine requires at least two different temperature sources. According to Carnot's theory, even the most efficient heat engine loses some fraction of its heat to the cold source, meaning this heat cannot be used for work. A refrigerator is a heat engine working in reverse: externally-supplied power pumps heat and entropy from the cold source to the hot source.

Helium. Colorless, odorless, inert, and relatively lightweight monoatomic gas.

Joule. A unit of energy in the international system of units (metric system).
1 Joule = Kilogram x (meter per second²)

Kinetic Energy. Energy associated with the motion of an object.

Maxwell's Demon. Proposed by Maxwell in an 1867 letter to the mathematician Peter Tait. The "Demon" is an intelligent small being who can observe atoms and manipulate their configuration in a way that decreases the entropy of the whole system without investing energy. The Demon's existence would challenge the validity of the Second Law of Thermodynamics.

Microstate. In classical mechanics, a microstate is the list of all the positions and velocities of the particles. In Boltzmann's theory, a thermodynamic system can be found in any possible microstate with a certain probability.

Potential Energy. The amount of energy invested in a body to bring it to a standstill at a certain position.

Pressure. A force applied perpendicularly to a surface by a system of particles. For an ideal gas, the pressure is proportional to the particle density and temperature.

Rechargeable Battery. A battery, which can be charged and discharged many times. Rechargeable batteries are used in mobile electronic devices, electric cars, and as stabilizers of electricity network. The batteries contain metallic electrodes and electrolyte materials, which chemically store the electric charge.

Solar Cell. Photovoltaic technology which converts the energy of sunlight into electricity.

Tachyon. A hypothetical particle that moves faster than the speed of light. According to Einstein's theory of relativity, if tachyons interact with ordinary matter, they could violate causality (i.e. go backwards in time) and create paradoxes, such as "you can kill your own grandfather, before your father was born". Most physicists do not believe Tachyons exist in our universe.

Thermodynamics. The theory of energy and heat in systems of a large number of particles. Thermodynamics describes relations between macroscopic quantities, such as pressure, temperature, density and entropy.

Thermodynamics, First Law. Energy is conserved in an isolated system. Otherwise, the change in a system's energy is equal to the work externally invested in it, minus the heat transferred to its surroundings.

Thermodynamics, Second Law. The entropy of an isolated system can only grow over time. Equivalent thermodynamic statements of the second law are:

- (Carnot) The maximal possible efficiency of a heat engine depends only on the temperature differences between the two heat sources.
- (Clausius) Heat can never pass from a colder body to a warmer body without external intervention.
- (Kelvin) It is impossible to derive mechanical work from any matter by cooling it below the temperature of the coldest surrounding object.

Temperature. Measured by a thermometer, temperature quantifies how hot a system is. In an ideal gas, temperature is proportional to the average kinetic energy of the atoms. Minimal temperature is zero degree Kelvin or -273°C .

Uranium Isotopes. Uranium atoms found in nature appear with three atomic masses: Uranium-238 (99.3%), Uranium-235 (0.7%), and Uranium-234 (0.005%). Nuclear fission occurs when Uranium-235 captures a slow neutron, breaks up into Krypton, Barium, and three neutrons. This process releases a large amount of nuclear binding energy. This is called nuclear fission. As little as seven kilograms of pure Uranium-235 can sustain a chain reaction, which can be used in an atomic bomb.

Brief Historical Biographies



Benjamin Thompson, Count Rumford, 1753 – 1814

Colorful inventor-physicist born in Woburn, Massachusetts. A British loyalist, he moved to England during the American Revolution. In 1798, he published the paper "*An Experimental Enquiry Concerning the Source of the Heat which is Excited by Friction*", refuting the then-accepted caloric theory by arguing that heat is a form of motion. This line of thinking later evolved into the first law of thermodynamics. He married the widow of the famous chemist, Antoine Lavoisier, after the latter was guillotined during the French reign of terror. He was the inventor of the popular Rumford Furnace, still in use today.



Nicolas Léonard Sadi Carnot, 1796 – 1832

Sadi Carnot was an engineer in Napoleon's Army and a physicist. His father was the leader of the French Revolutionary Army and his nephew later became the president of the Third Republic. Today N. L. Sadi Carnot is recognized as the founder of Thermodynamics. In his 1824 book, "*Reflections on the Motive Power of Fire*", Carnot proved the maximal efficiency of heat engines. Posthumously, Émile Clapeyron, Rudolf Clausius and Lord Kelvin used Carnot's theory to formulate *the Second Law of Thermodynamics*. Unfortunately, Carnot died in a cholera epidemic and most of his writings were buried with him.



James Clerk Maxwell, 1831 – 1879

Maxwell was a Scottish mathematical physicist who many consider to be as influential as Newton and Einstein. He was a child prodigy known to be highly inquisitive and mathematically talented. In his paper "*The Mathematical Theory of Electromagnetic Waves*", electricity and magnetism were unified by *Maxwell's equations*, which predicted electromagnetic radiation and explained light. Maxwell co-developed the *Kinetic Theory of Gases* with Ludwig Boltzmann. In a letter to Peter Guthrie Tait, *Maxwell's Demon* was invented as an intellectual challenge to the Second Law of Thermodynamics.



Ludwig Boltzmann, 1844 – 1906

Boltzmann was an Austrian philosopher-physicist. He is the creator of *Statistical Mechanics*, which supplied the mathematical and physical basis for thermodynamics. Boltzmann's atomistic description of matter and energy was misunderstood and criticized by his contemporary physicists and philosophers. This contributed to his depression and anxiety which eventually led to his suicide. Boltzmann's Theory was posthumously vindicated by experimental observation of atoms, and justified theoretically by the advent of *Quantum Mechanics*.



Richard Feynman, 1918 – 1988

Born in Queens, New York, Feynman had a strong Brooklyn accent and a keen sense of humor. While still in college, he was chosen to work on the Manhattan (atom bomb) Project. He went on to co-invent *Quantum Electrodynamics*, the quantum theory of light, for which he shared the 1965 Nobel Prize. Feynman pioneered the field of *Quantum Information* and earned world fame for his recorded lectures on physics and his popular autobiography.

About the Authors



Assa Auerbach. A radio operator on merchant ships in the 1970's, a graduate student at Stony Brook, NY, during the 1980's, now a Professor of Physics at Technion, Israel. Assa researches the theory of condensed matter, and is fascinated by superconductivity. Author of "*Interacting Electrons and Quantum Magnetism*" which is widely used in physics graduate courses. Assa has talked about thermodynamics to schoolchildren at Aspen Center for Physics, and in outreach events around the world.



Richard Codor makes a living drawing humorously. For many years, he was editorial cartoonist for Crain's NY Business and the NY Observer. His illustrations have appeared in numerous publications in the U.S. and abroad. His work is featured in the *The Big Book of Jewish Humor* and the Israeli social satire classic, *Zoo Eretz Zoo*. As a story artist Richard contributed to TV shows and movies, such as "Doug", "Lizzy McGuire", and "Robots". Richard, with his wife Liora, created, wrote, illustrated and published the perennial best selling cartoon *Joyous Haggadah*. He lives and works in Brooklyn, NY.

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Science, Physics, Graphic Novel, Young Adults

There is no Energy Crisis in the World. There is an *Entropy* Crisis!

Max, a character based on the mythical Maxwell's Demon, is sent on a mission to help save Earth from environmental disaster. First, Max must learn about energy, heat and entropy from the historical giants of science. Along the way, there is suspense, villainy and near catastrophe. This fun-to-read adventure story explains the first and second laws of thermodynamics in a way that is accessible to everyone.

"I really enjoyed the Demon adventures of Max! A good introduction to central ideas of entropy and energy, without sacrificing accuracy! A really cool book!"
— F. Duncan M. Haldane, 2016 Physics Nobel Laureate

"Entropy is a measure of disorder that affects everything from the emergence of life to the cosmic expansion. I can think of no better way to introduce this concept to a non-professional, but curious audience, than this witty, entertaining book."

—Mario Livio, Author of *Brilliant Blunders; The Golden Ratio; Is God a Mathematician?*

"This is a most impressive book that pioneers a style of presentation that makes sophisticated ideas in physics accessible to a wide audience in the form of an entertaining and beautifully illustrated story."

— Michael B. Green, Lucasian Professor of Mathematics, Cambridge University, Pioneer of String Theory



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