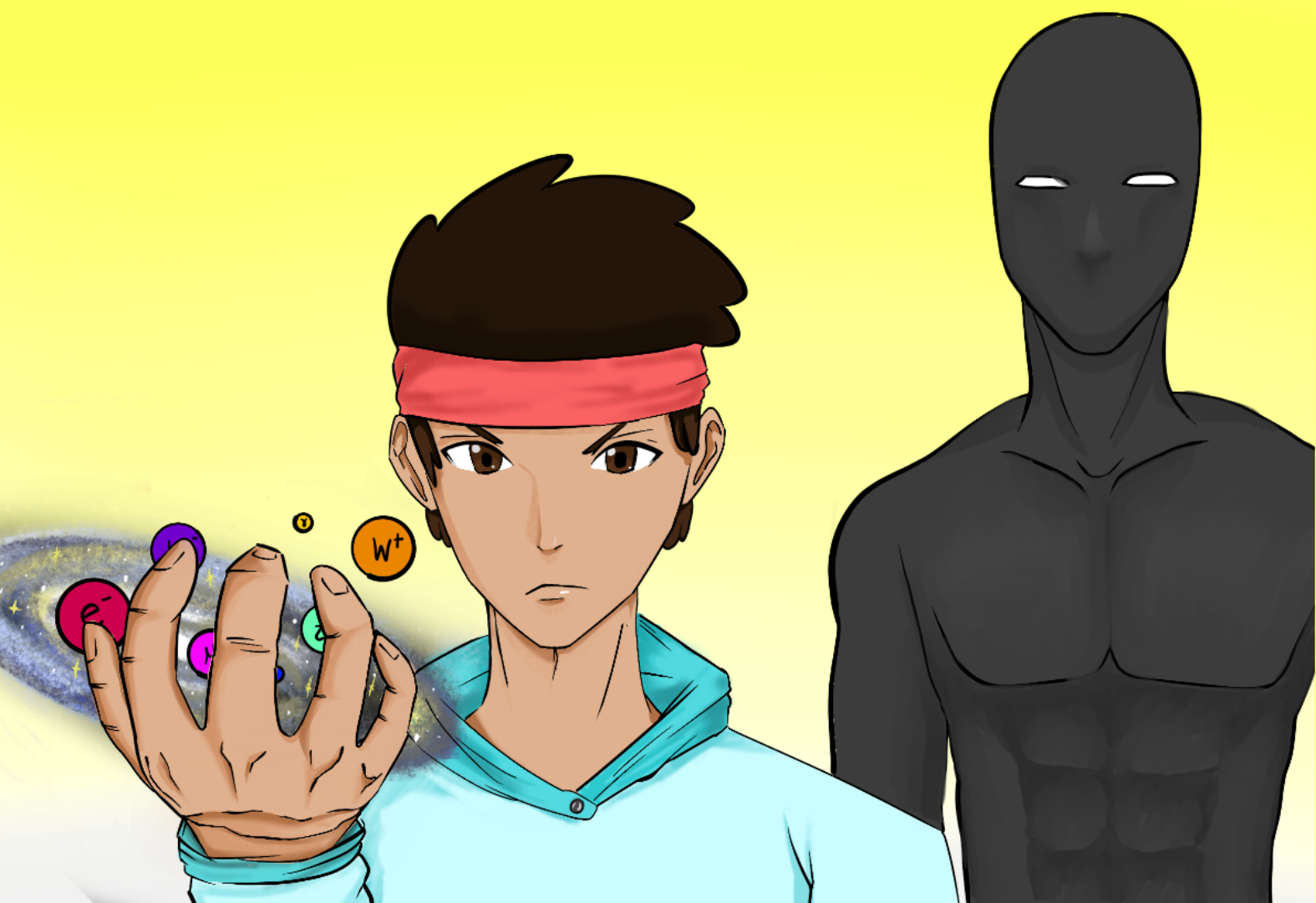
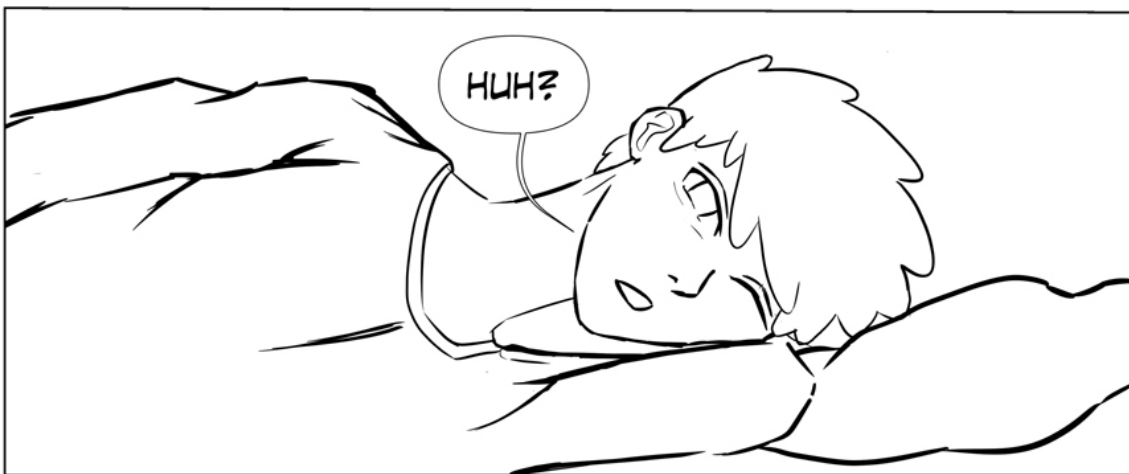
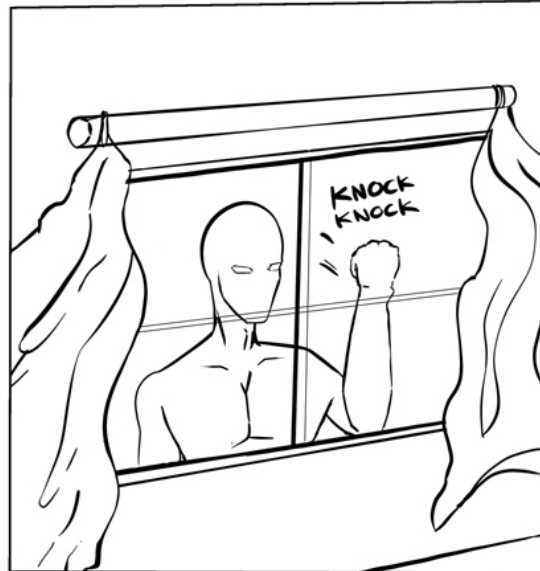
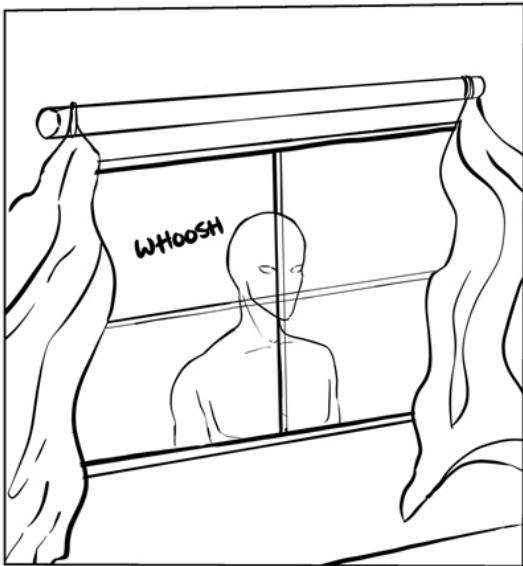
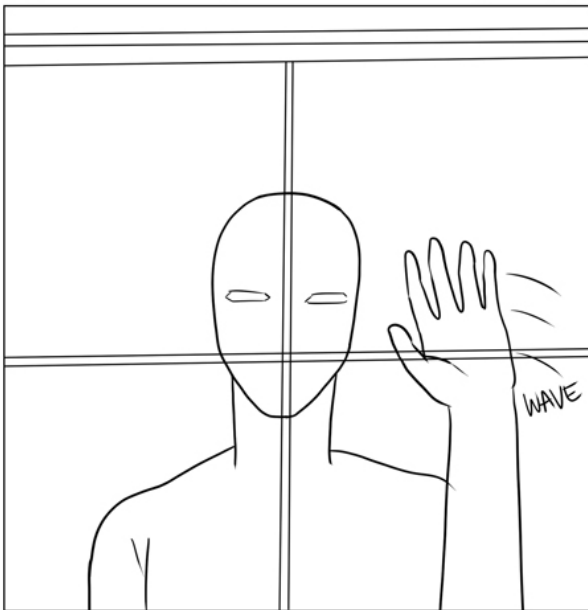


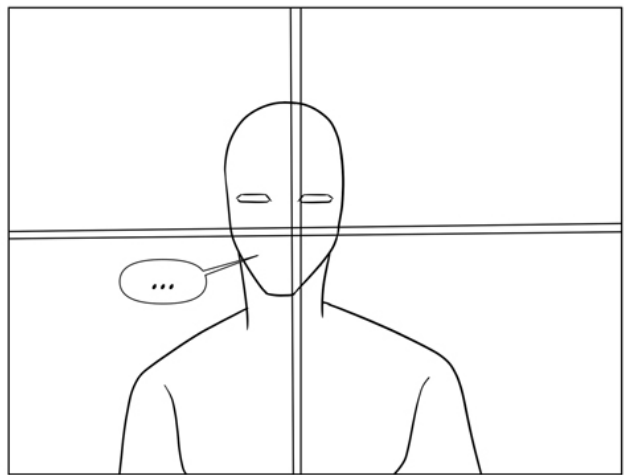
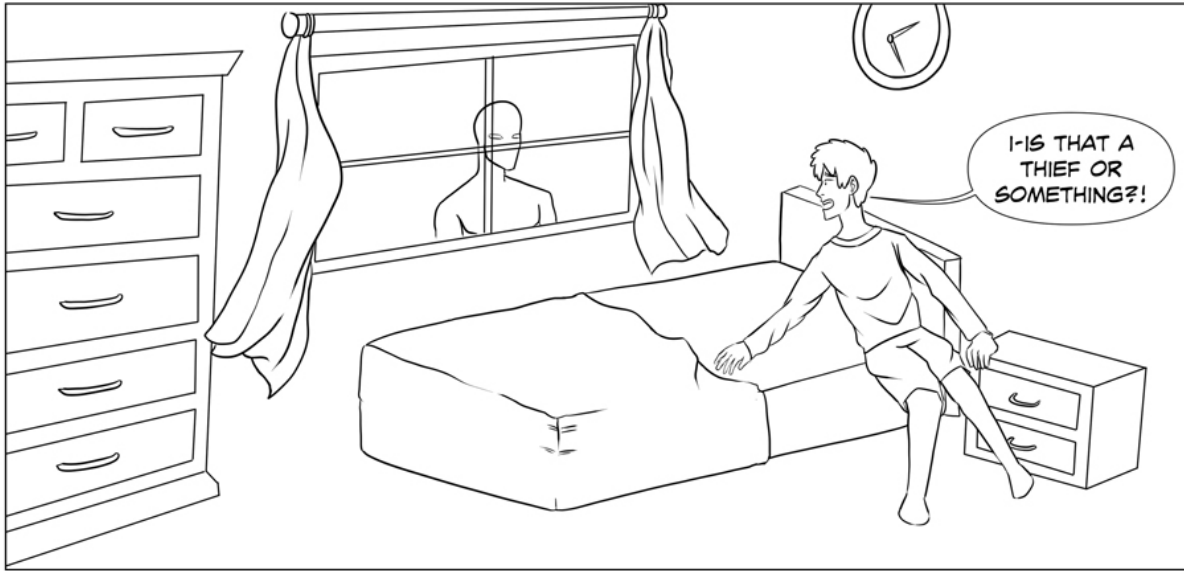
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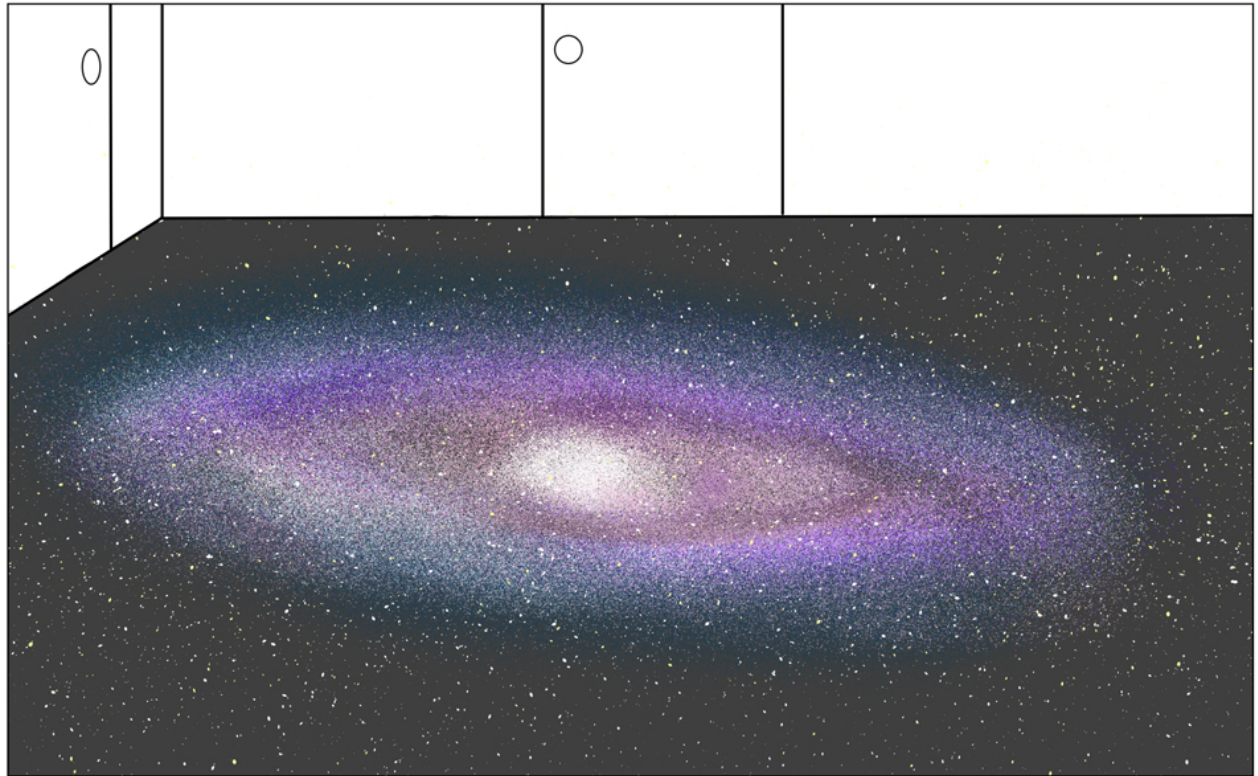
WRITTEN AND ILLUSTRATED BY
ARNAV CHOPRA

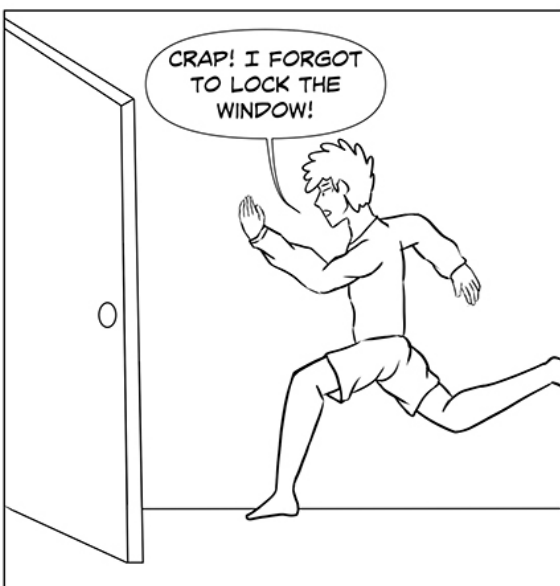
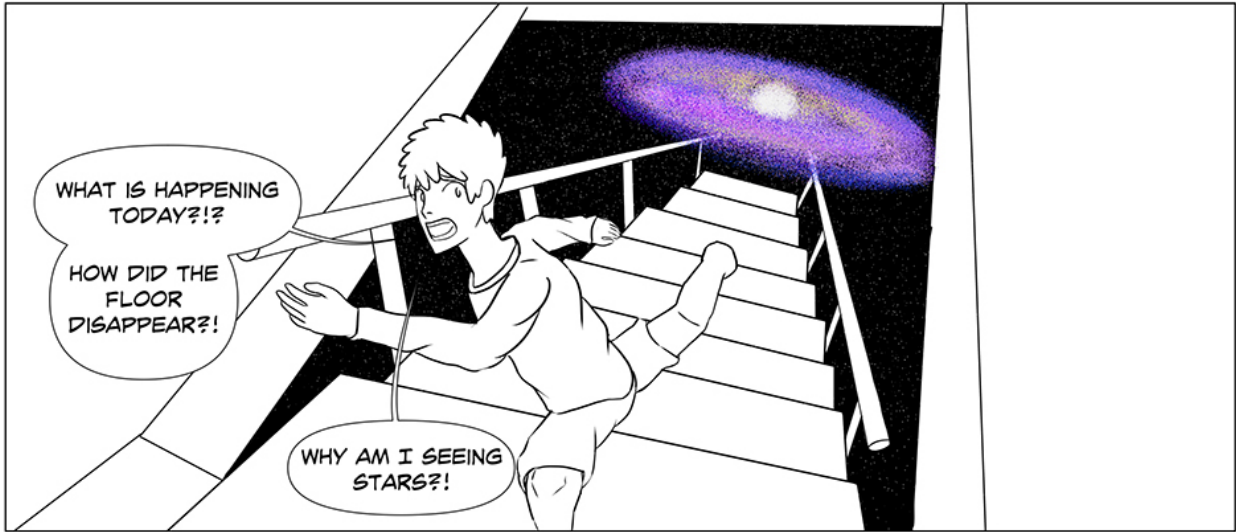


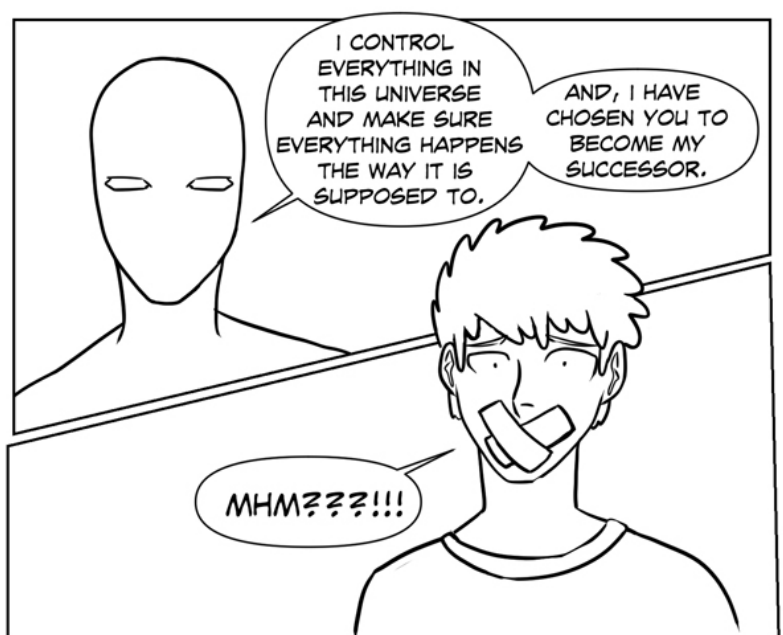
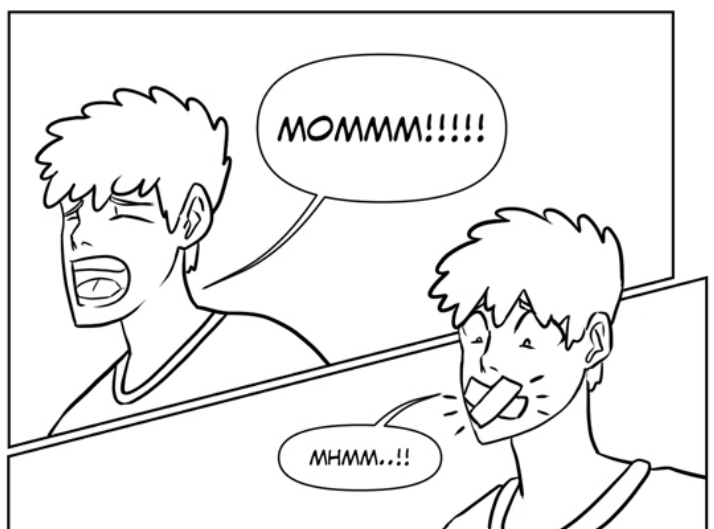
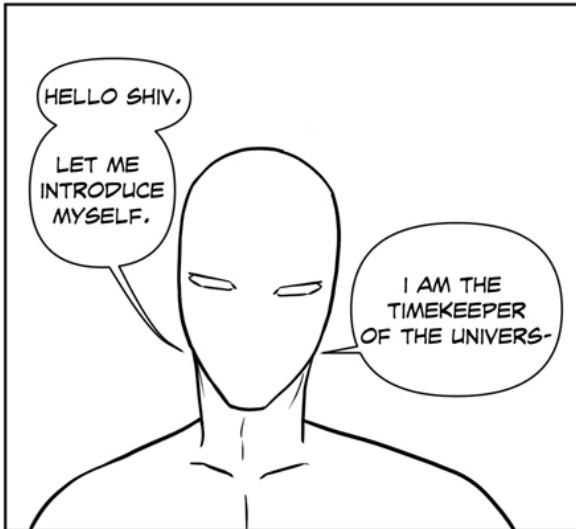
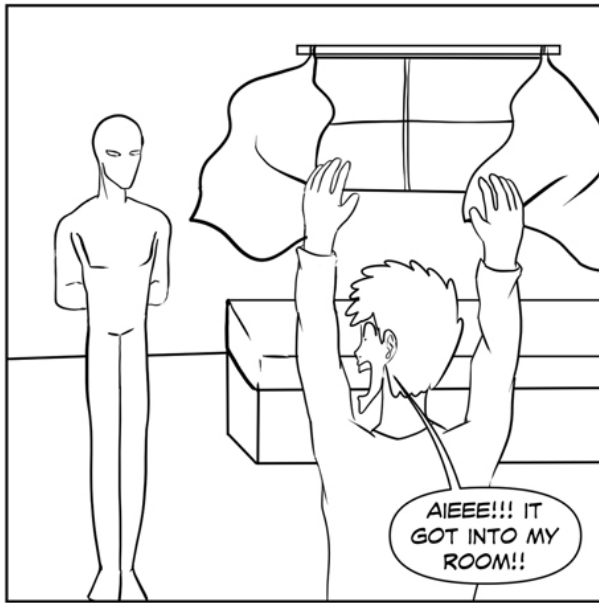


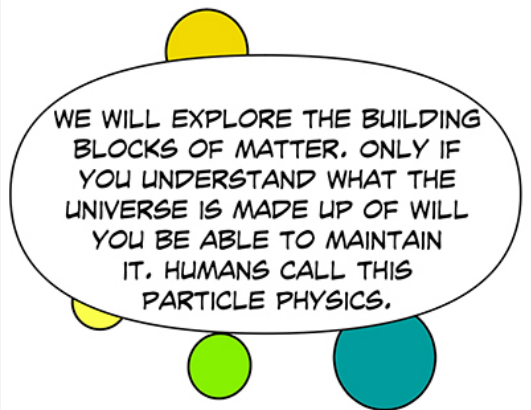
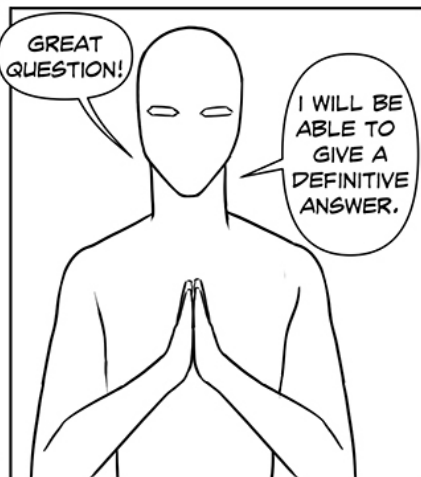
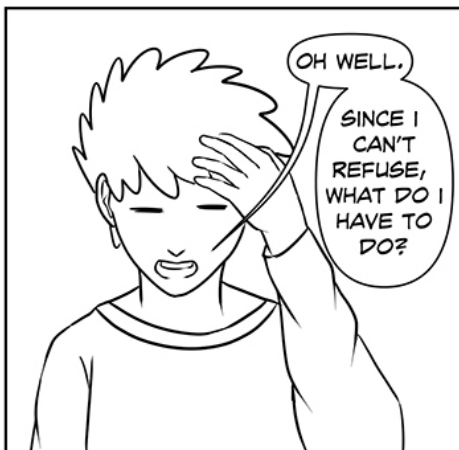
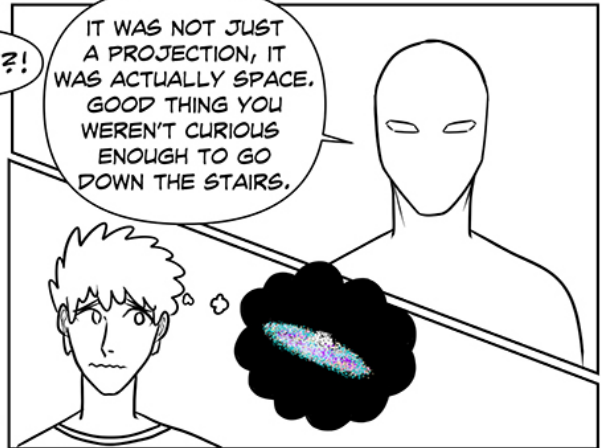
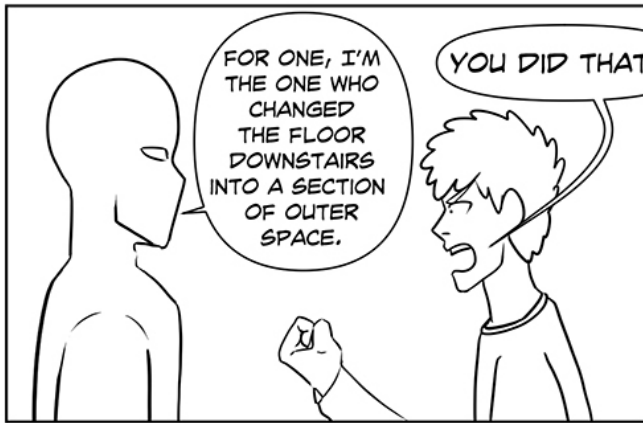


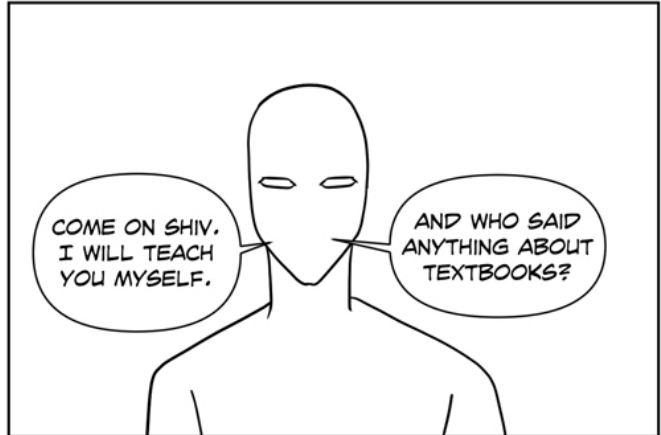


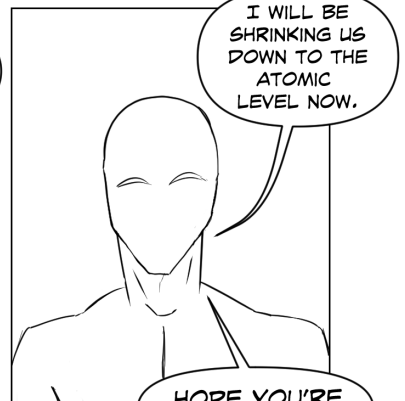
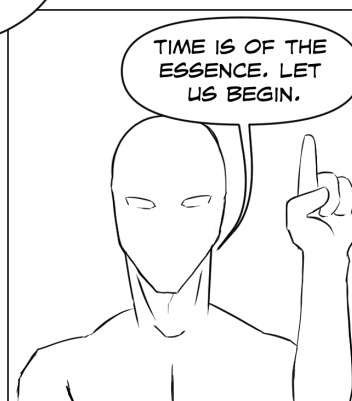
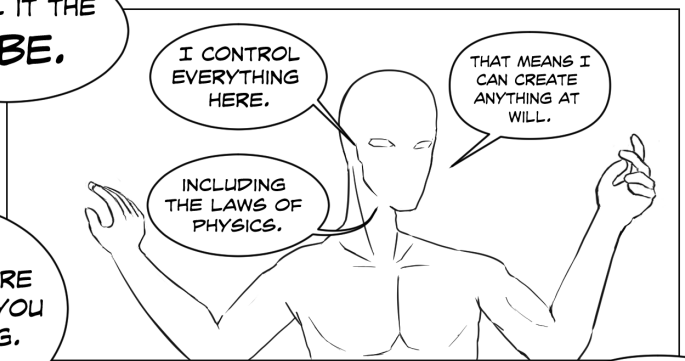




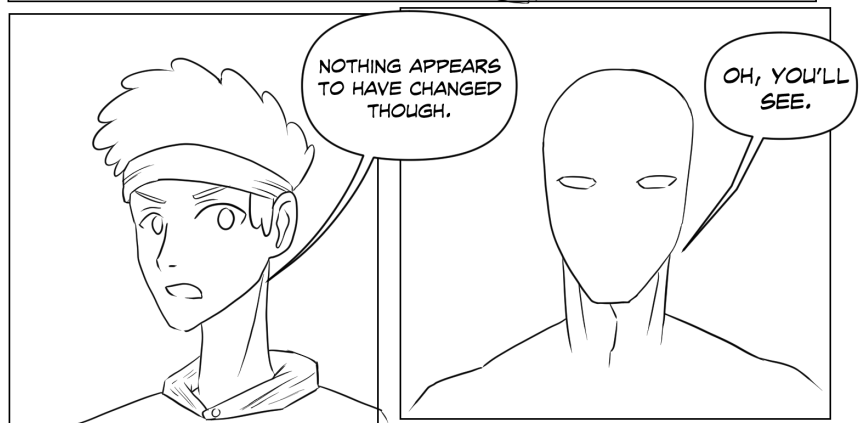
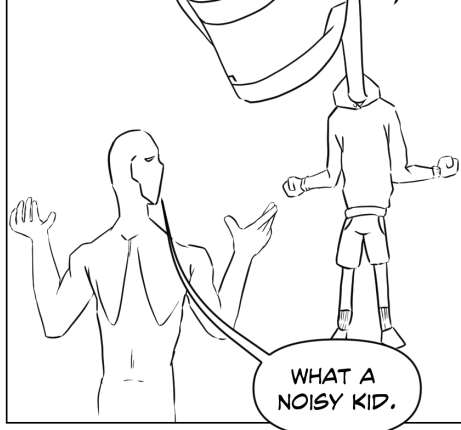
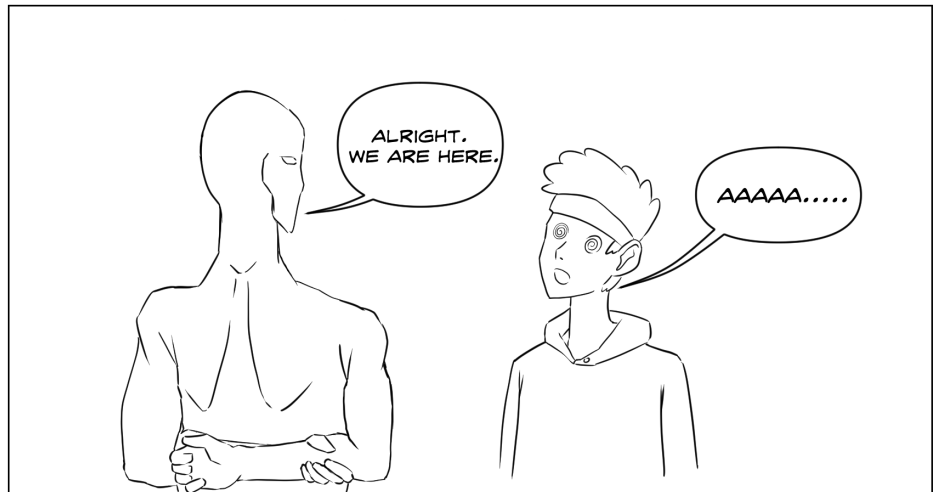


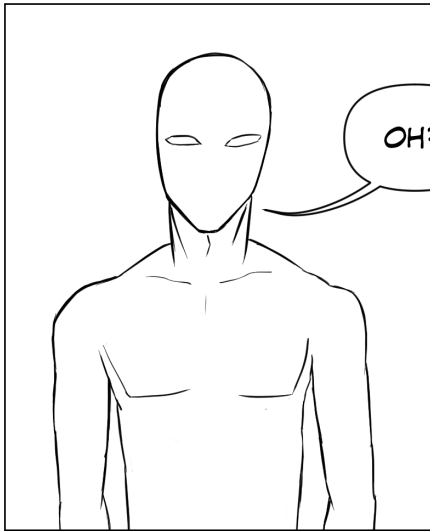






HOPE YOU'RE READY!





OH?



NOT AGAIN.



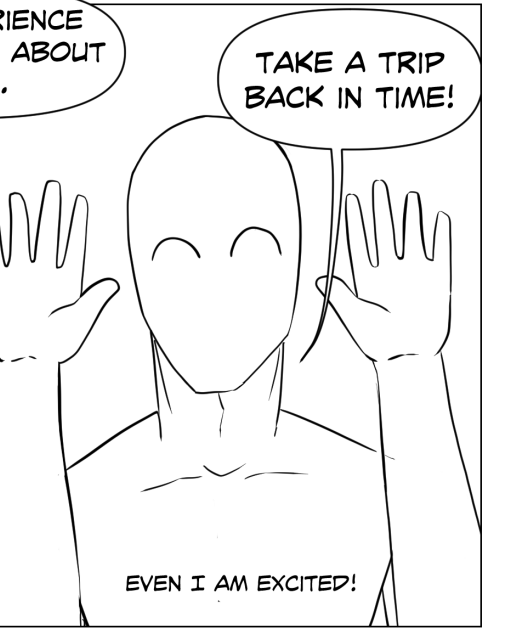
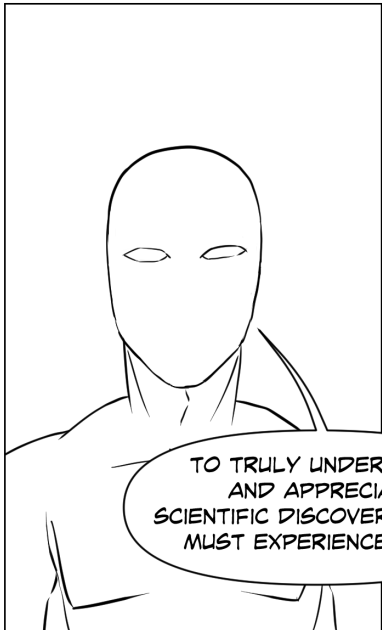
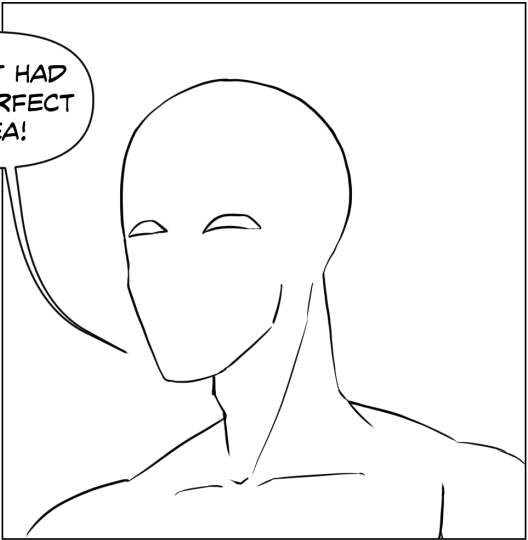
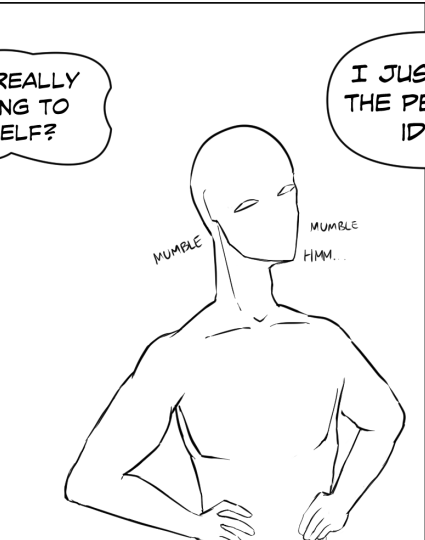
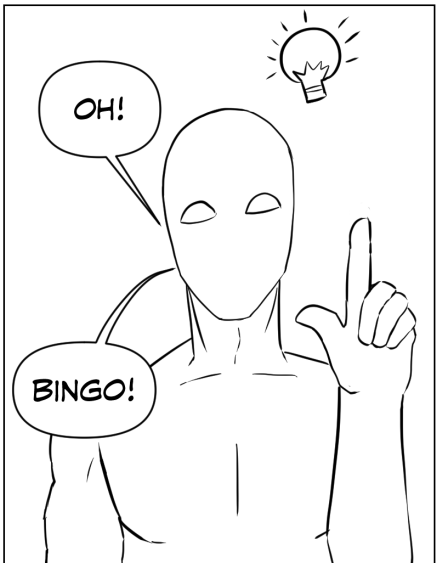
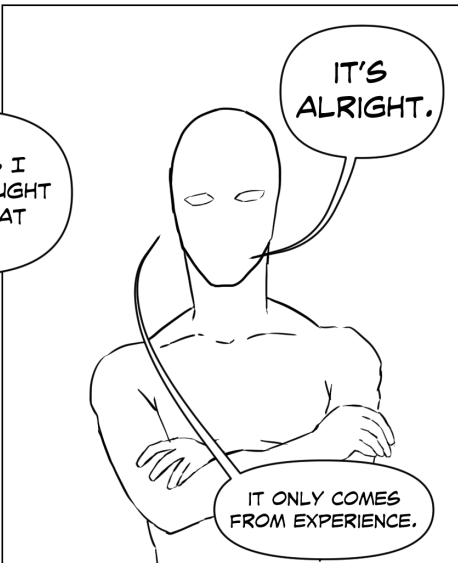
THIS IS THE
BIGGEST MISTAKE
YOU HUMANS
MAKE.

IT IS VERY EASY TO
GET OVERCONFIDENT,
THINKING THAT YOU
UNDERSTAND
EVERYTHING.

IT TOOK CENTURIES OF
EFFORTS AND THOUSANDS OF
AMAZING MINDS TO CREATE
WHAT YOU LEARN IN SCHOOL.

EVERYTHING HAS A
STORY. WITHOUT KNOWING
THAT STORY, YOU CAN'T
TRULY UNDERSTAND
ANYTHING.

IF YOU DON'T APPRECIATE
THOSE EFFORTS AND KEEP
AN OPEN MIND, YOUR JOURNEY
OF LEARNING WILL STOP.



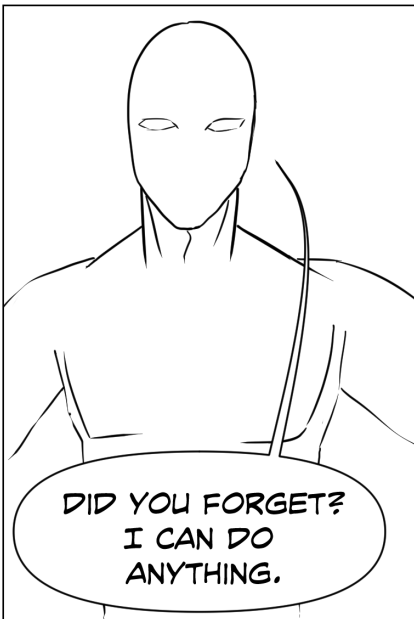
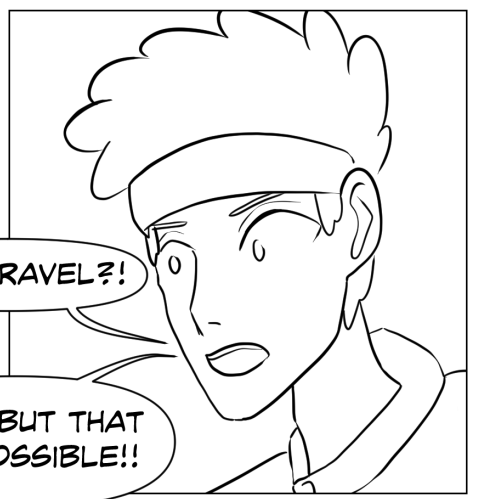


WHAT?!



TIME TRAVEL?!

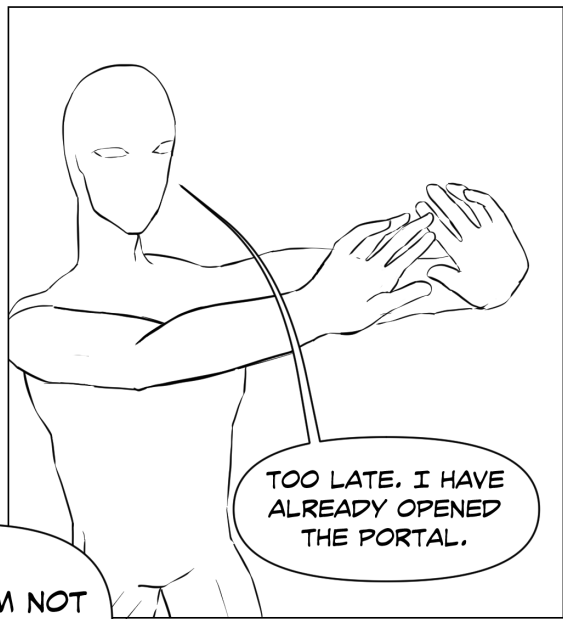
BUT... BUT THAT IS IMPOSSIBLE!!



DID YOU FORGET?
I CAN DO ANYTHING.



BUT... I'M NOT READY. I WAN-



TOO LATE. I HAVE ALREADY OPENED THE PORTAL.



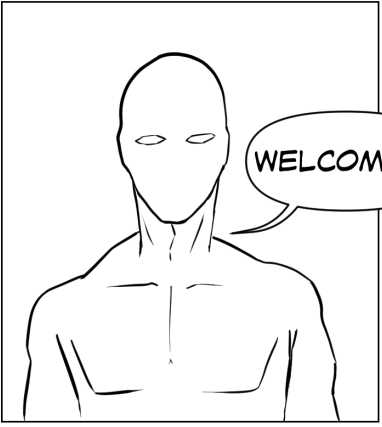
OH..



CRAP!!



WHY WON'T YOU GIVE ME A PROPER HEADS UP?!



UHH..

WHERE AM I?

WELCOME...



TO 404 BC
GREECE.

I'VE GOT YOU
HERE TO SEE
DEMOCRITUS.

THE HUMAN WHO
FIRST SUGGESTED
THE EXISTENCE
OF ATOMS.



WOAH... SO HE IS THE GUY WHO FIRST THOUGHT OF ATOMS, HUH?

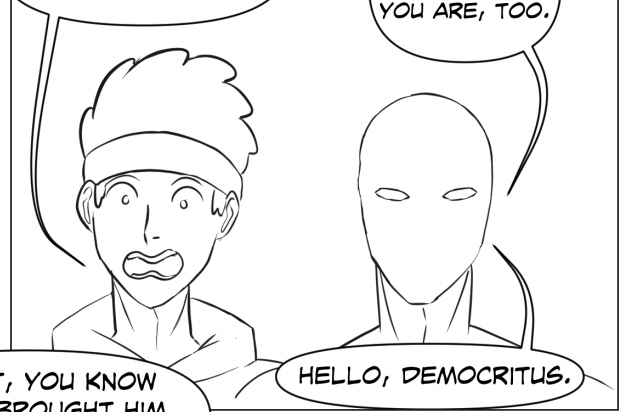


WHAT?! HE KNOWS WHO YOU ARE?

YES. AND HE KNOWS WHO YOU ARE, TOO.



OH TIMEKEEPER! I DID NOT SEE YOU THERE. WELCOME.



ALRIGHT, YOU KNOW WHAT I BROUGHT HIM HERE FOR, DEMOCRITUS.

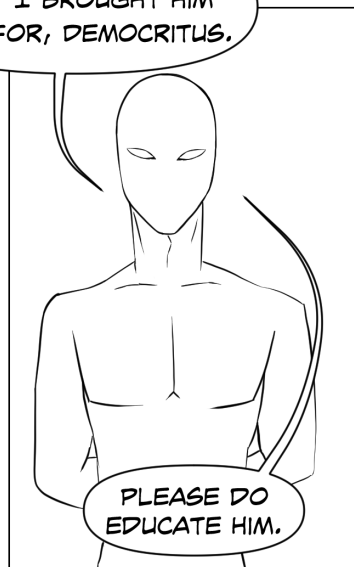
HELLO, DEMOCRITUS.



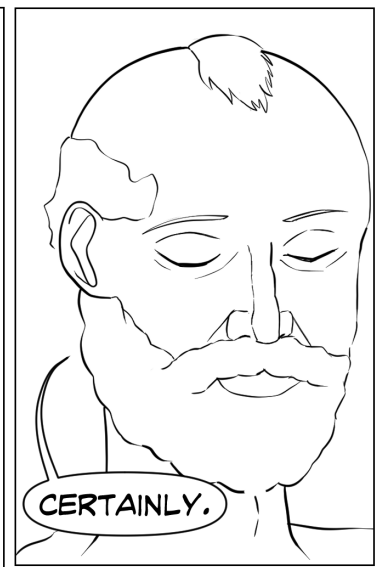
YOU MUST BE SHIV. IT IS A PLEASURE TO MEET YOU.

LIKewise, SIR.

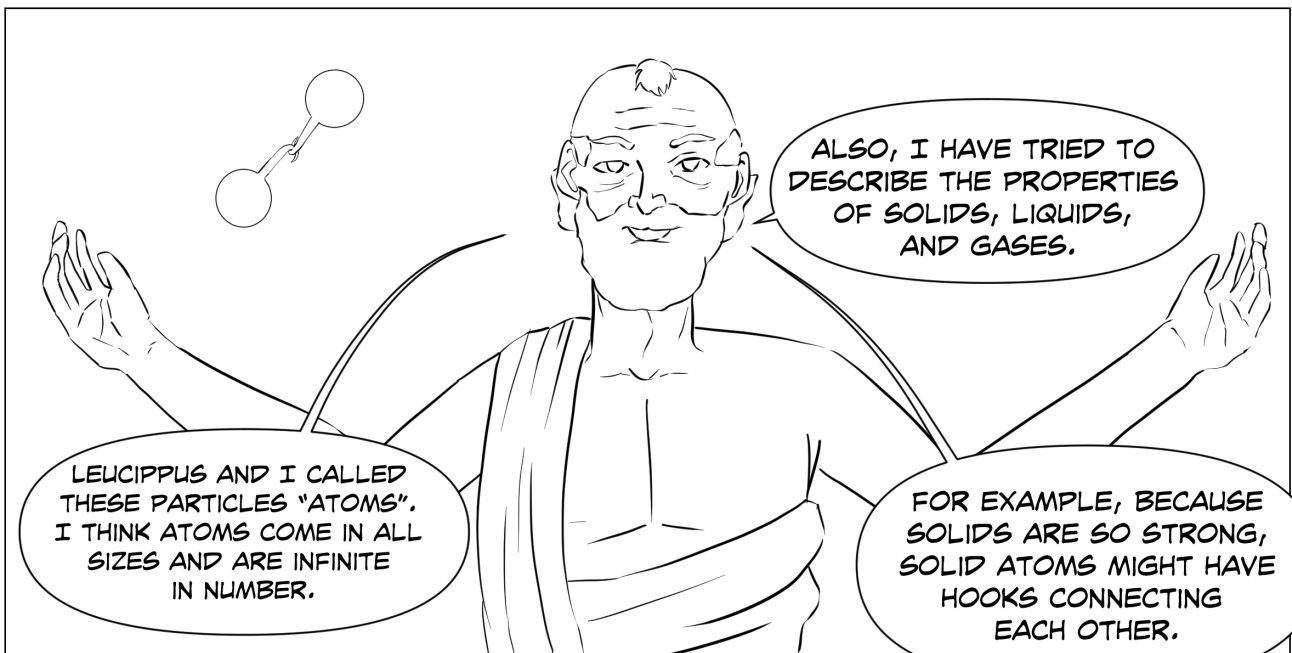
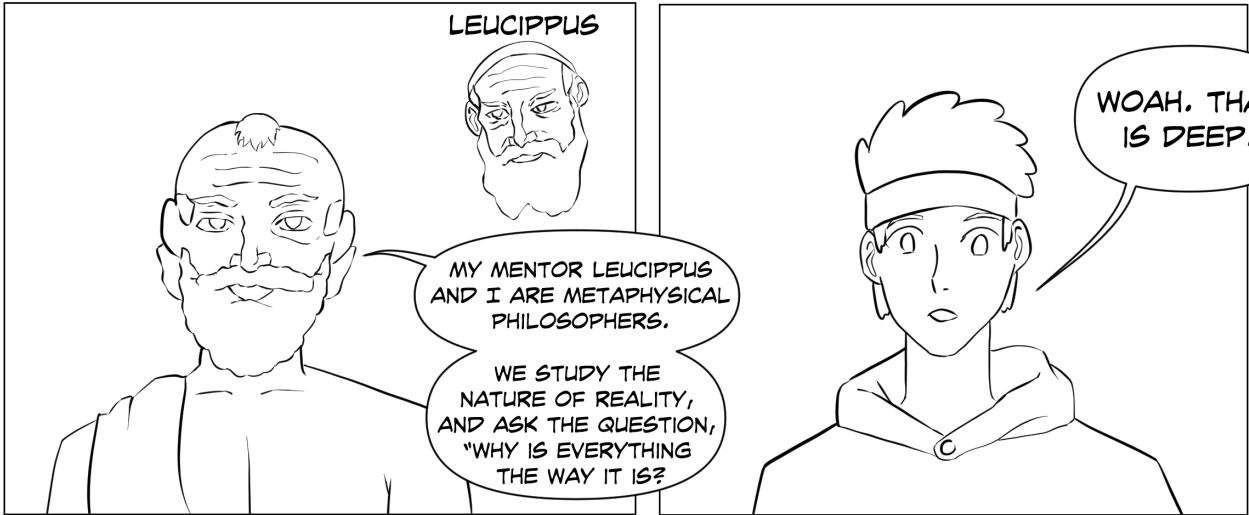
HOW DOES HE KNOW MY NAME?

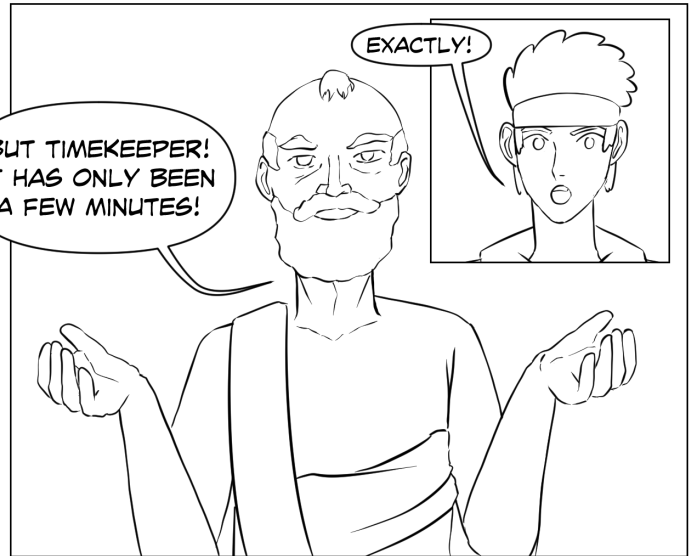
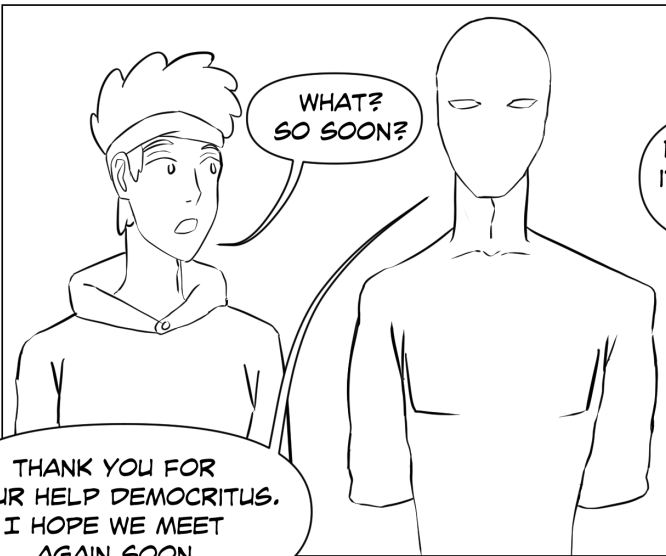


PLEASE DO EDUCATE HIM.

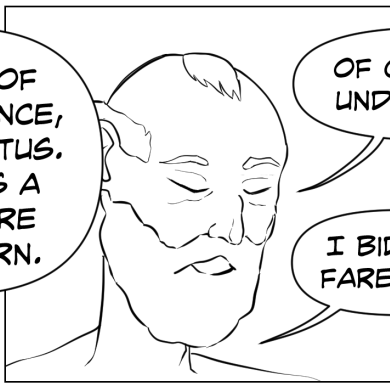


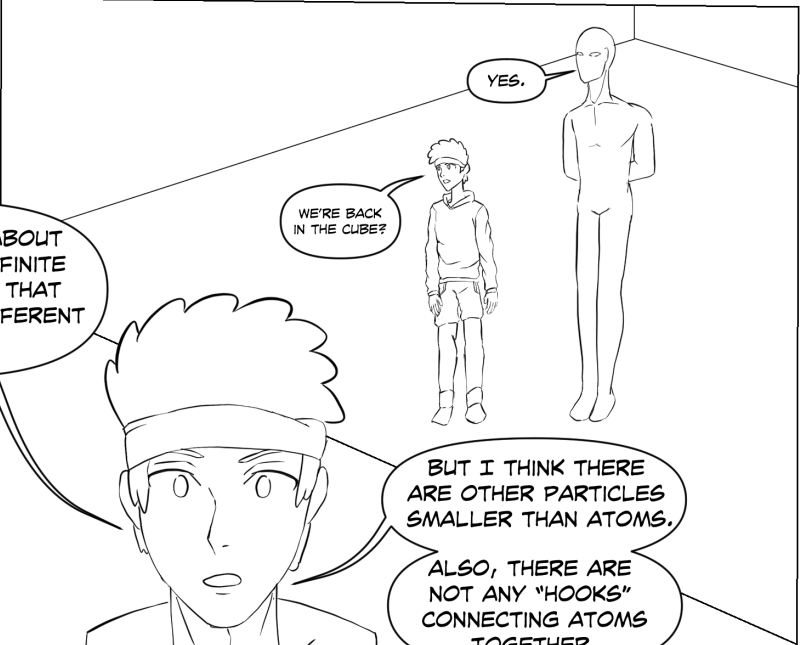
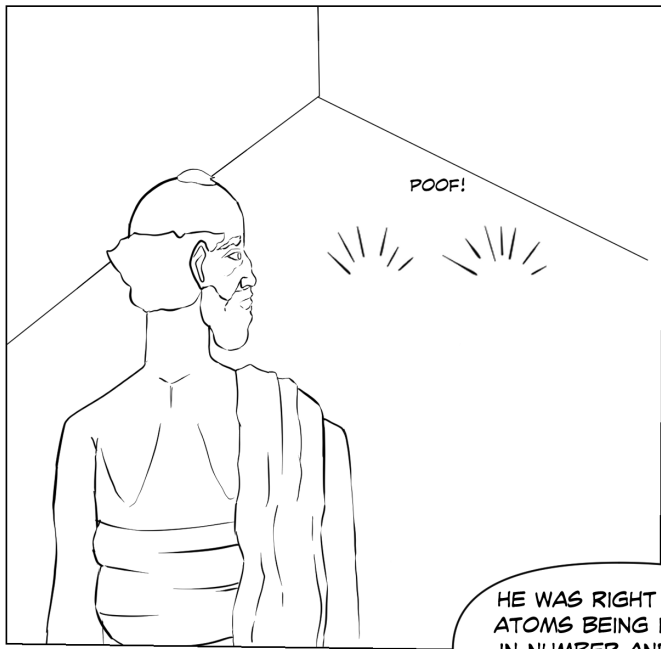
CERTAINLY.





THANK YOU FOR YOUR HELP DEMOCRITUS. I HOPE WE MEET AGAIN SOON.

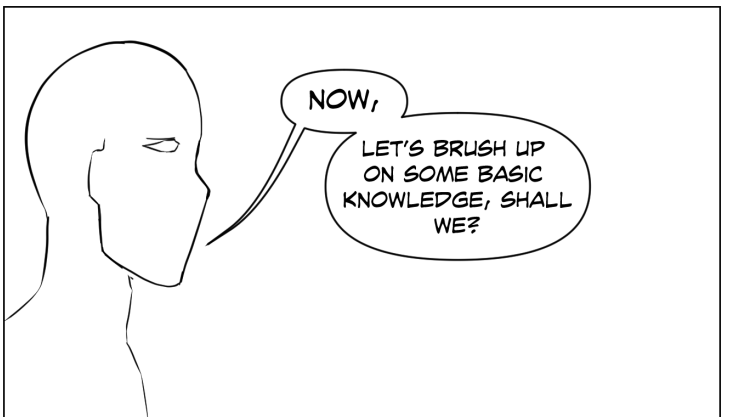
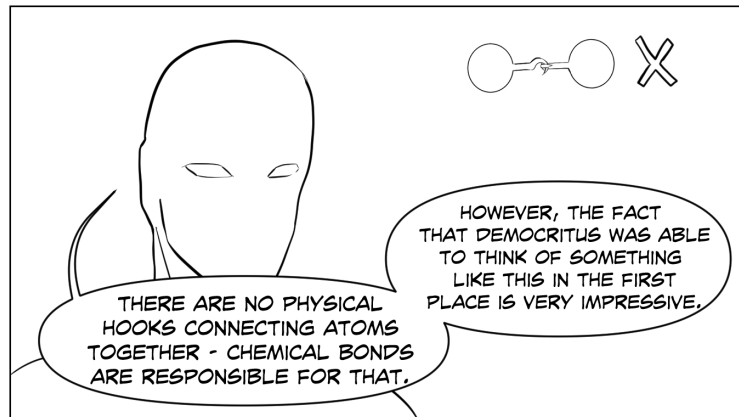
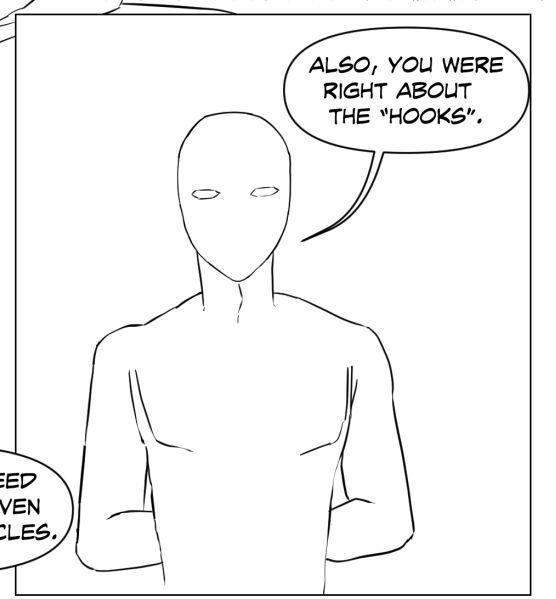
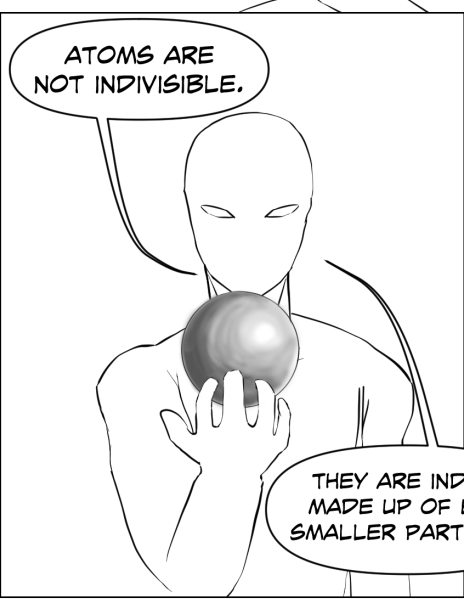
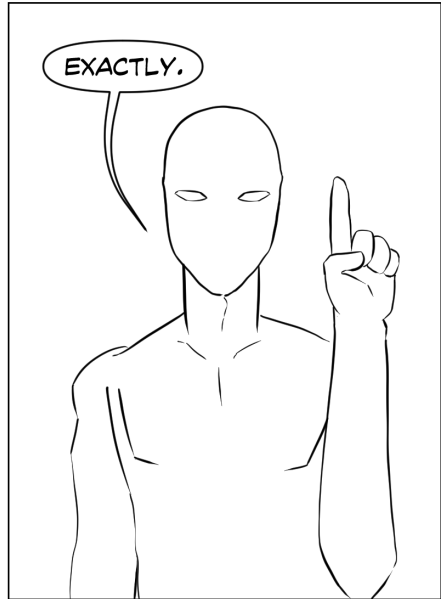




HE WAS RIGHT ABOUT ATOMS BEING INFINITE IN NUMBER AND THAT THEY COME IN DIFFERENT SIZES...

BUT I THINK THERE ARE OTHER PARTICLES SMALLER THAN ATOMS. ALSO, THERE ARE NOT ANY "HOOKS" CONNECTING ATOMS TOGETHER.

AT LEAST THAT'S WHAT I LEARN'T IN SCHOOL...



ATOMS ARE MADE OF PROTONS, NEUTRONS AND ELECTRONS.

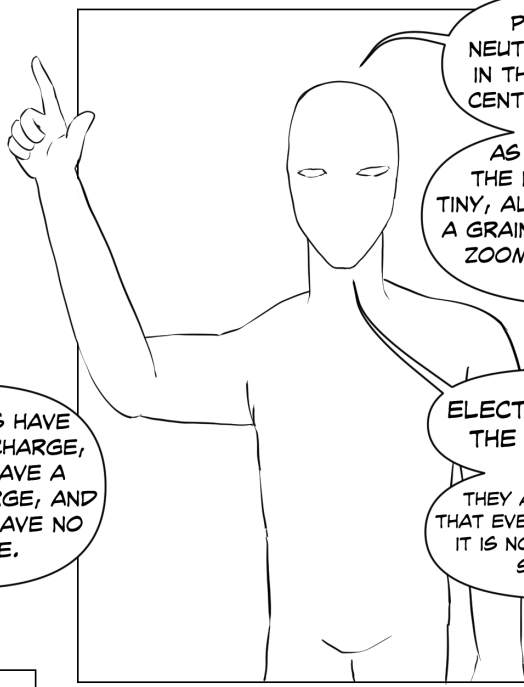
$\times 2,000,000,000,000$
NUCLEUS



ELECTRONS HAVE A NEGATIVE CHARGE, PROTONS HAVE A POSITIVE CHARGE, AND NEUTRONS HAVE NO CHARGE.

PROTONS AND NEUTRONS ARE FOUND IN THE NUCLEUS, THE CENTER OF THE ATOM.

AS YOU CAN SEE, THE NUCLEUS IS VERY TINY, ALMOST THE SIZE OF A GRAIN OF SAND WHEN I ZOOM IN TWO TRILLION TIMES!

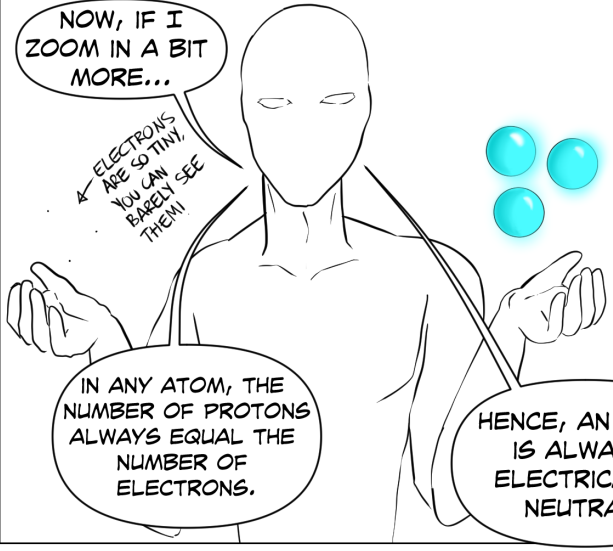


ELECTRONS ORBIT THE NUCLEUS.

THEY ARE SO SMALL, THAT EVEN ON THIS SCALE, IT IS NOT POSSIBLE TO SEE THEM.

NOW, IF I ZOOM IN A BIT MORE...

ELECTRONS ARE SO TINY, YOU CAN BARELY SEE THEM!



IN ANY ATOM, THE NUMBER OF PROTONS ALWAYS EQUAL THE NUMBER OF ELECTRONS.

HENCE, AN ATOM IS ALWAYS ELECTRICALLY NEUTRAL.

THE MORE PROTONS AND NEUTRONS AN ATOM HAS, THE HEAVIER AN ATOM.

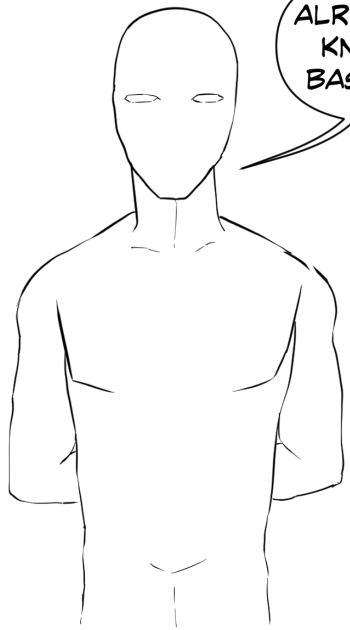
ELECTRONS ARE SO TINY THAT THEIR MASS CAN BE IGNORED.

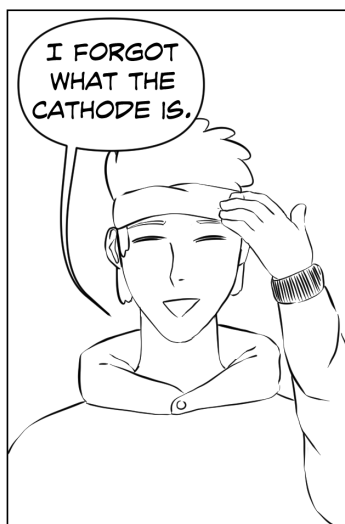
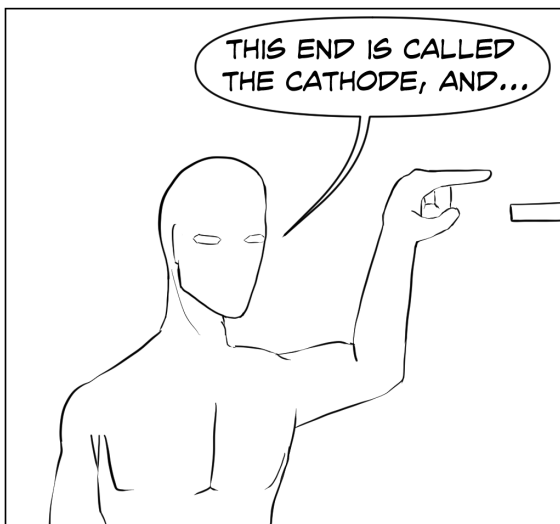
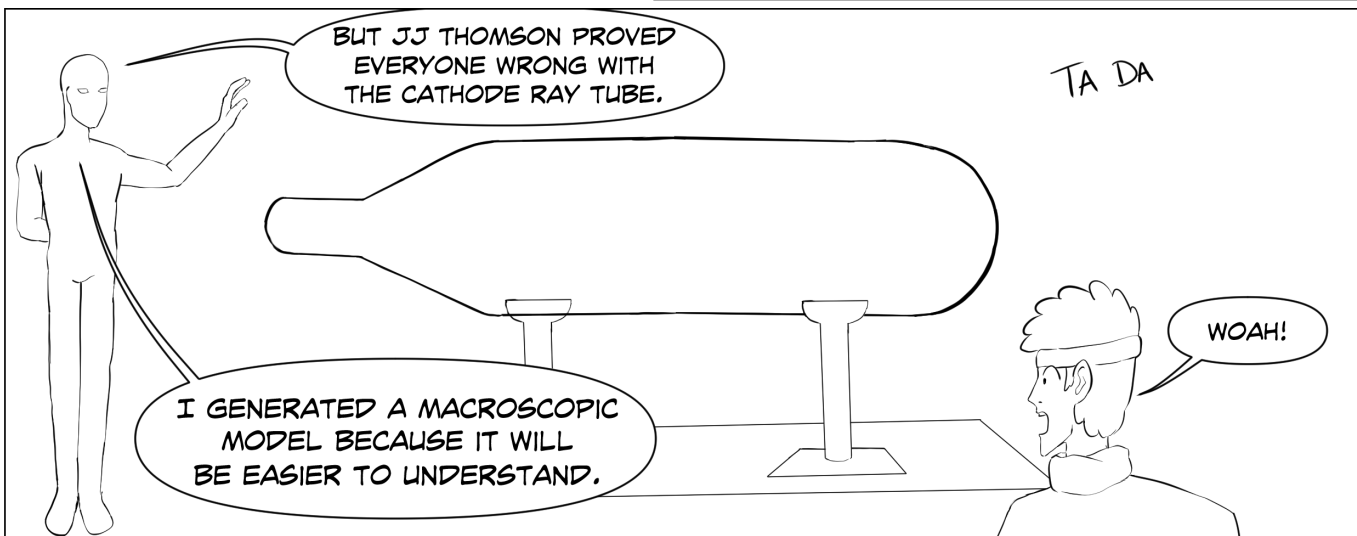
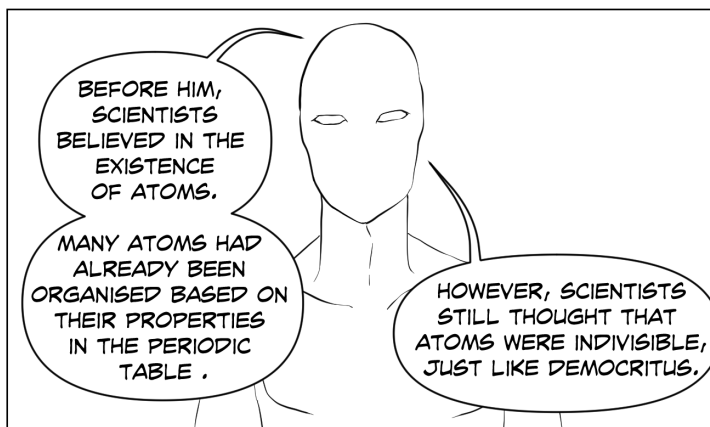
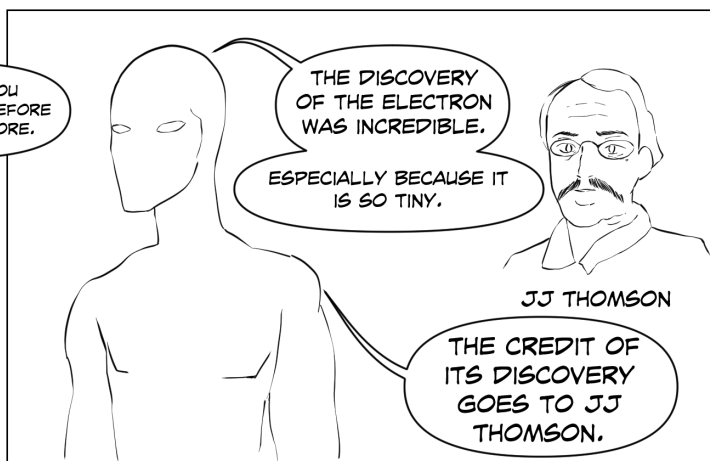
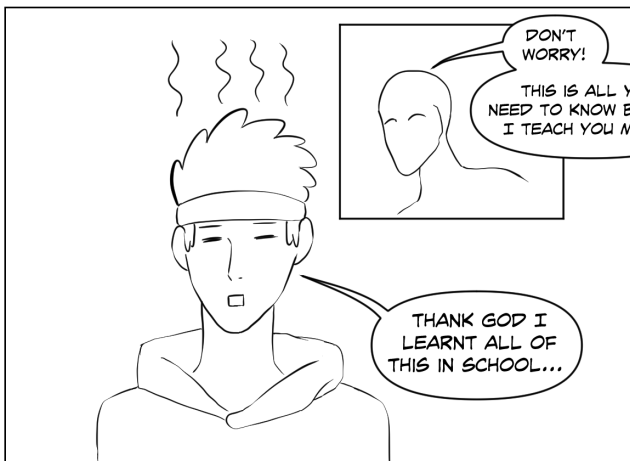


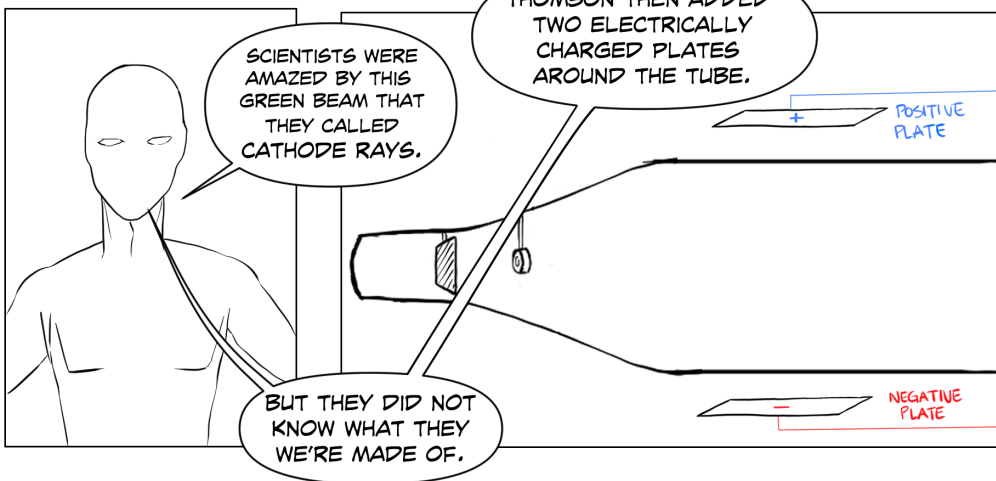
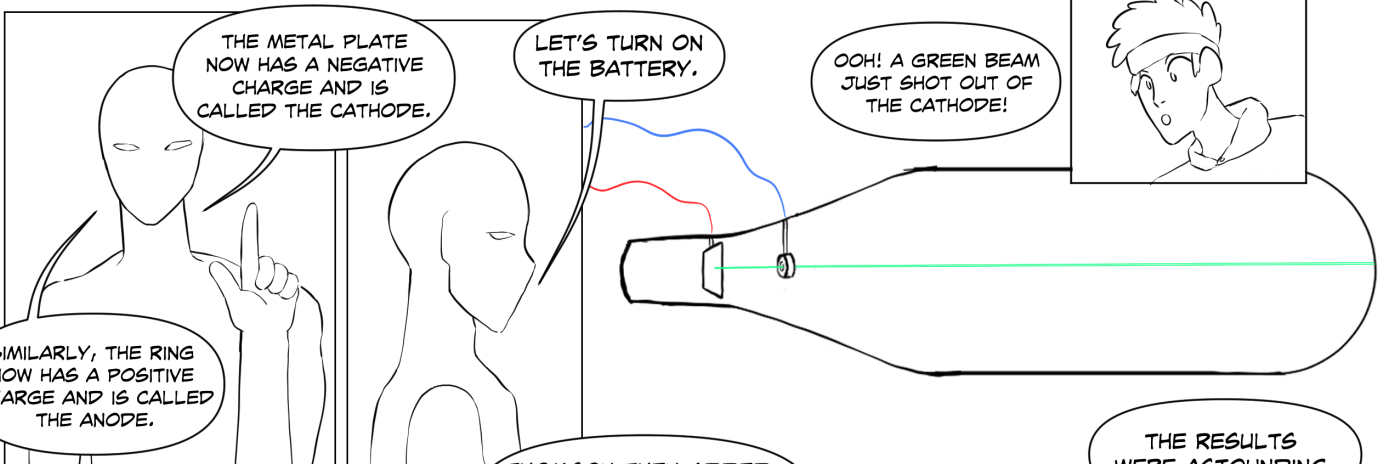
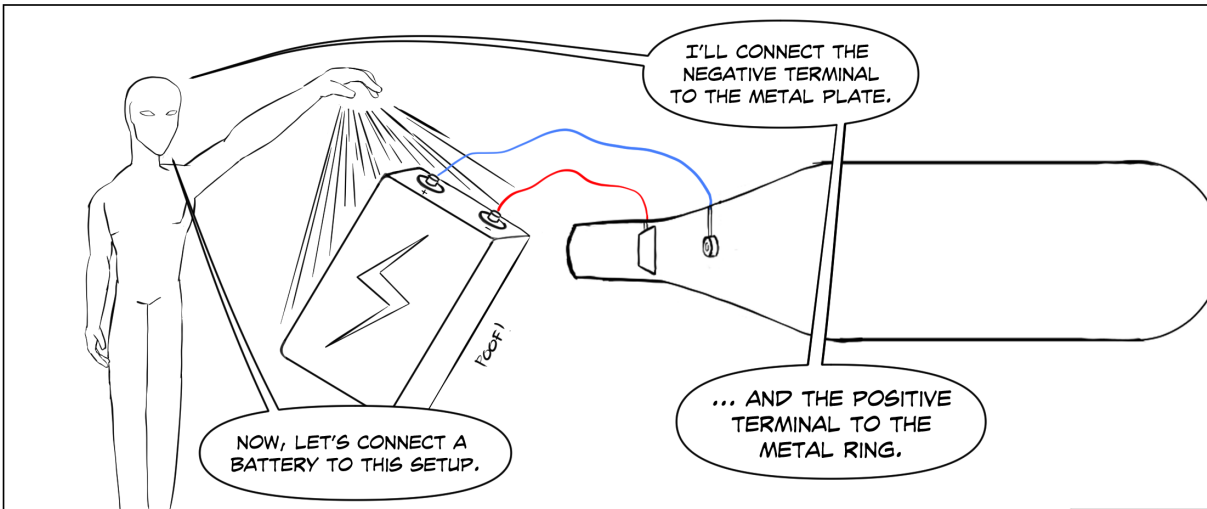
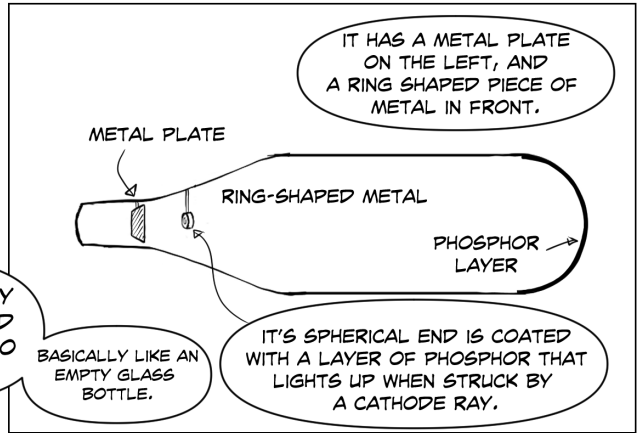
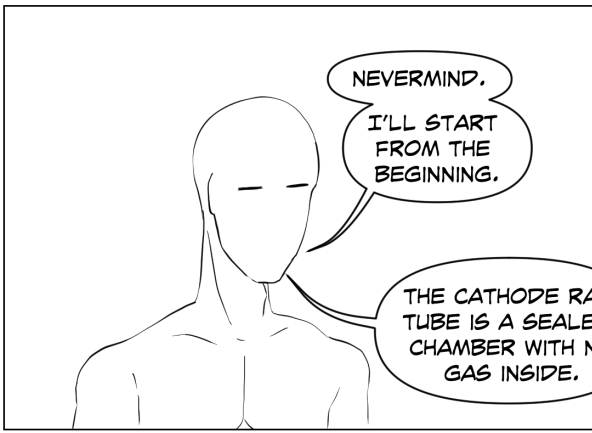
THE PERIODIC TABLE
[H]

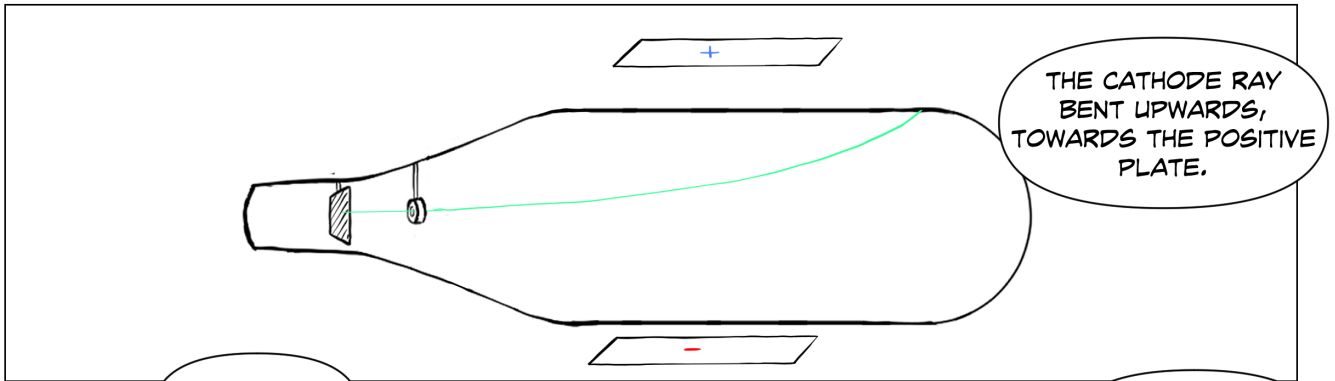
THE ATOMS ARE ARRANGED ON THE BASIS OF THE NUMBER OF PROTONS IN THE PERIODIC TABLE.

ALRIGHT, YOU KNOW THE BASICS NOW.

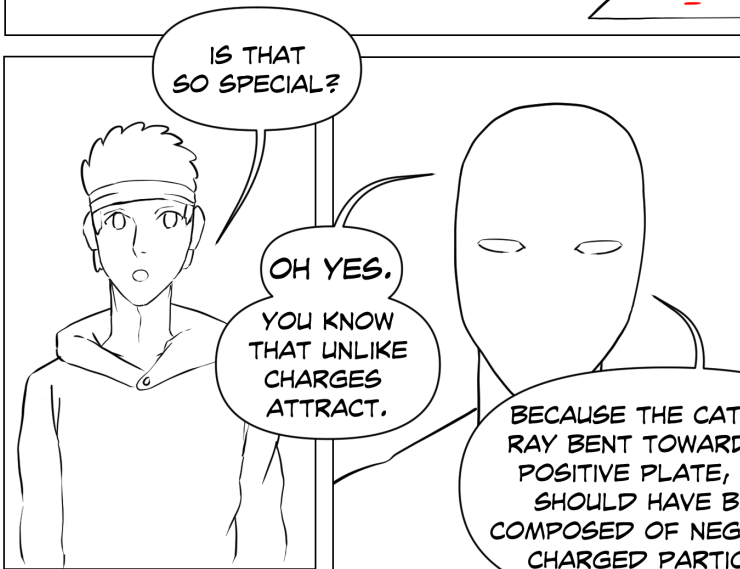








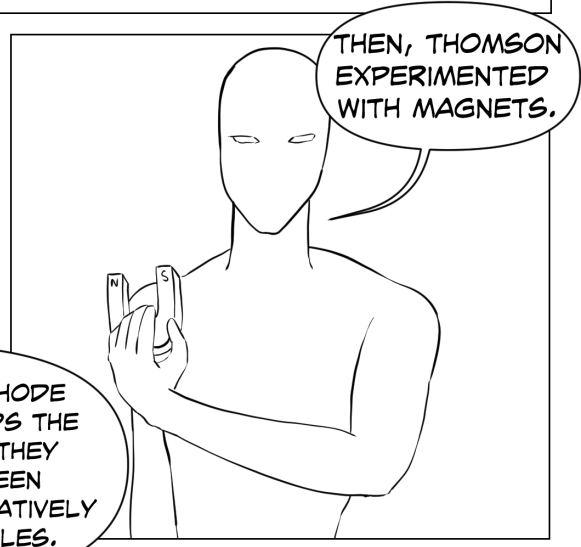
THE CATHODE RAY BENT UPWARDS, TOWARDS THE POSITIVE PLATE.



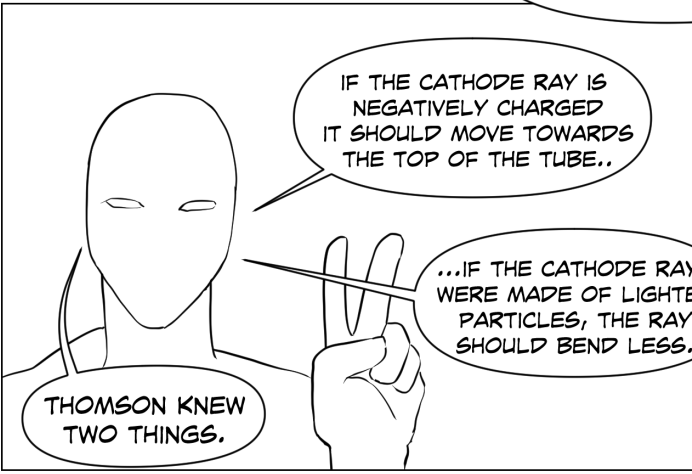
IS THAT SO SPECIAL?

OH YES. YOU KNOW THAT UNLIKE CHARGES ATTRACT.

BECAUSE THE CATHODE RAY BENT TOWARDS THE POSITIVE PLATE, THEY SHOULD HAVE BEEN COMPOSED OF NEGATIVELY CHARGED PARTICLES.



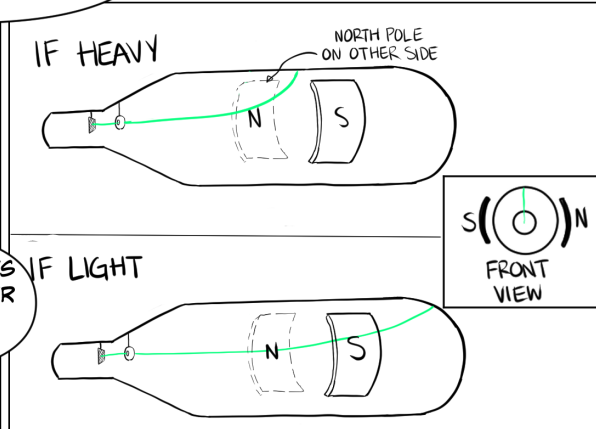
THEN, THOMSON EXPERIMENTED WITH MAGNETS.



IF THE CATHODE RAY IS NEGATIVELY CHARGED IT SHOULD MOVE TOWARDS THE TOP OF THE TUBE..

...IF THE CATHODE RAYS WERE MADE OF LIGHTER PARTICLES, THE RAY SHOULD BEND LESS.

THOMSON KNEW TWO THINGS.

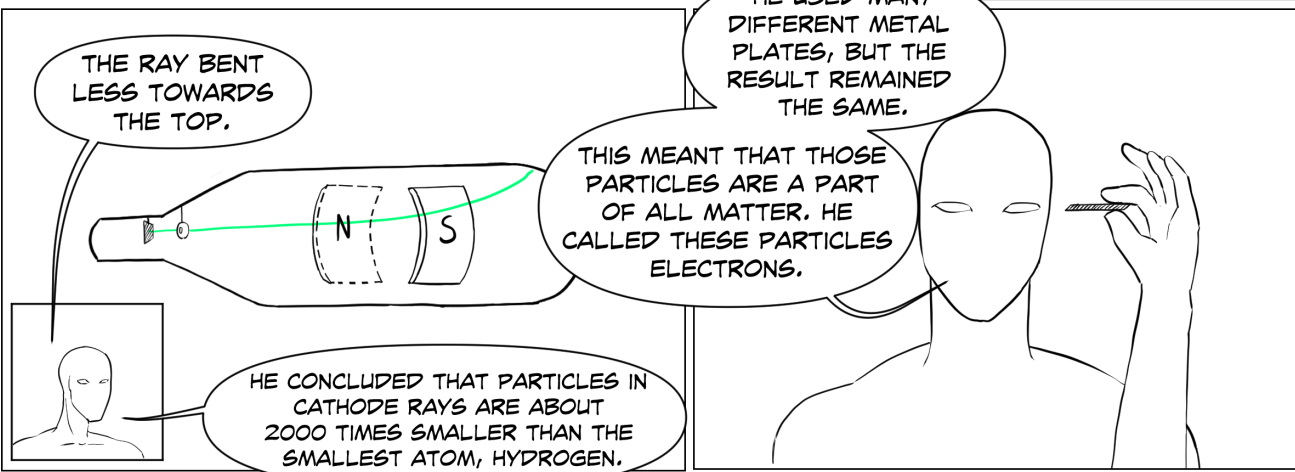


IF HEAVY

NORTH POLE ON OTHER SIDE

IF LIGHT

S (O) N
FRONT VIEW



THE RAY BENT LESS TOWARDS THE TOP.

HE USED MANY DIFFERENT METAL PLATES, BUT THE RESULT REMAINED THE SAME.

THIS MEANT THAT THOSE PARTICLES ARE A PART OF ALL MATTER. HE CALLED THESE PARTICLES ELECTRONS.



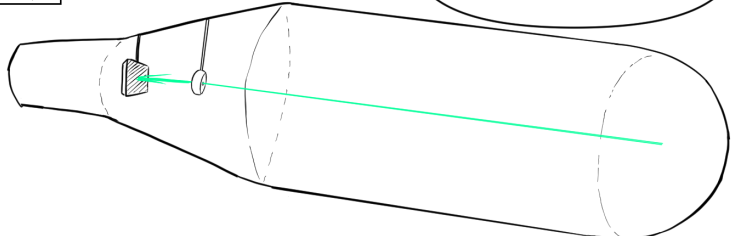
HE CONCLUDED THAT PARTICLES IN CATHODE RAYS ARE ABOUT 2000 TIMES SMALLER THAN THE SMALLEST ATOM, HYDROGEN.

WHEW! THAT WAS SO MUCH!

OH! I FORGOT TO MENTION THAT.

THE CATHODE, EMITS A CATHODE RAY, BASICALLY A STREAM OF ELECTRONS.

THE ANODE ATTRACTS THESE ELECTRONS AND HELPS FOCUS THEM INTO A BEAM.



WHY IS THE ANODE IMPORTANT?

BUT I HAVE A QUESTION.

AFTER THOMSON DISCOVERED ELECTRONS, HE CAME UP WITH A NEW MODEL OF THE ATOM.

HMM..

CAN YOU REMEMBER WHAT IT WAS?

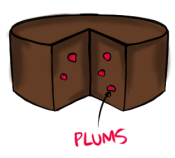
NOPE! I GUESS I WASN'T PAYING ATTENTION IN CLASS.

HE CALLED IT THE PLUM PUDDING MODEL. QUITE LITERALLY.

JUST LIKE THE PIECES OF PLUM ARE PLACED RANDOMLY IN THE CAKE, HE THOUGHT ELECTRONS DID NOT HAVE A PROPER ARRANGEMENT IN THE ATOM.

HE THOUGHT OF AN ATOMS AS A CAKE OR "PUDDING".

THIS PUDDING HAD A POSITIVE CHARGE.



AND HE THOUGHT OF ELECTRONS AS PIECES OF "PLUMS" INSIDE THE PUDDING.

BUT IN THE END, HIS MODEL WAS DISPROVED.

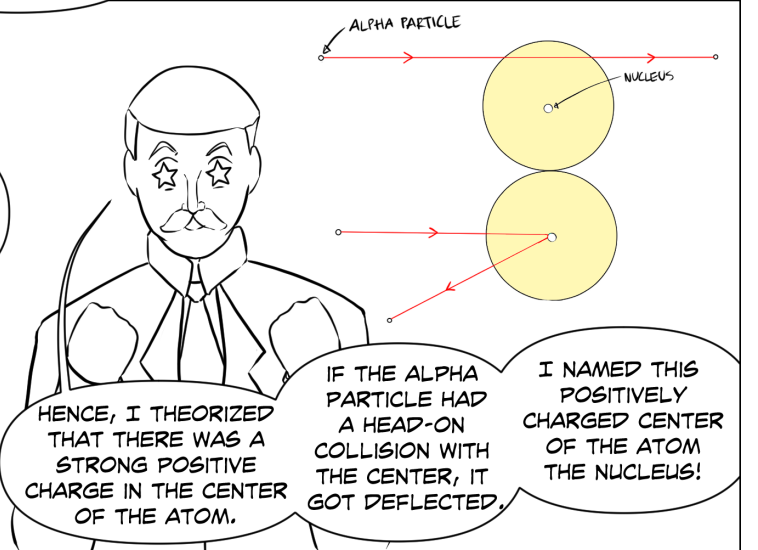
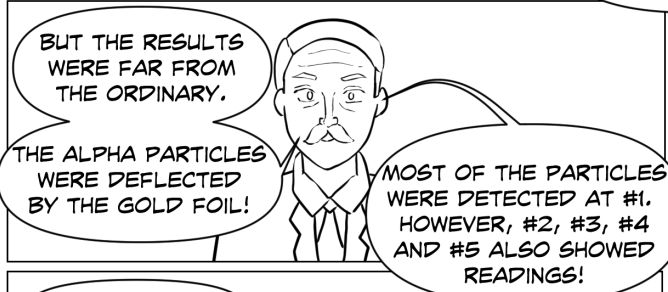
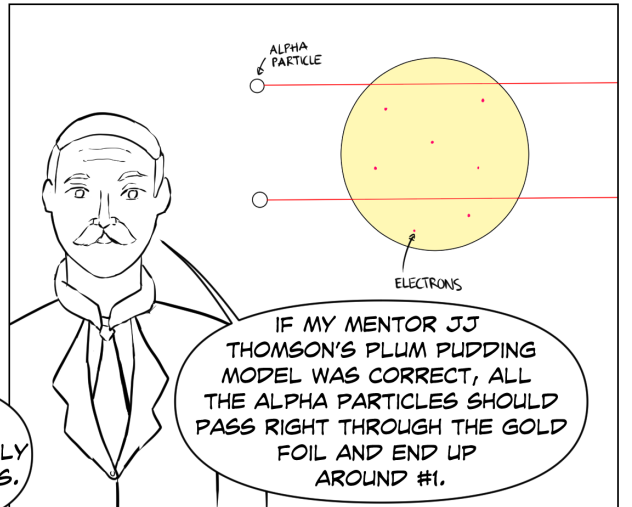
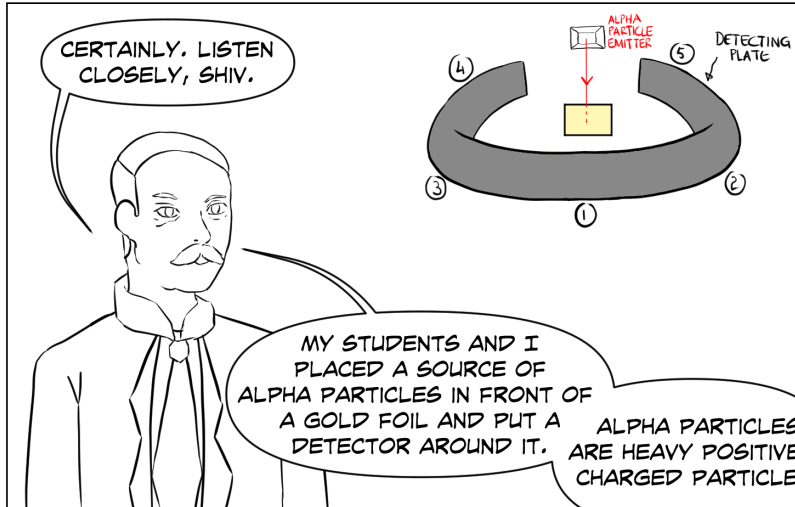
CAN YOU THINK OF A REASON WHY?

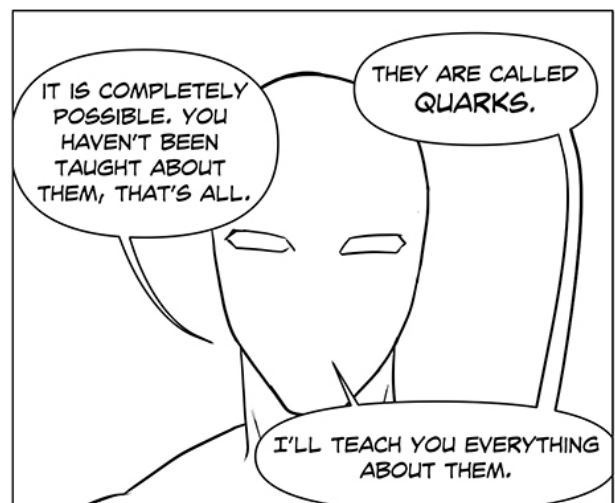
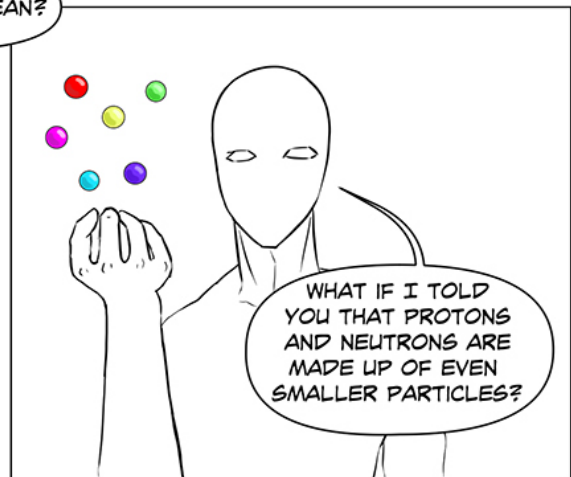
WELL, ATOMS HAVE A NUCLEUS IN THE CENTER RIGHT?

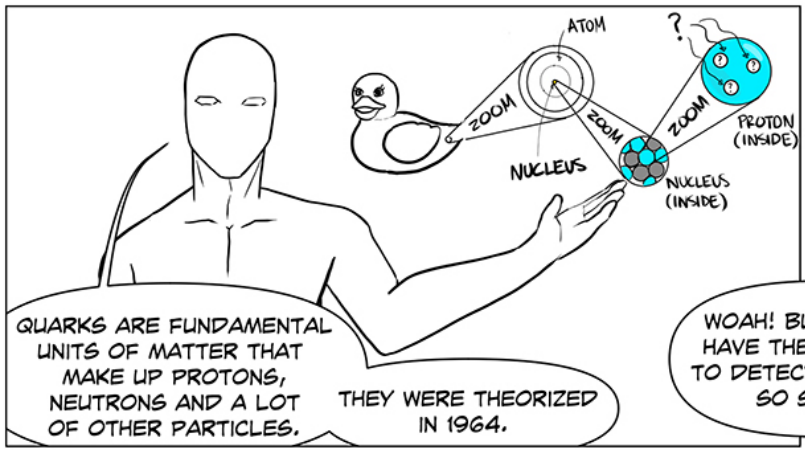
THE PLUM PUDDING MODEL DOES NOT CONSIDER THAT.

EXACTLY!

LET'S GO MEET THE MAN WHO DISPROVED THOMSON - ERNEST RUTHERFORD, THOMSON'S STUDENT!





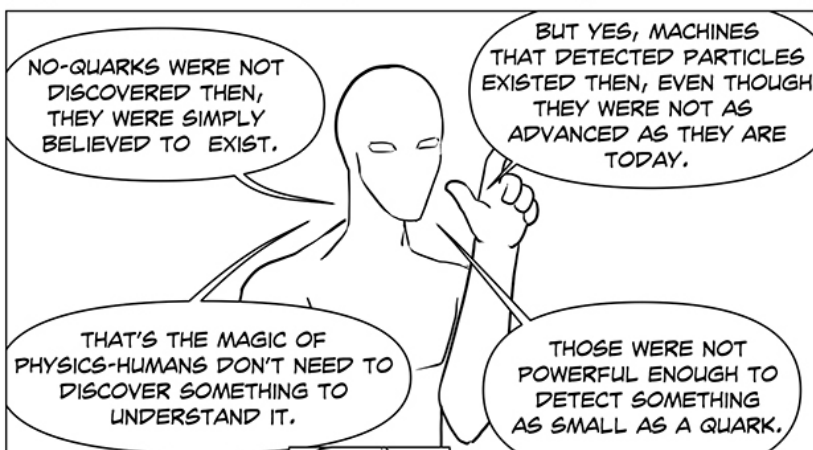


QUARKS ARE FUNDAMENTAL UNITS OF MATTER THAT MAKE UP PROTONS, NEUTRONS AND A LOT OF OTHER PARTICLES. THEY WERE THEORIZED IN 1964.



WOAH! BUT DID THEY HAVE THE MACHINERY TO DETECT SOMETHING SO SMALL?

OOH! SO WERE THERE COOL EXPLOSIONS BETWEEN PROTONS WHICH BROKE AND QUARKS CAME OUT??



NO-QUARKS WERE NOT DISCOVERED THEN, THEY WERE SIMPLY BELIEVED TO EXIST.

BUT YES, MACHINES THAT DETECTED PARTICLES EXISTED THEN, EVEN THOUGH THEY WERE NOT AS ADVANCED AS THEY ARE TODAY.

THAT'S THE MAGIC OF PHYSICS-HUMANS DON'T NEED TO DISCOVER SOMETHING TO UNDERSTAND IT.

THOSE WERE NOT POWERFUL ENOUGH TO DETECT SOMETHING AS SMALL AS A QUARK.



SIGH

AWW MAN..

NOPE. IT WAS MORE ELEGANT THAN THAT.

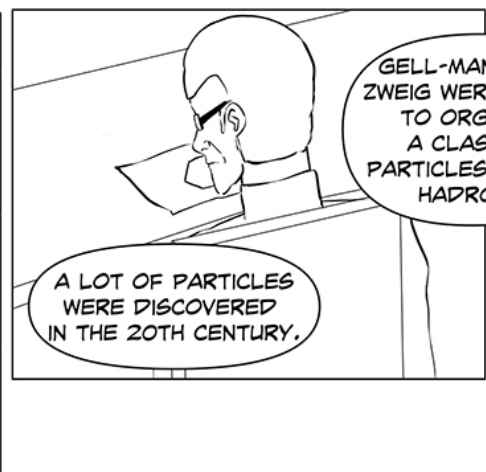
TWO PHYSICISTS THEORIZED QUARKS...

MURRAY GELL-MANN...

...AND GEORGE ZWEIG.

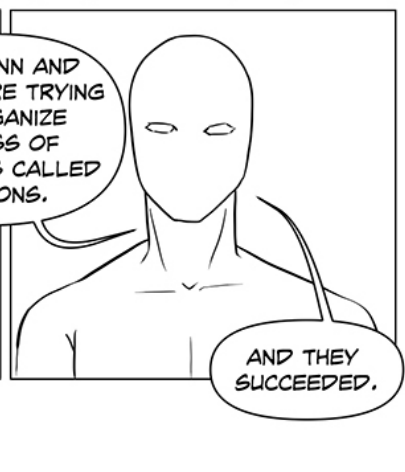


THEY DIDN'T COLLABORATE - THEY THEORIZED QUARKS INDEPENDENTLY.



A LOT OF PARTICLES WERE DISCOVERED IN THE 20TH CENTURY.

GELL-MANN AND ZWEIG WERE TRYING TO ORGANIZE A CLASS OF PARTICLES CALLED HADRONS.



AND THEY SUCCEEDED.

THE VAST NUMBER OF DISCOVERED PARTICLES HAD TO HAVE SOME KIND OF ORDER TO THEM, JUST LIKE ELEMENTS IN THE PERIODIC TABLE.

BOTH GELL-MANN AND ZWEIG THOUGHT THAT HADRONS COULD BE BETTER CLASSIFIED IF THEY WERE MADE UP OF SOMETHING SMALLER.

LIKE PROTONS ARE HELPFUL IN CLASSIFYING ELEMENTS.

GELL-MANN CALLED THESE PARTICLES QUARKS...

ZWEIG CALLED THEM ACES, AFTER THE PLAYING CARD.

HOW DID GELL-MANN COME UP WITH THE NAME 'QUARK'?

OH, YOU WON'T BELIEVE IT.

*"Three Quarks for Muster Mark
Sure he hasn't got much of a bark,
And sure he has it's all besides the mark."*

IT CAME FROM A POEM WRITTEN BY JAMES JOYCE CALLED 'FINNEGANS WAKE'.

THE WORD JUST STOOD OUT TO HIM.

THERE'S NO MEANING BEHIND IT.

ANYWAY, WE ARE GOING OFF-TOPIC.

...AT SLAC, STANFORD UNIVERSITY'S PARTICLE ACCELERATOR.

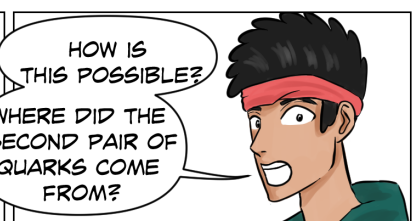
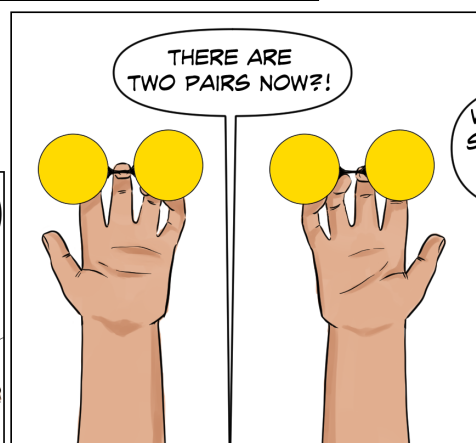
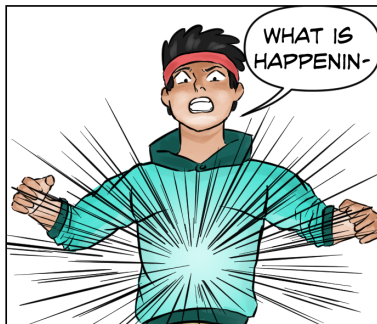
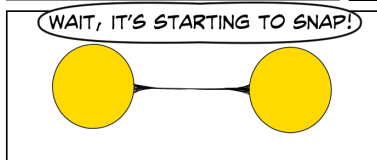
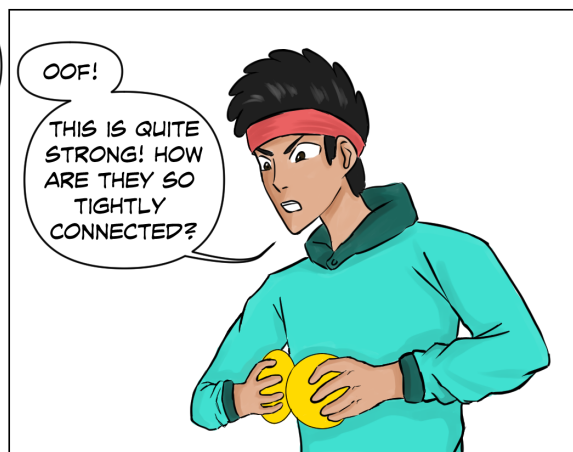
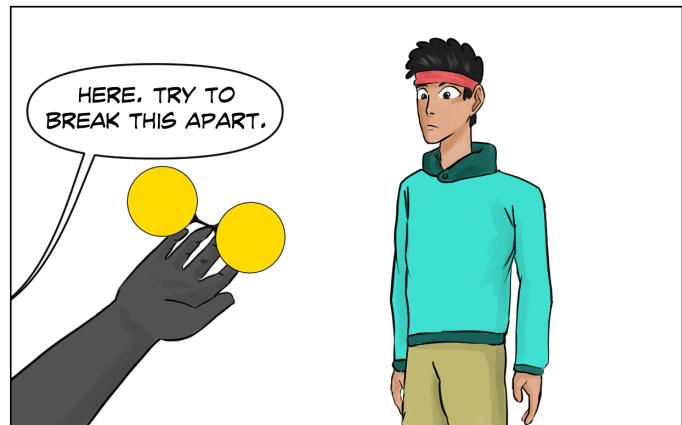
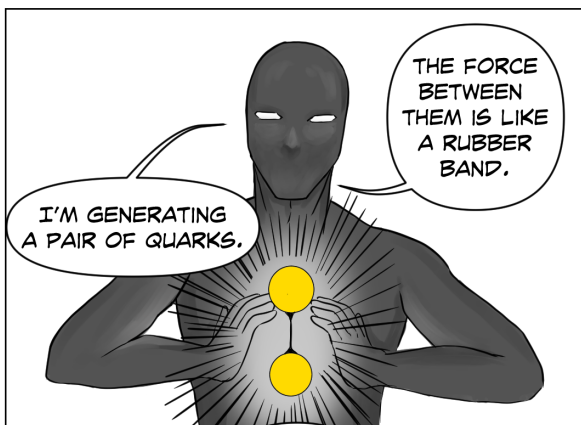
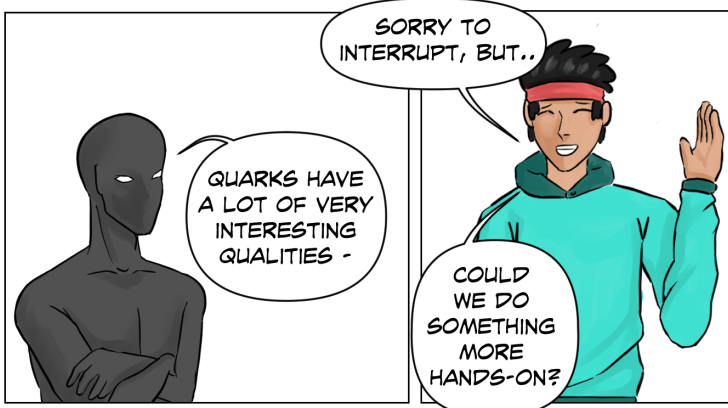
AFTER QUARKS WERE THEORIZED IN 1964, THEY WERE DISCOVERED JUST 4 YEARS LATER...

EVENTUALLY, 5 MORE QUARKS WERE DISCOVERED OVER THE NEXT 27 YEARS.

THE UP QUARK WAS THE FIRST TO BE DISCOVERED, AND THE BOTTOM WAS THE LAST.

- u UP
- d DOWN
- s STRANGE
- c CHARM
- t TOP
- b BOTTOM

WHOEVER NAMED THEM MUST HAVE BEEN A GENIUS.



QUARK CONFINEMENT MEANS THAT QUARKS CANNOT EXIST IN ISOLATION.

THE ATTRACTION BETWEEN TWO QUARKS IS VERY HARD TO OVERCOME.

HOWEVER, ONCE YOU PUT IN A LOT OF ENERGY THE PAIR OF QUARKS BREAKS.

BUT THE ENERGY USED TO BREAK THE PAIR GETS CONVERTED INTO MASS. THIS MASS TAKES FORM AS NEW QUARKS, FORMING A NEW PAIR.

WHAT?! ENERGY CAN BE CONVERTED INTO MASS?
HOW IS THAT POSSIBLE?!

IT IS POSSIBLE. AND ALBERT EINSTEIN PROVED IT.

$$E = mc^2$$

YOU DON'T EXPERIENCE THIS IN OUR DAY-TO-DAY LIFE, BUT IT HAPPENS ALL THE TIME IN THE SUBATOMIC WORLD.

WOAH. THIS IS CRAZY!

IT GETS EVEN MORE INTERESTING.

DON'T WORRY. IT WILL GET EASIER TO UNDERSTAND.

AT SLAC, IT WAS DISCOVERED THAT PROTONS WERE MADE OF THREE QUARKS - 2 UP QUARKS AND ONE DOWN QUARK.

YOU KNOW THAT WE SAY THAT A PROTON HAS A CHARGE OF +1.

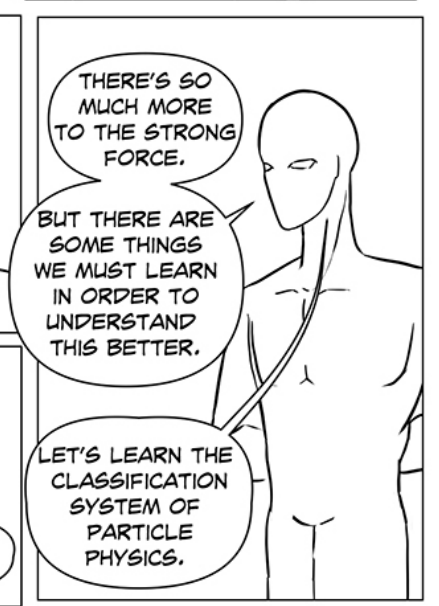
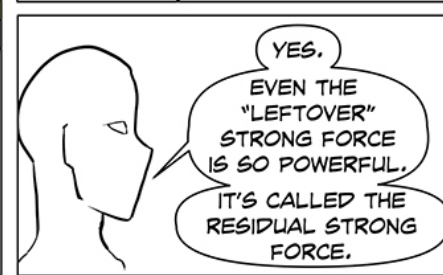
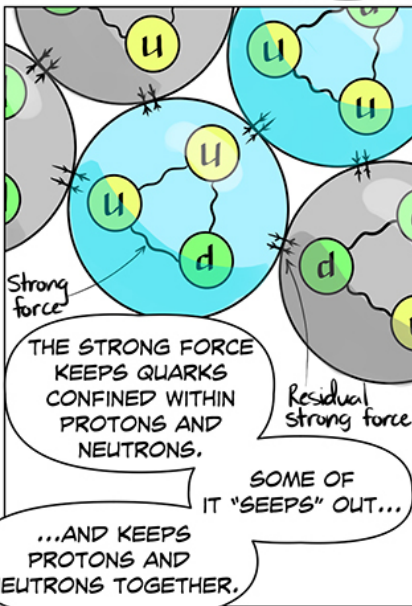
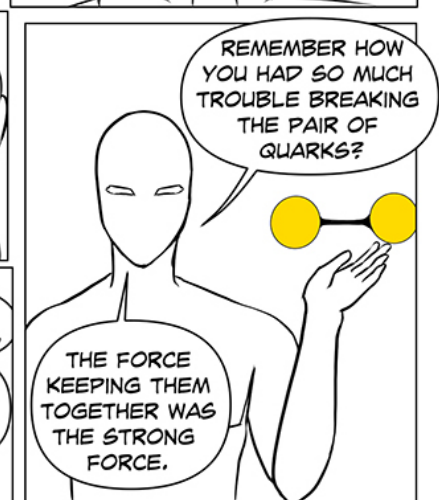
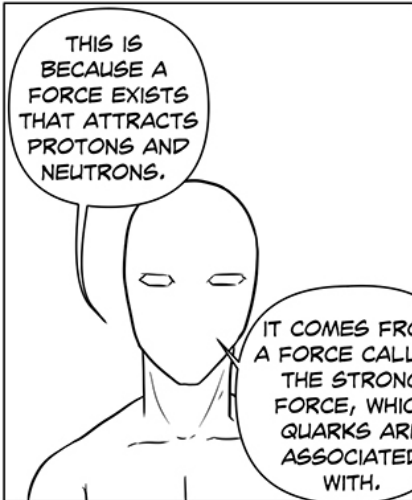
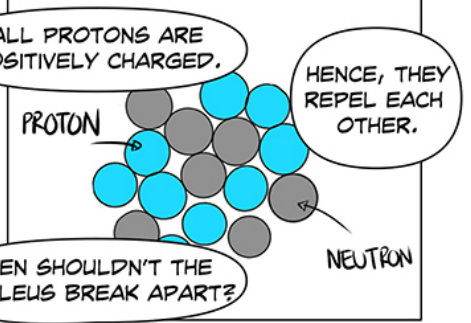
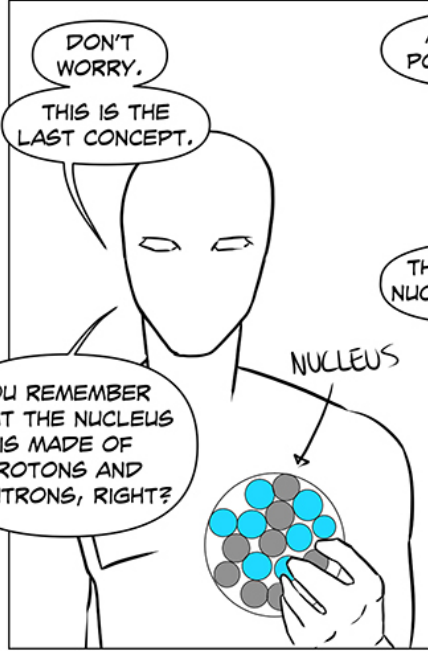
QUARKS HAVE FRACTIONAL CHARGES. PHYSICISTS ALWAYS THOUGHT NOTHING CAN HAVE A CHARGE LESS THAN THAT OF A PROTON.

ANOTHER REASON WHY QUARKS ARE SO FASCINATING.

AN UP QUARK HAS A CHARGE OF $+2/3$ AND A DOWN QUARK HAS A CHARGE OF $-1/3$.

ADDING TWO UP QUARKS AND ONE DOWN QUARK GIVES US +1, THE CHARGE OF A PROTON.

$$\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = 1$$



LET ME INTRODUCE YOU TO THE IDEA OF ELEMENTARY PARTICLES.

ELEMENTARY PARTICLES CANNOT BE BROKEN DOWN INTO ANYTHING SMALLER.

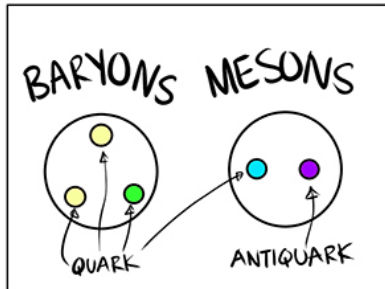
NOW, BIGGER PARTICLES THAT ARE MADE UP OF QUARKS ARE CALLED HADRONS.

SO QUARKS ARE ELEMENTARY PARTICLES, BUT PROTONS AND NEUTRONS AREN'T.

THERE ARE TWO TYPES OF HADRONS TOO-MESONS AND BARYONS.

BARYONS ARE MADE UP OF THREE QUARKS.

MESONS ARE MADE UP OF A QUARK AND AN ANTIQUARK.



OOH! THAT'S BY FAR THE COOLEST THING I'VE HEARD TODAY!

WHAT ARE ANTIQUARKS?

WE WILL LEARN ABOUT ANTIQUARKS LATER.

YOU NEED TO KNOW SOME MORE TO BE ABLE TO UNDERSTAND THEM.

...WE HAVE ALREADY TALKED ABOUT TWO BARYONS PREVIOUSLY.

CAN YOU FIGURE OUT WHICH TWO?

HMM..

BARYONS ARE PARTICLES THAT ARE MADE UP OF THREE QUARKS, RIGHT...?

OH WAIT - THE PROTONS AND NEUTRONS RIGHT? THEY BOTH HAVE THREE QUARKS EACH!

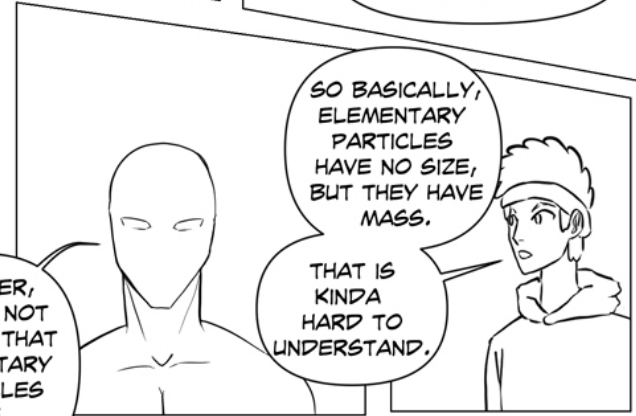
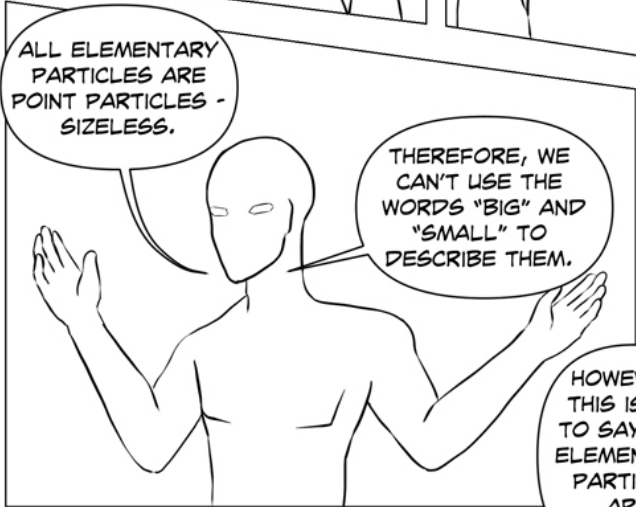
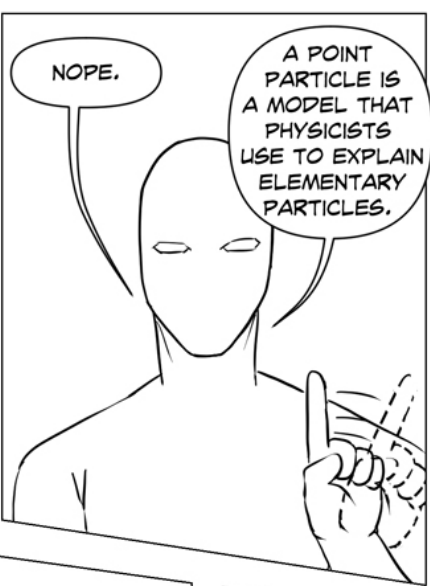
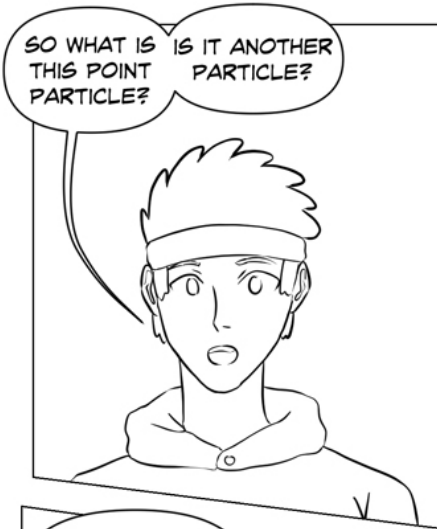
THERE ARE HUNDREDS OF DIFFERENT BARYONS AND MESONS.

THE QUARK MODEL SUCCESSFULLY CLASSIFIES THEM.

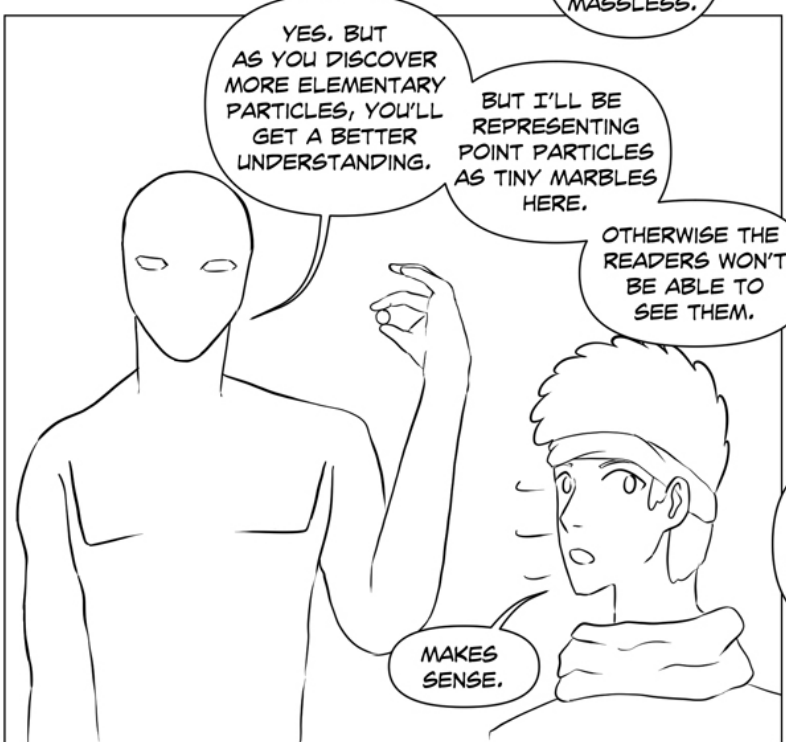
BUT THERE IS ONE MORE THING THAT YOU MUST LEARN.

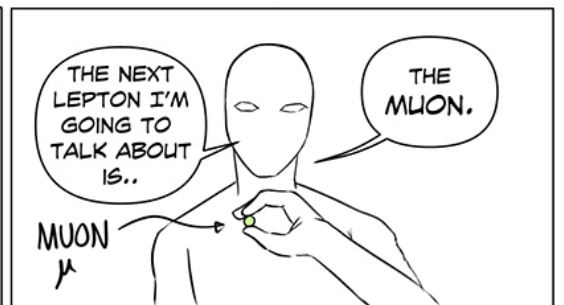
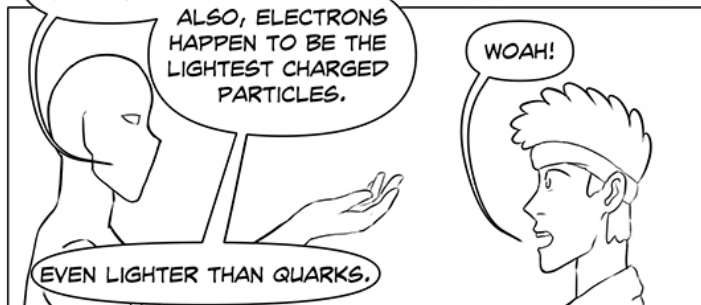
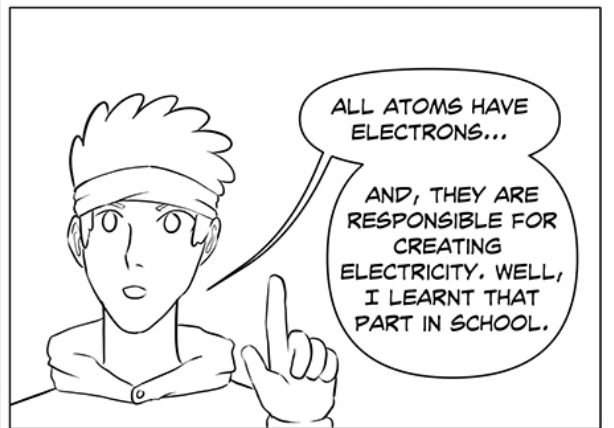
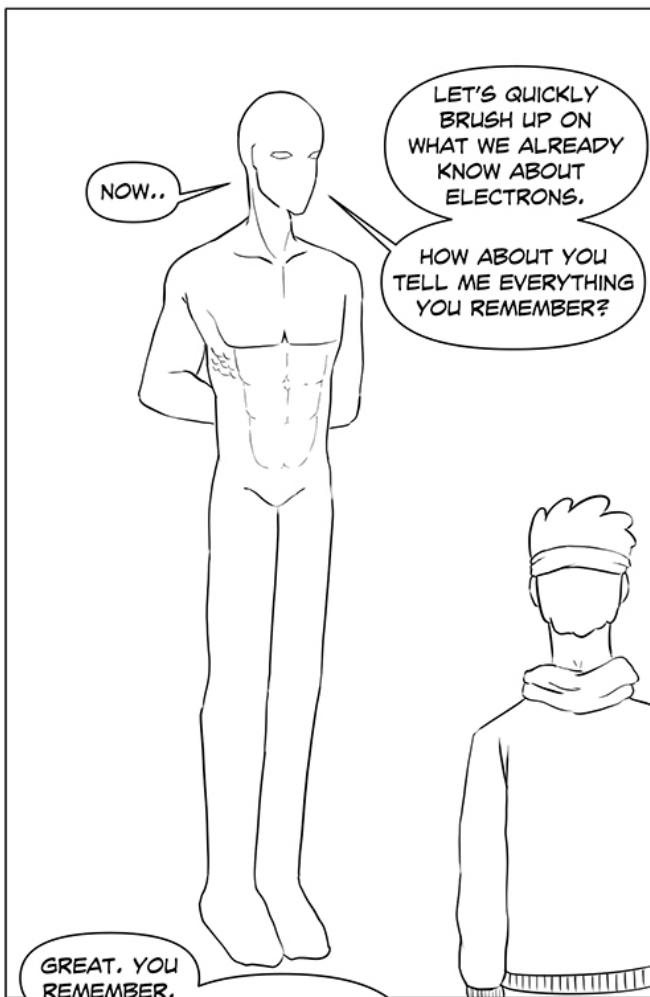
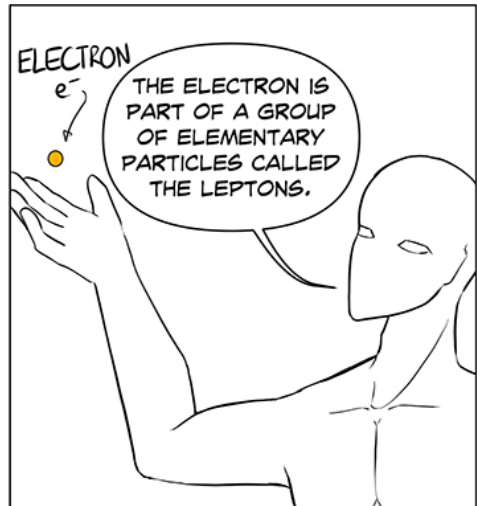
IT'S THE NOTION OF A POINT PARTICLE.

THAT'S CORRECT!



HOWEVER, THIS IS NOT TO SAY THAT ELEMENTARY PARTICLES ARE MASSLESS.





FINALLY, THE NAMES ARE GETTING BETTER.

STOP COMMENTING ON THE NAMES!

* COUGH COUGH*
- AHEM -

HMPH.

AS I WAS SAYING, MUONS ARE ANOTHER TYPE OF LEPTONS.

BUT WHAT PROPERTIES DO MUONS HAVE? HOW ARE THEY DIFFERENT FROM ELECTRONS?

THE NEW PARTICLES WERE LATER CALLED MUONS.

COSMIC RAYS COME FROM VERY FAR AWAY, EVEN BEYOND OUR SOLAR SYSTEM.

IN 1937, TWO PHYSICISTS, CARL ANDERSON AND SETH NEDDERMEYER WERE ANALYZING COSMIC RAYS.

THEY DISCOVERED THAT A NEW PARTICLE WAS A LARGE PART OF THOSE COSMIC RAYS.

JUST LIKE ELECTRONS, MUONS ARE ELEMENTARY PARTICLES.

YOU CAN THINK OF THEM AS JUST "FAT" ELECTRONS.

MUONS HAVE THE SAME CHARGE AS ELECTRONS...

BUT THEY ARE ABOUT 200 TIMES HEAVIER.

MUONS ARE EVERYWHERE. THOUSANDS MIGHT JUST BE PASSING THROUGH YOUR BODY RIGHT NOW.

WOAH! REALLY?

TAU
 τ

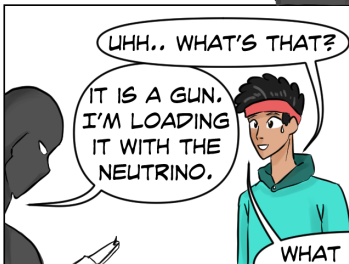
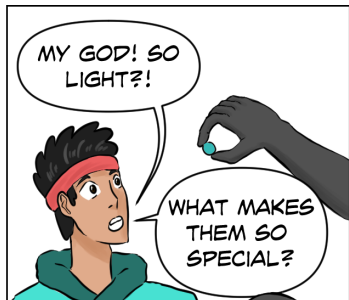
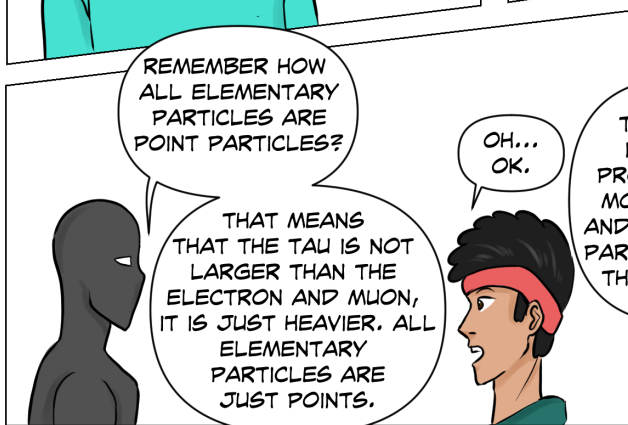
MARTIN LEWIS PERL

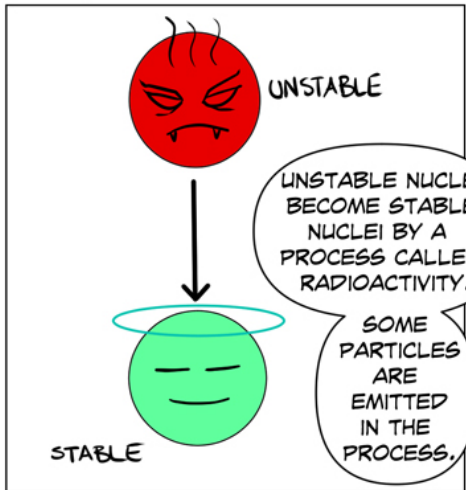
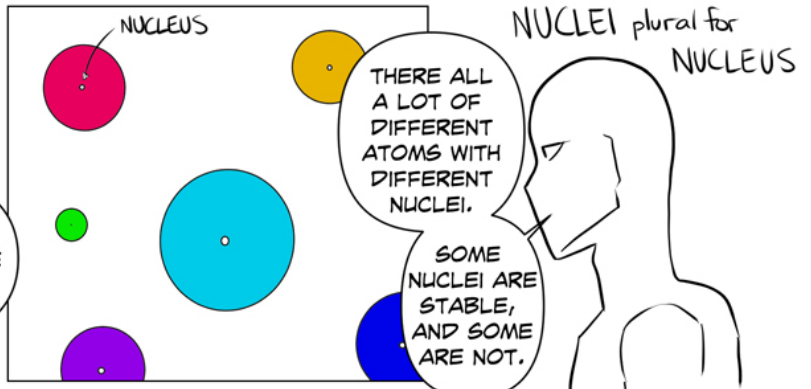
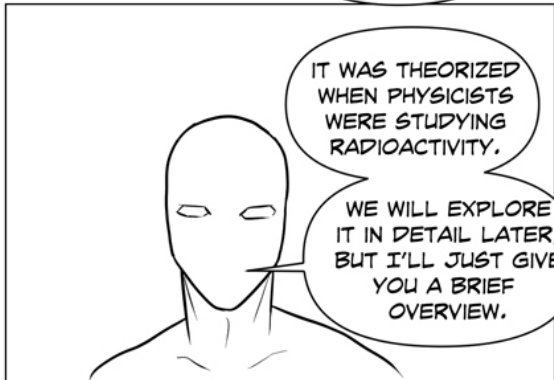
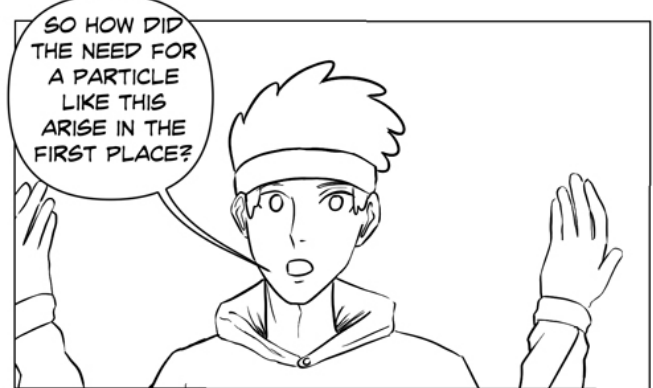
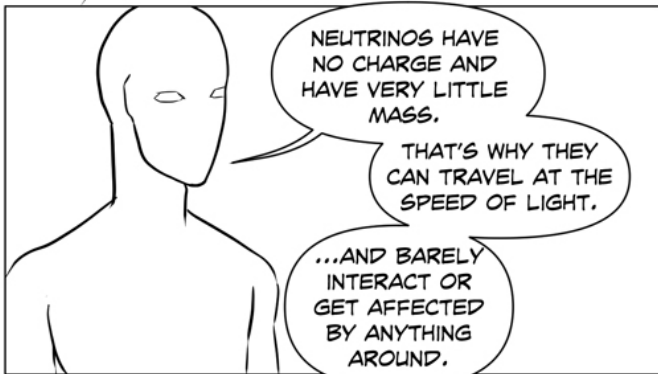
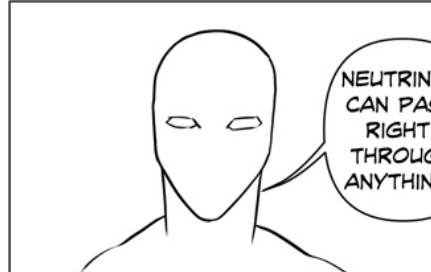
IN 1977, THE TAU WAS DISCOVERED.

THEY ARE THE HEAVIEST LEPTONS, ABOUT 3500 TIMES HEAVIER THAN THE ELECTRON.

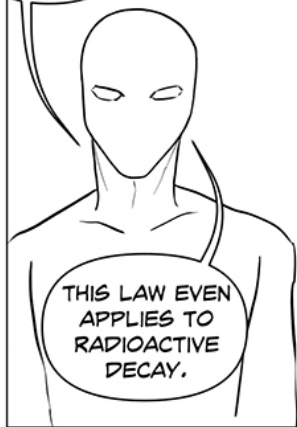
THEY WERE DISCOVERED AT SLAC, UNDER THE LEADERSHIP OF PHYSICIST MARTIN LEWIS PERL.

THE RESULTS GOTTEN AFTER PARTICLES WERE SMASHED TOGETHER WERE WEIRD - AND ONLY THE EXISTENCE OF A NEW LEPTON COULD EXPLAIN THEM.





YUP. THAT IS RIGHT.



THIS LAW EVEN APPLIES TO RADIOACTIVE DECAY.

ENERGY BEFORE DECAY > ENERGY AFTER DECAY

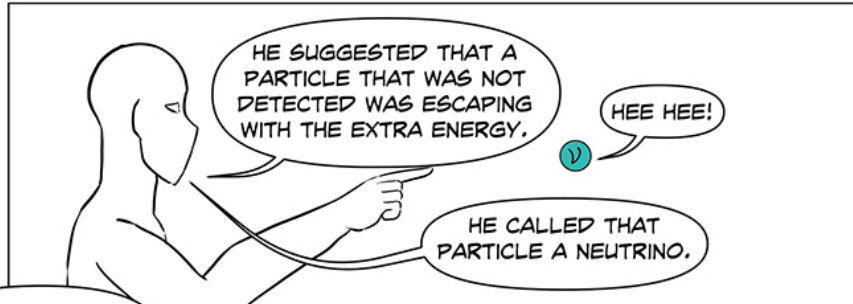


WHEN PHYSICISTS DID EXPERIMENTS ON RADIOACTIVE DECAY, THE LAW WAS SEEMINGLY NOT OBEYED.

THE ENERGY OF THE PARTICLES AFTER DECAY WAS LESS THAN THAT BEFORE DECAY.

WAS A FUNDAMENTAL LAW OF THE UNIVERSE VIOLATED?

FORTUNATELY, PHYSICIST WOLFGANG PAULI CAME TO THE RESCUE.

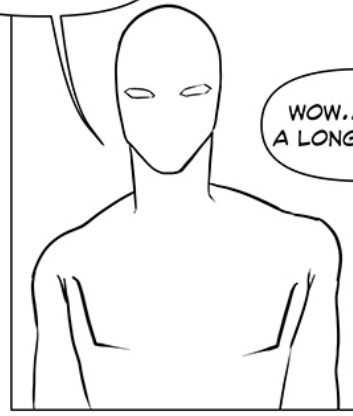


HE SUGGESTED THAT A PARTICLE THAT WAS NOT DETECTED WAS ESCAPING WITH THE EXTRA ENERGY.

HEE HEE!

HE CALLED THAT PARTICLE A NEUTRINO.

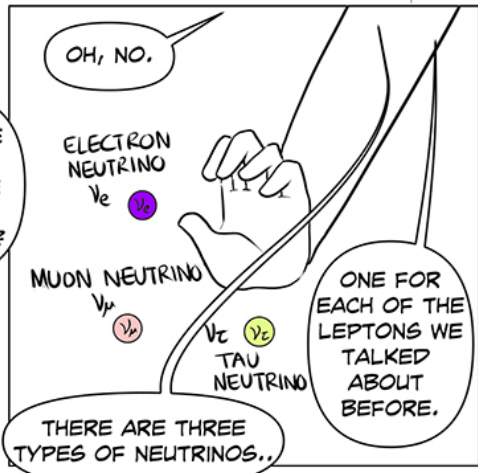
SOON LATER, THE NEUTRINO WAS DISCOVERED.



WOW... WHAT A LONG STORY!



I PRESUME THAT WE ARE DONE WITH LEPTONS?



OH, NO.

ELECTRON NEUTRINO ν_e

MUON NEUTRINO ν_μ

TAU NEUTRINO ν_τ

ONE FOR EACH OF THE LEPTONS WE TALKED ABOUT BEFORE.

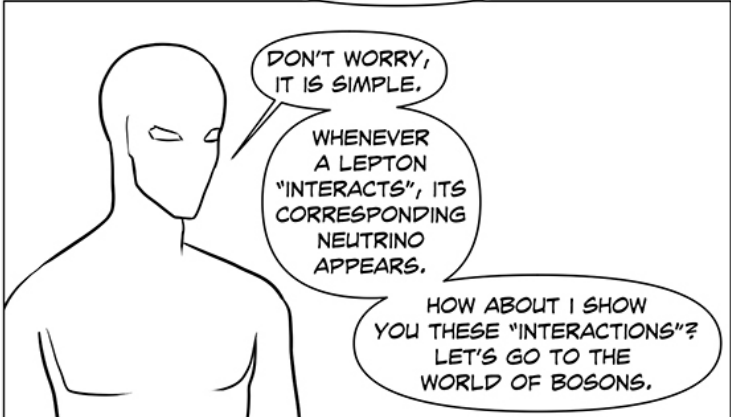
THERE ARE THREE TYPES OF NEUTRINOS..

WHAT!



THIS IS TOO MUCH!

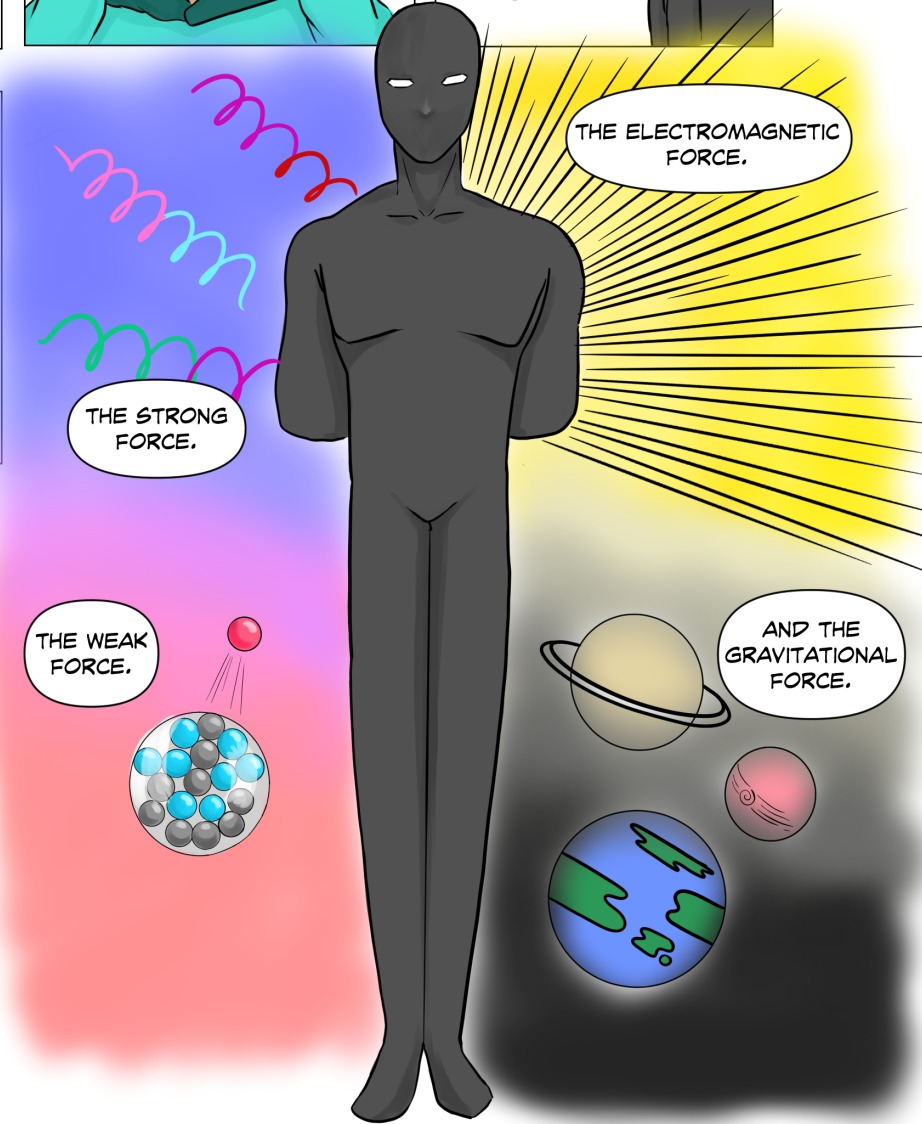
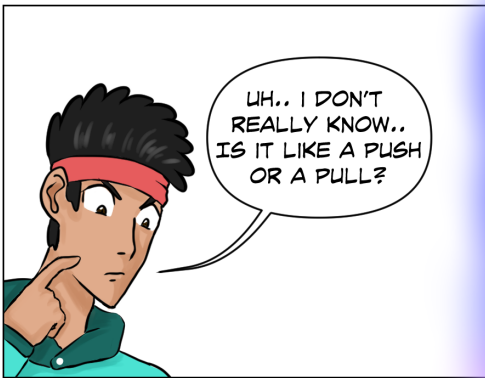
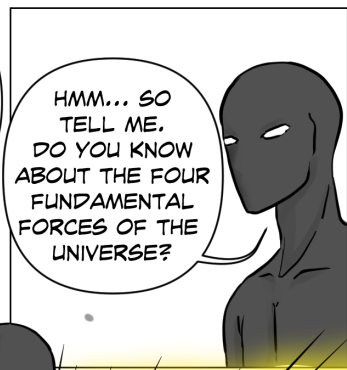
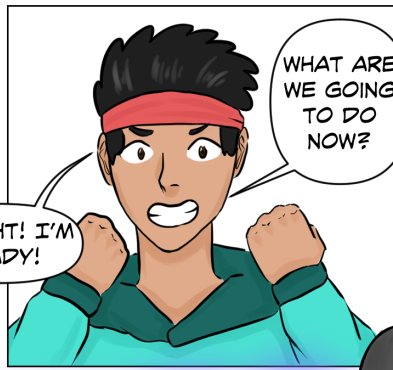
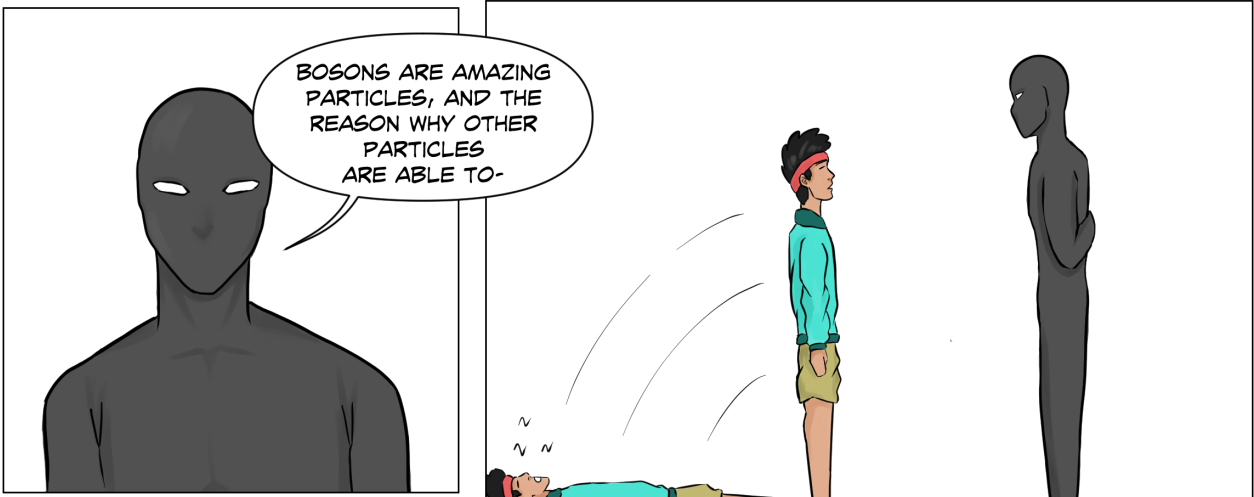
NOW HOW ARE THEY DIFFERENT?!



DON'T WORRY, IT IS SIMPLE.

WHENEVER A LEPTON "INTERACTS", ITS CORRESPONDING NEUTRINO APPEARS.

HOW ABOUT I SHOW YOU THESE "INTERACTIONS"? LET'S GO TO THE WORLD OF BOSONS.

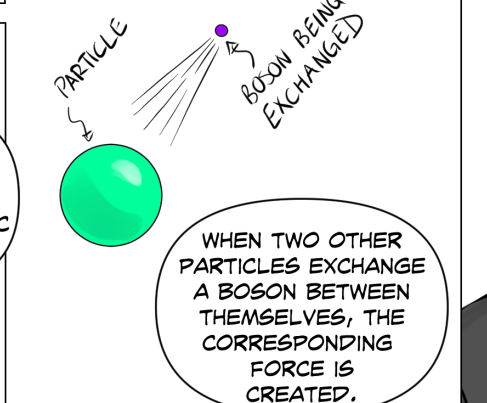
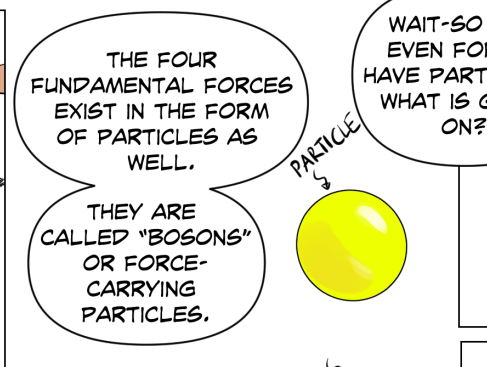
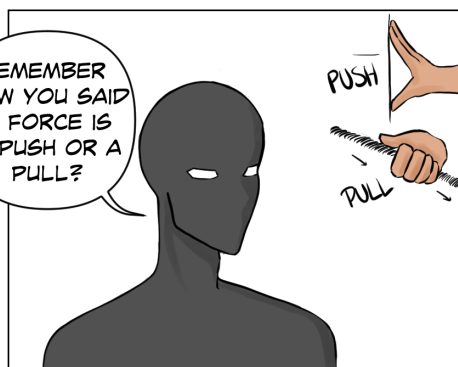
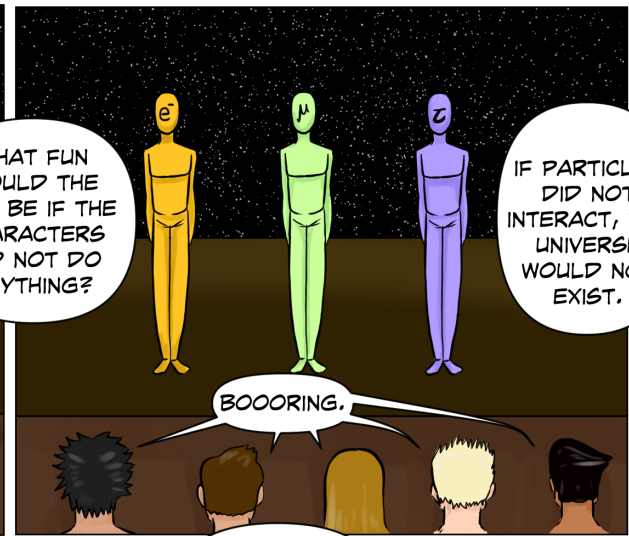
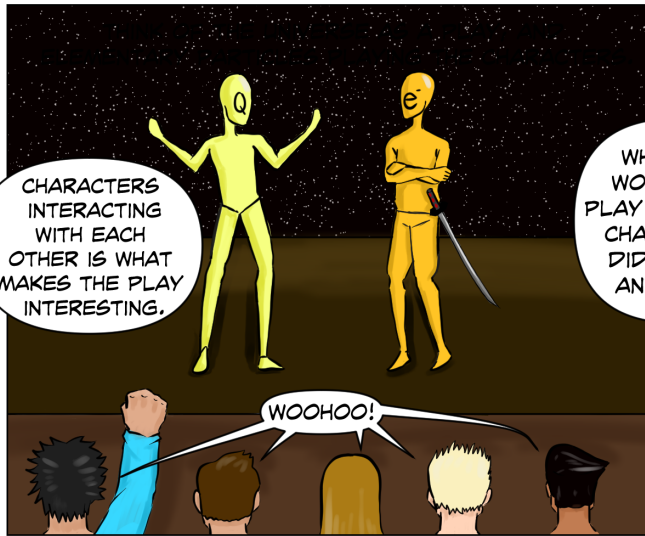
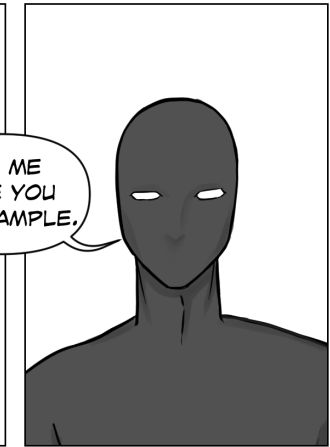
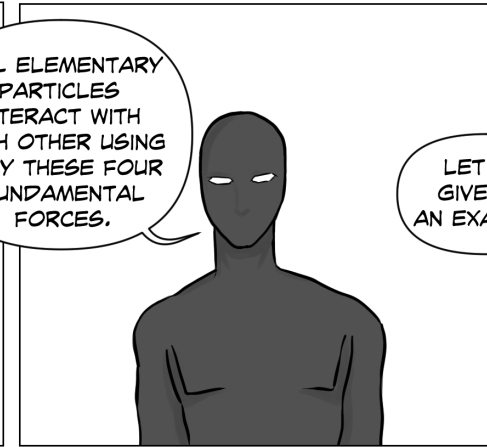
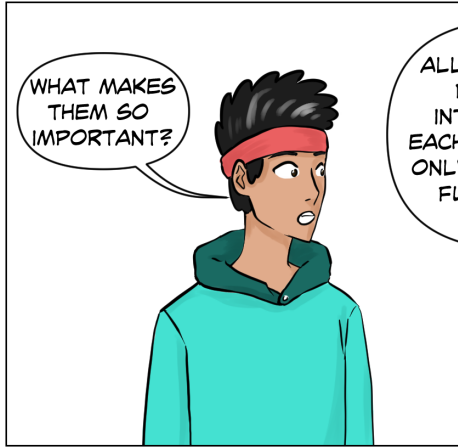


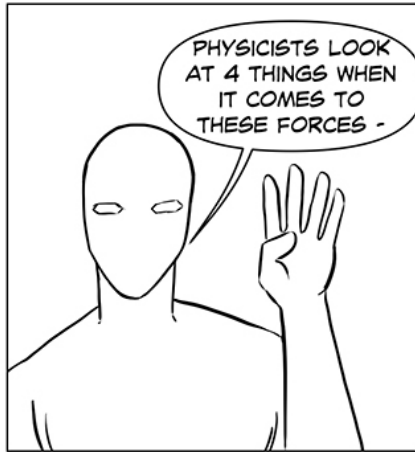
THE STRONG FORCE.

THE WEAK FORCE.

THE ELECTROMAGNETIC FORCE.

AND THE GRAVITATIONAL FORCE.





Range

Strength

Boson

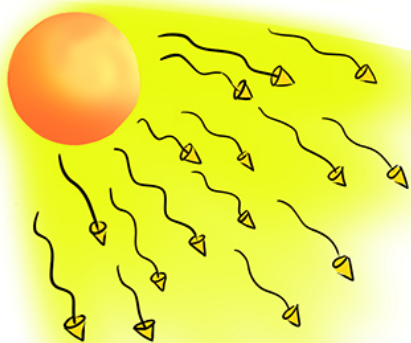
Particles Interacted

THE RANGE, OR HOW FAR THE FORCE'S EFFECTS CAN BE EXPERIENCED...

THE STRENGTH OF THE FORCE...

THE EXCHANGE PARTICLE OR BOSON OF THE FORCE...

AND THE CLASSES OF PARTICLES WHICH THE FORCE INTERACTS WITH.



THE FIRST FORCE THAT I AM GOING TO TEACH YOU ABOUT IS THE **ELECTROMAGNETIC FORCE.**

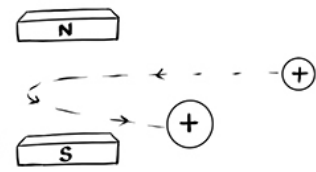
IT IS A COMBINATION OF TWO FORCES - THE ELECTRIC AND THE MAGNETIC FORCE.

Electric Force

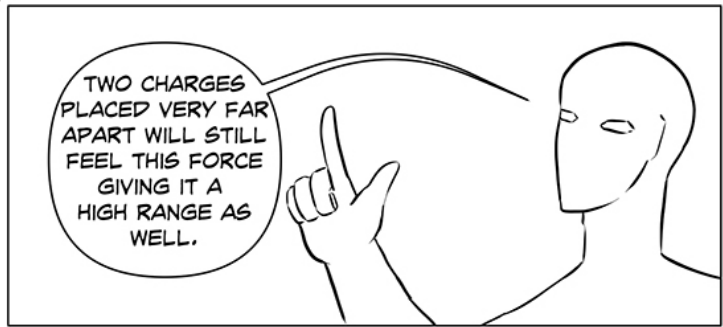
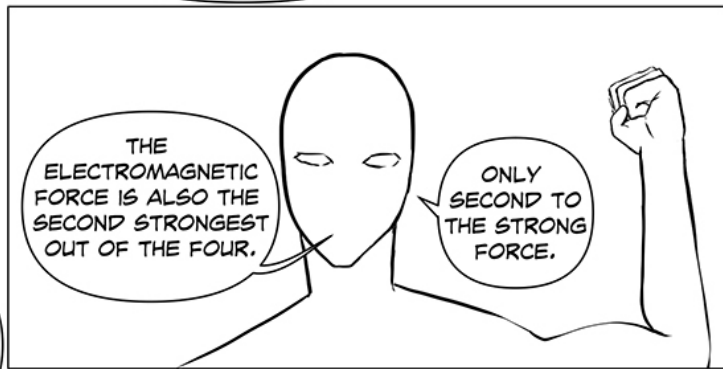
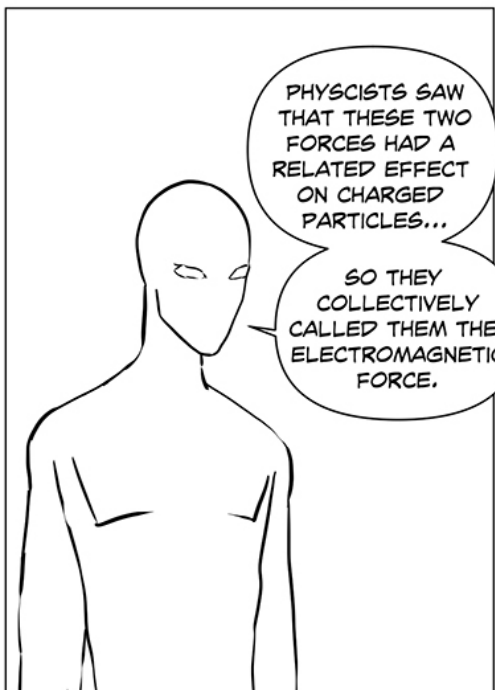


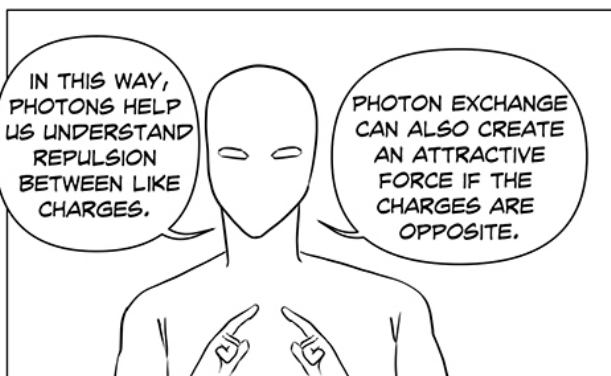
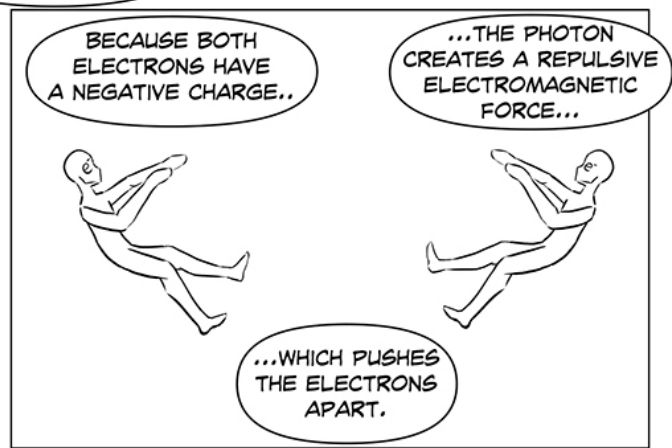
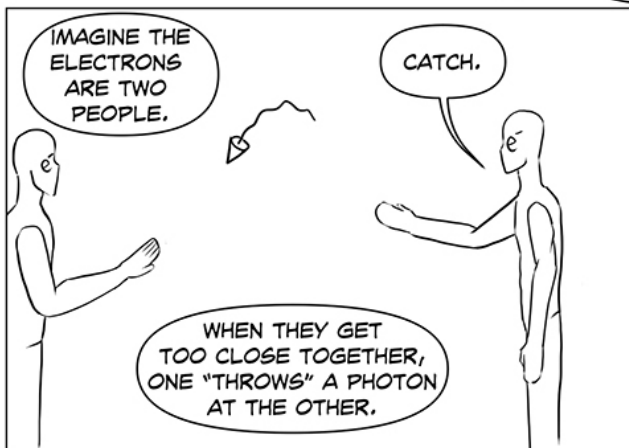
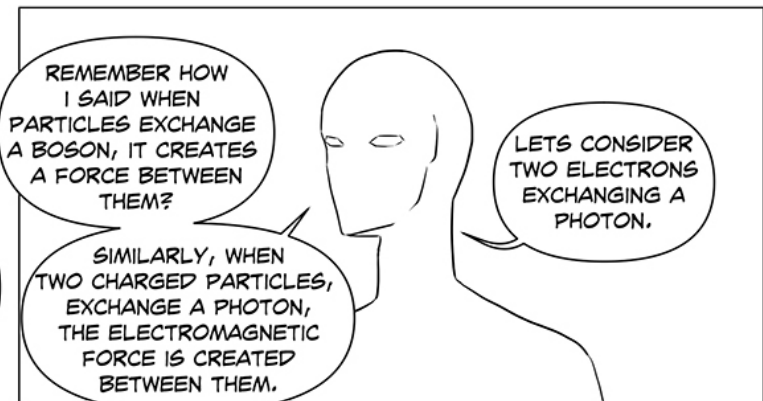
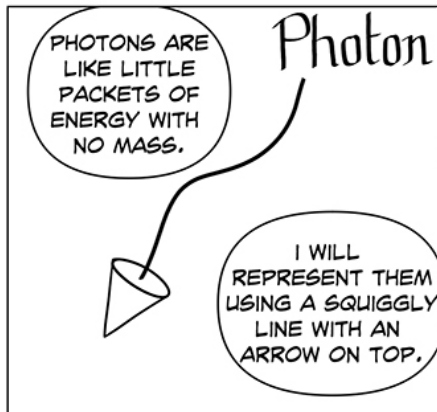
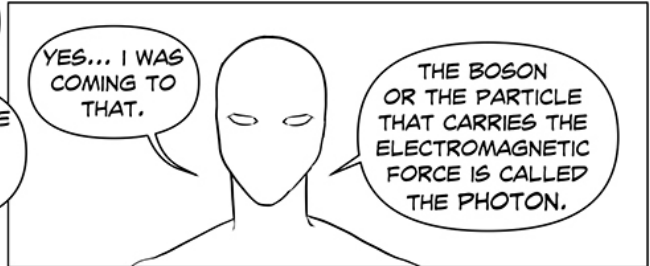
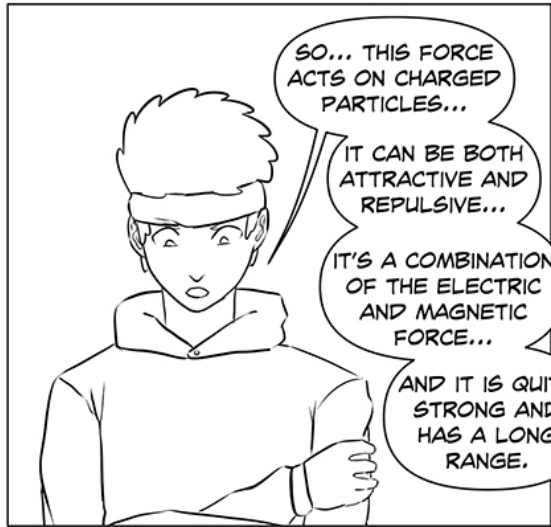
THE ELECTRIC FORCE ACTS ON ALL CHARGED PARTICLES, WHETHER THEY ARE MOVING OR NOT.

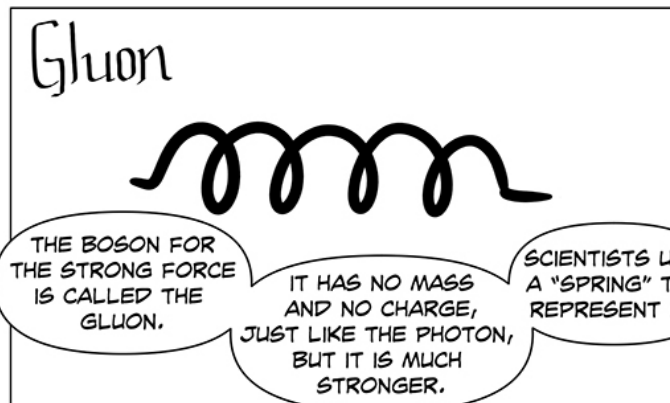
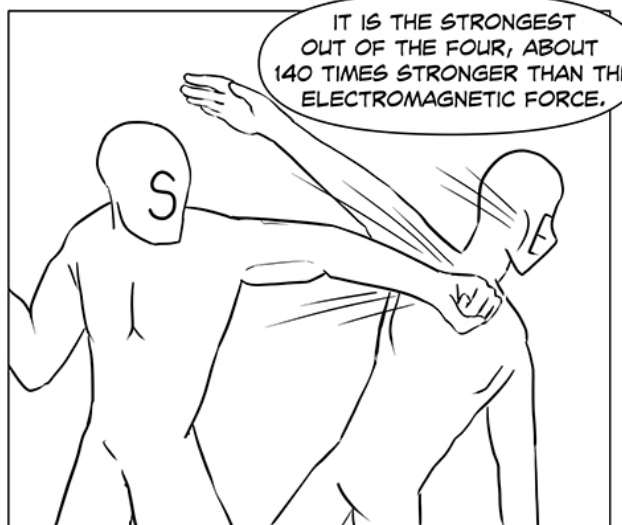
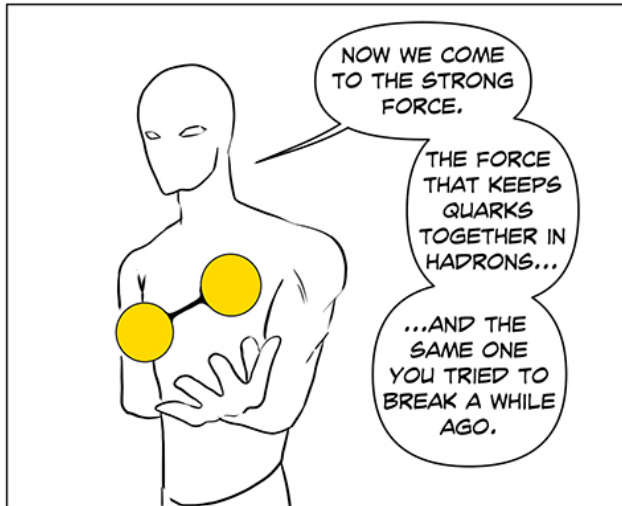
Magnetic Force



THE MAGNETIC FORCE ONLY ACTS ON CHARGED PARTICLES THAT ARE MOVING.



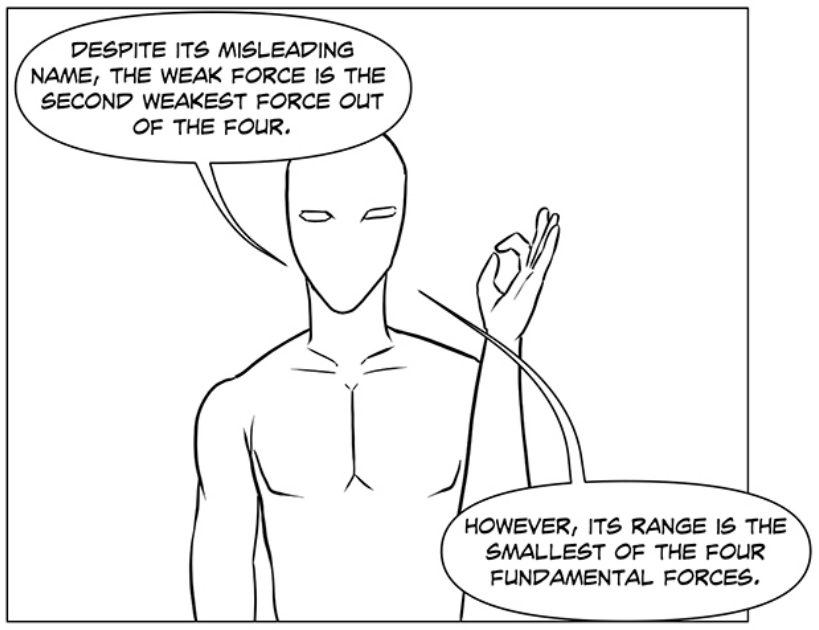
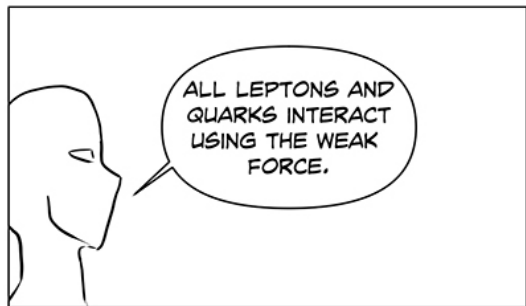
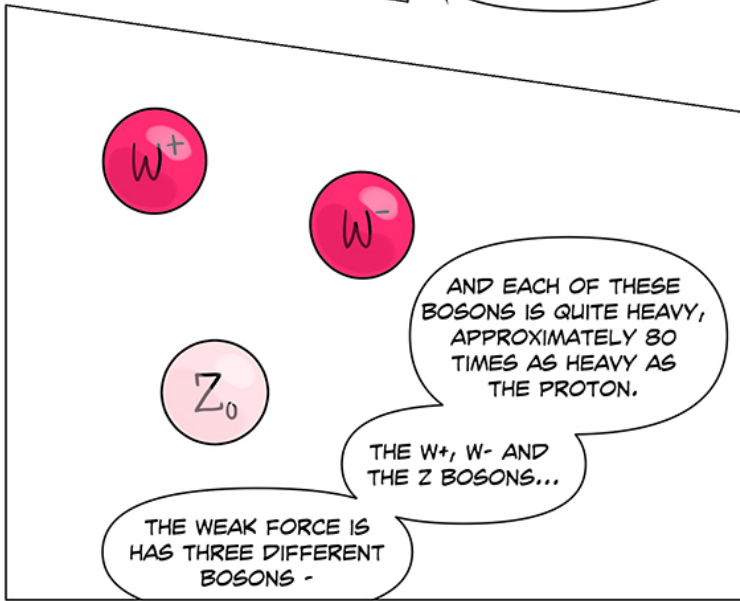


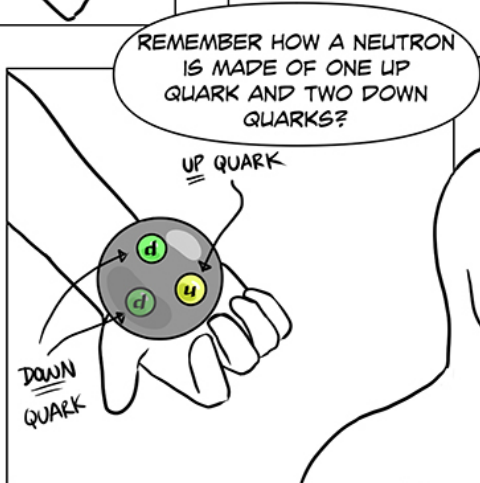
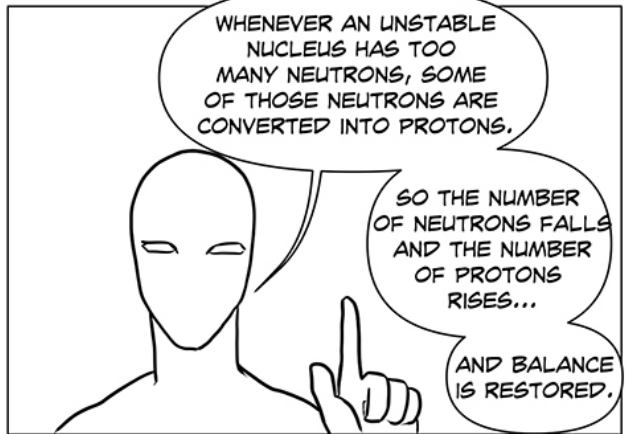
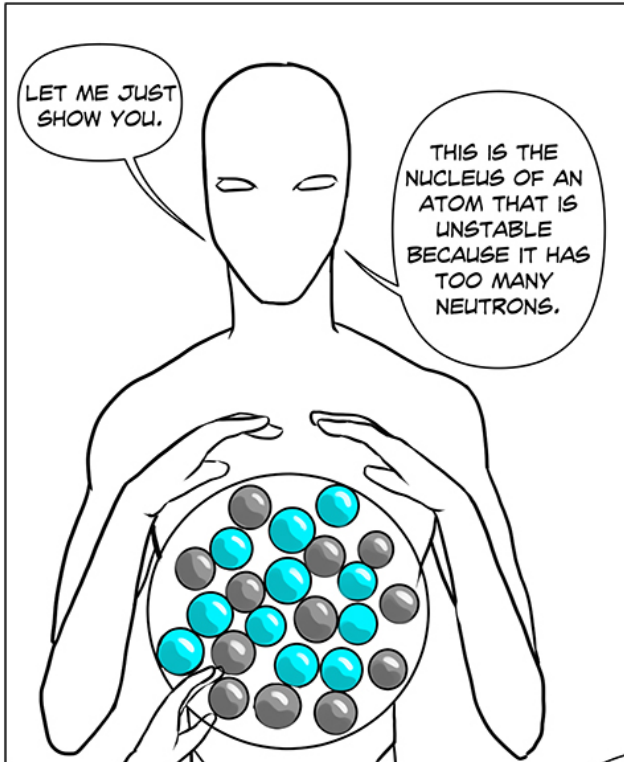
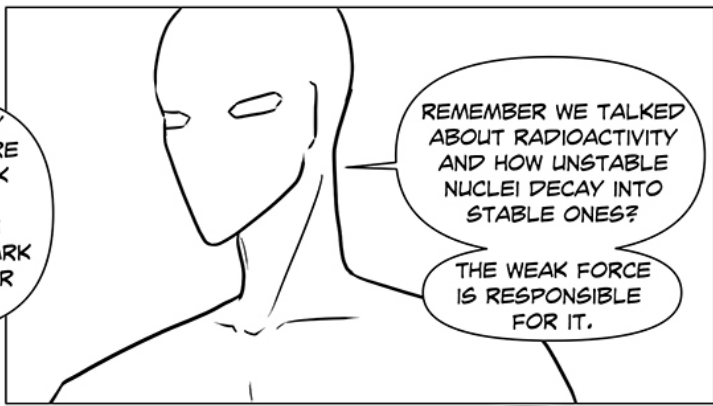
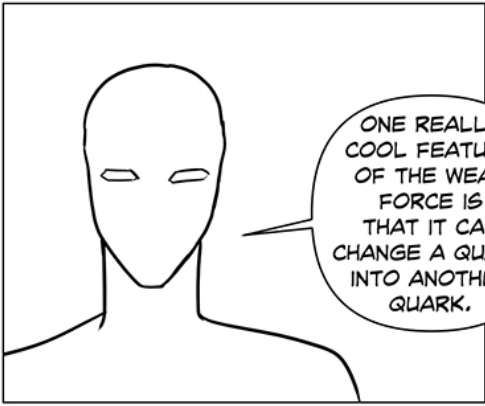


WHEN QUARKS EXCHANGE IT, A STRONG FORCE IS CREATED BETWEEN THEM.



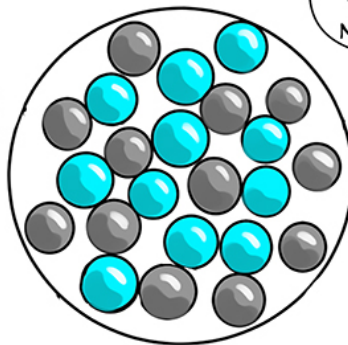
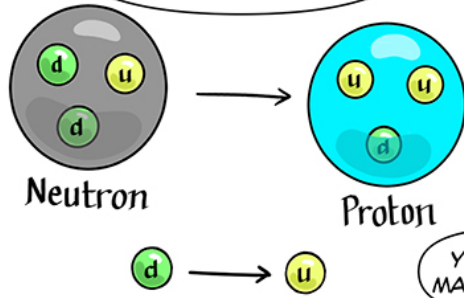
THERE ARE 8 DIFFERENT TYPES GLUONS, BUT WE WON'T LEARN ABOUT THEM JUST YET.



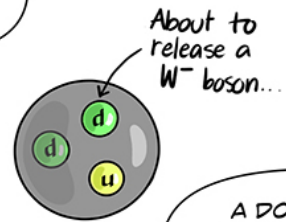




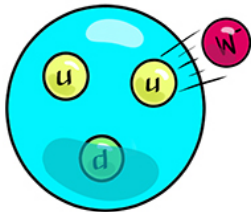
YES. IF WE COULD SOMEHOW CHANGE A DOWN QUARK IN A NEUTRON TO AN UP QUARK, IT WOULD BECOME A PROTON, RIGHT?



WHENEVER A NUCLEUS HAS TOO MANY NEUTRONS...



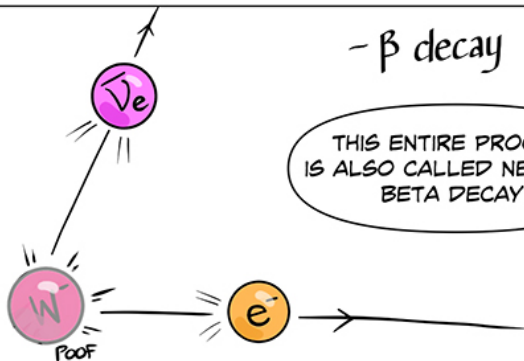
A DOWN QUARK IN A RANDOM NEUTRON GETS READY TO RELEASE A W^- BOSON.



BUT THE STORY DOES NOT END THERE.

JUST AFTER RELEASING THE W^- BOSON, THE DOWN QUARK BECOMES AN UP QUARK AND THE NEUTRON BECOMES A PROTON.

THE W^- BOSON QUICKLY CONVERTS INTO TWO LIGHTER PARTICLES - THE ANTI-ELECTRON NEUTRINO AND AN ELECTRON.



- β decay

THIS ENTIRE PROCESS IS ALSO CALLED NEGATIVE BETA DECAY.

WHEN A NUCLEUS HAS TOO MANY PROTONS, A PROTONS GET CONVERTED INTO NEUTRONS BY A SIMILAR PROCESS.

AN UP QUARK IN THE PROTON BECOMES A DOWN QUARK BY EMITTING A W^+ BOSON.

THAT W^+ BOSON BECOMES AN ELECTRON NEUTRINO AND A POSITRON.

THIS ENTIRE PROCESS IS CALLED POSITIVE BETA DECAY.

SO ARE THE ANTI-ELECTRON NEUTRINO AND POSITRON FORMS OF ANTIMATTER?

YES, THEY ARE. WE WILL LEARN ABOUT THEM NEXT.

β^+ decay

Becomes down from u

W^+

ELECTRON NEUTRINO

POSITRON

BUT BEFORE WE MOVE ON, WHAT HAPPENED TO GRAVITY? IT IS A FUNDAMENTAL FORCE, RIGHT?

SO IT MUST HAVE A BOSON OF ITS OWN, RIGHT?

GOOD THINKING.

GRAVITY IS THE WEAKEST FORCE OF ALL THE FOUR.

AND YES, GRAVITY COULD HAVE A BOSON OF ITS OWN.

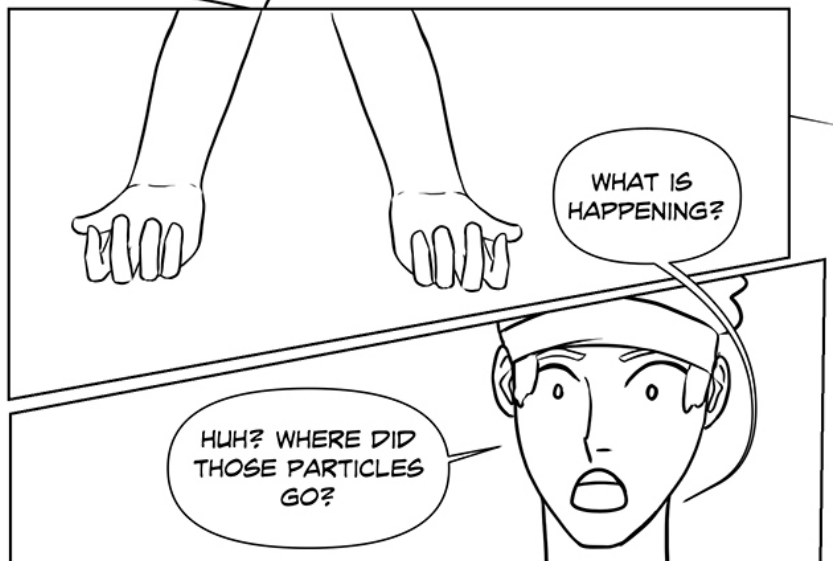
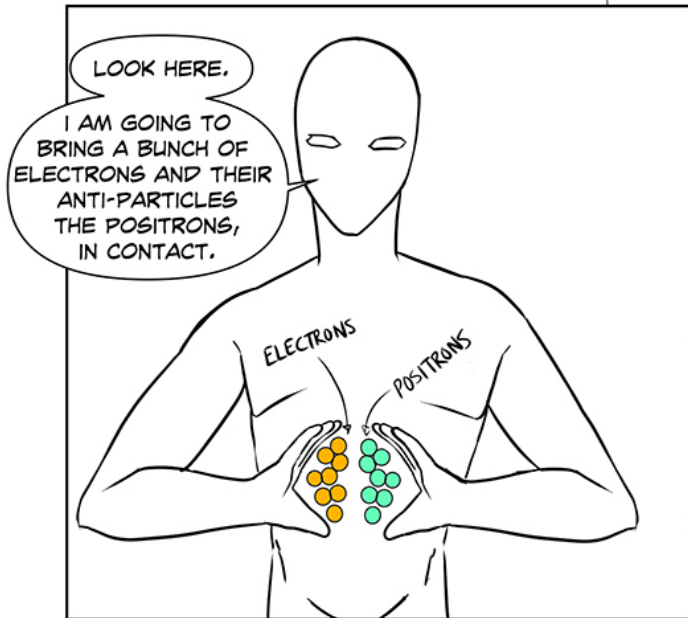
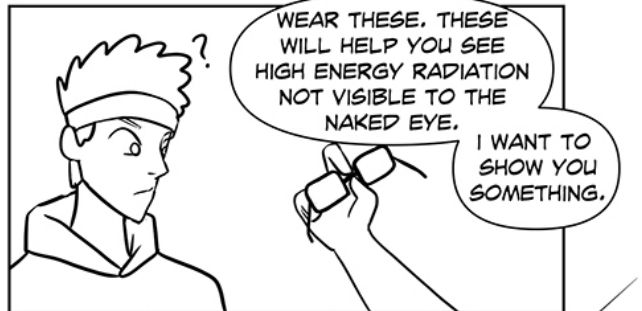
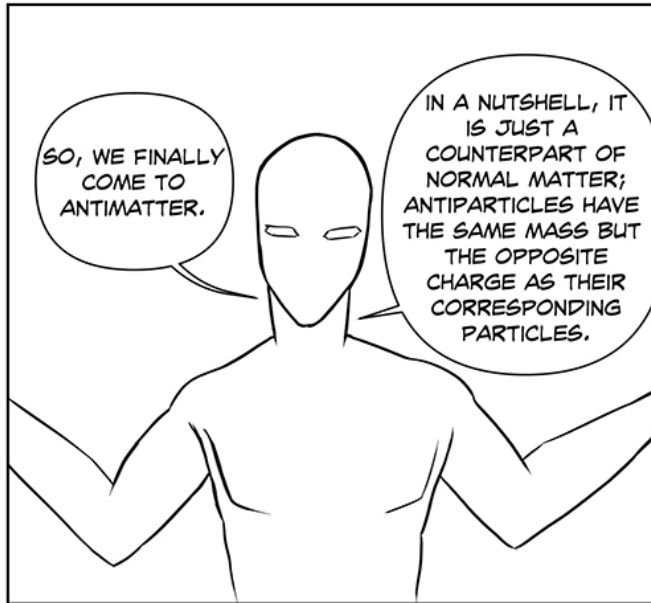
IT IS CALLED THE GRAVITON.

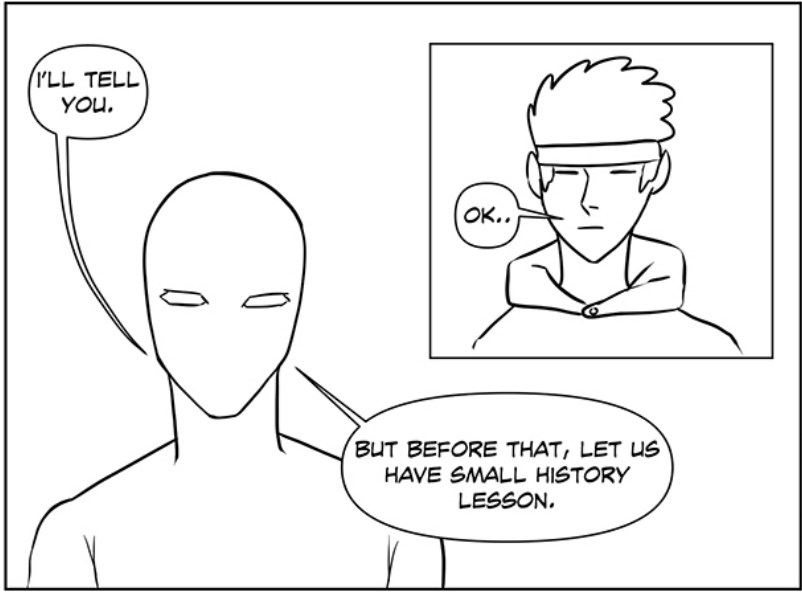
HOWEVER, IT HAS NOT BEEN DISCOVERED IT YET.

WELL, BUT I KNOW EVERYTHING, SO I WILL TEACH YOU ALL ABOUT IT LATER.

LET'S LEARN ABOUT ANTIMATTER FIRST.

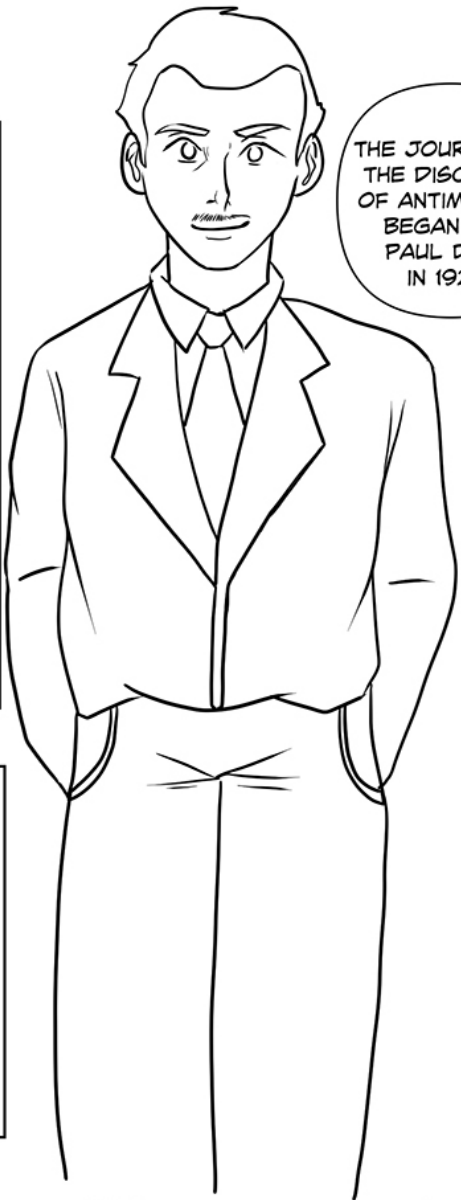
WOOHOO! FINALLY!!





BUT BEFORE THAT, LET US HAVE SMALL HISTORY LESSON.

THE JOURNEY OF THE DISCOVERY OF ANTIMATTER BEGAN WITH PAUL DIRAC IN 1928.



Dirac's Equation

$$\psi(i\partial - m) = 0$$

IN SIMPLE TERMS, HE CREATED AN EQUATION THAT DESCRIBED THE ELECTRON.

IT IS SOMEWHAT SIMILAR TO A QUADRATIC EQUATION WHICH, GIVES TWO ANSWERS. YOU MAY HAVE STUDIED IT IN SCHOOL.

HOWEVER, WHEN HE SOLVED THAT EQUATION, HE GOT FOUR ANSWERS.

Electron

TWO ANSWERS WERE FOR THE ELECTRON, BUT THE OTHER TWO ANSWERS WERE FOR A PARTICLE WITH A POSITIVE CHARGE.

???

THIS GOT HIM THINKING. HE THOUGHT THAT THE OTHER TWO ANSWERS HE GOT WERE FOR THE PROTON, BECAUSE IT WAS THE ONLY POSITIVELY CHARGED PARTICLE KNOWN AT THE TIME.

SOON, PHYSICISTS REALISED THAT IT COULD NOT HAVE BEEN THE PROTON SINCE THE MYSTERY PARTICLE ALSO HAD TO HAVE THE SAME MASS AS THE ELECTRON.

HENCE, ANTIMATTER WAS FIRST THEORIZED.

back then, physcisits did not know that quarks existed!

The same person who found the MUON in 1936!

CARL ANDERSON FOUND THE POSITRON IN A CLOUD CHAMBER IN 1932.

CLOUD CHAMBERS WERE USED BY PHYSICISTS TO SEE THE PATH OF PARTICLES AND IDENTIFY THEM.

THAT'S QUITE THE STORY.

CAN COMPOSITE PARTICLES LIKE PROTONS ALSO HAVE ANTIPARTICLES?

YES, THEY CAN.

FOR EXAMPLE, AN ANTIPROTON IS MADE UP OF TWO ANTI-UP AND ONE ANTI-DOWN QUARKS.

ANTIPROTON

HOWEVER, ANTIMATTER IS VERY VERY RARE IN THIS UNIVERSE.

THAT IS BECAUSE OF A PHENOMENON CALLED ANNIHILATION.

THAT SOUNDS SO COOL! WHAT IS IT?

DO YOU REMEMBER WHAT HAPPENED WHEN I BROUGHT ANTI-PARTICLES AND PARTICLES IN CONTACT?

WHEN THAT HAPPENS, THE PARTICLES AND ANTI-PARTICLES COMPLETELY DESTROY EACH OTHER.

THE ENERGY RELEASED DURING ANNIHILATION LEAVES IN THE FORM OF PHOTONS AND SOME OTHER PARTICLES, DEPENDING ON THE TYPE OF PARTICLE ANNIHILATED.

THAT IS SO COOL!



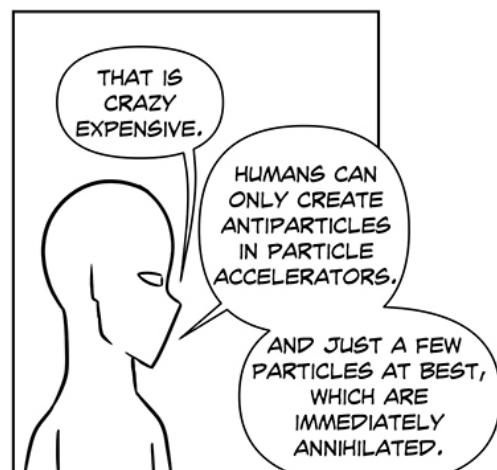
YUP, IT IS.

ONE GRAM OF ANTI-HYDROGEN ATOMS WILL COST ABOUT 60 TRILLION DOLLARS TO MAKE.



60 TRILLION?!

FOR ONE GRAM?!



THAT IS CRAZY EXPENSIVE.

HUMANS CAN ONLY CREATE ANTI-PARTICLES IN PARTICLE ACCELERATORS.

AND JUST A FEW PARTICLES AT BEST, WHICH ARE IMMEDIATELY ANNIHILATED.

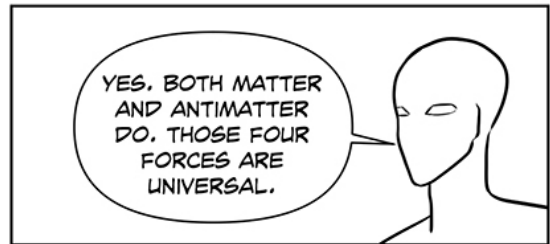


WELL, IT IS ALL FOR THE BEST.

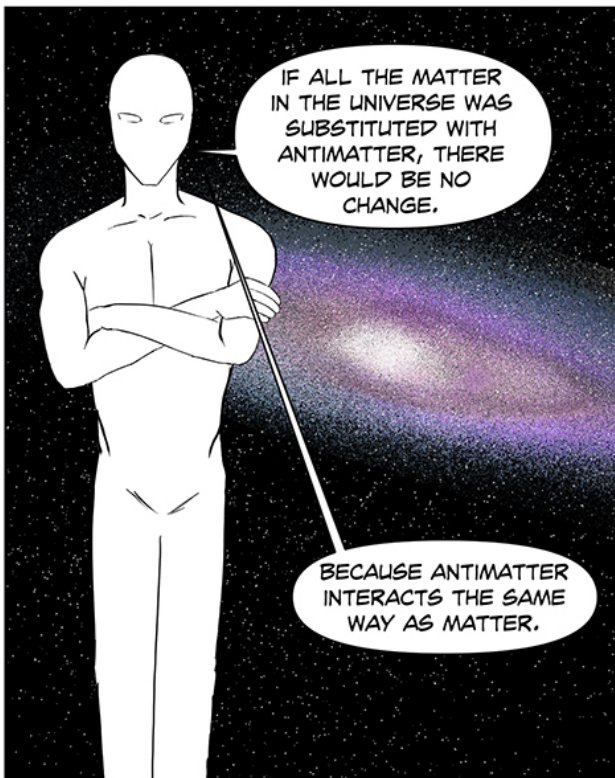
IF ANTIMATTER WAS UBIQUITOUS, MATTER WOULDN'T BE ABLE TO EXIST.



SO DOES ANTIMATTER ALSO INTERACT VIA THE FOUR FUNDAMENTAL FORCES?

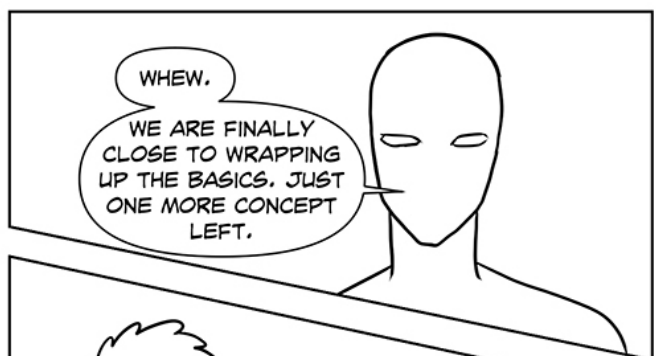


YES. BOTH MATTER AND ANTIMATTER DO. THOSE FOUR FORCES ARE UNIVERSAL.



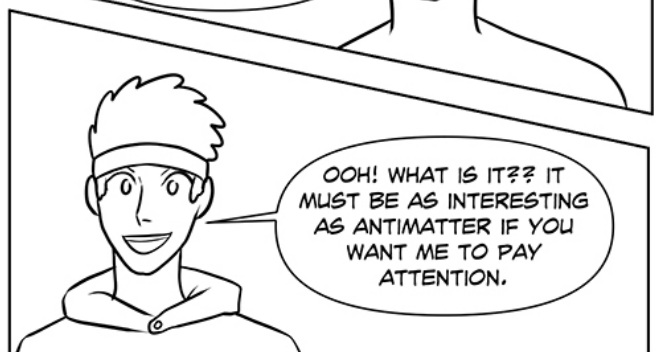
IF ALL THE MATTER IN THE UNIVERSE WAS SUBSTITUTED WITH ANTIMATTER, THERE WOULD BE NO CHANGE.

BECAUSE ANTIMATTER INTERACTS THE SAME WAY AS MATTER.

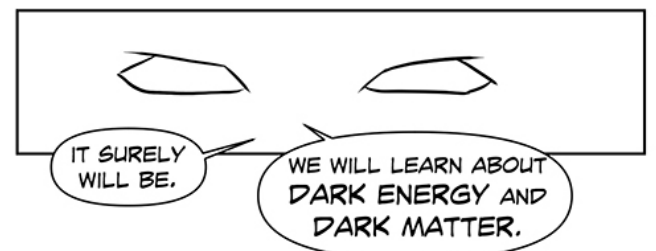


WHEW.

WE ARE FINALLY CLOSE TO WRAPPING UP THE BASICS. JUST ONE MORE CONCEPT LEFT.

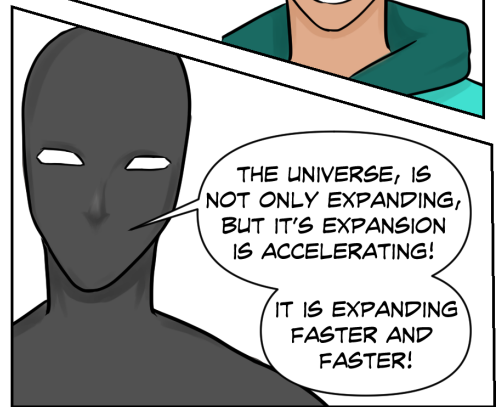
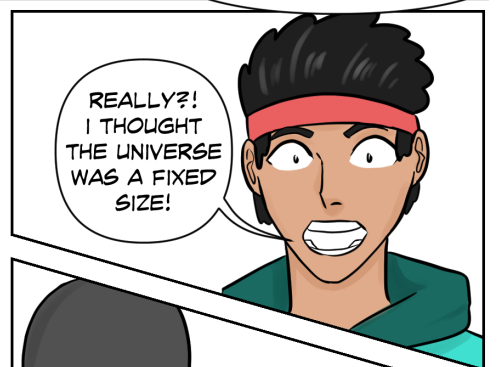
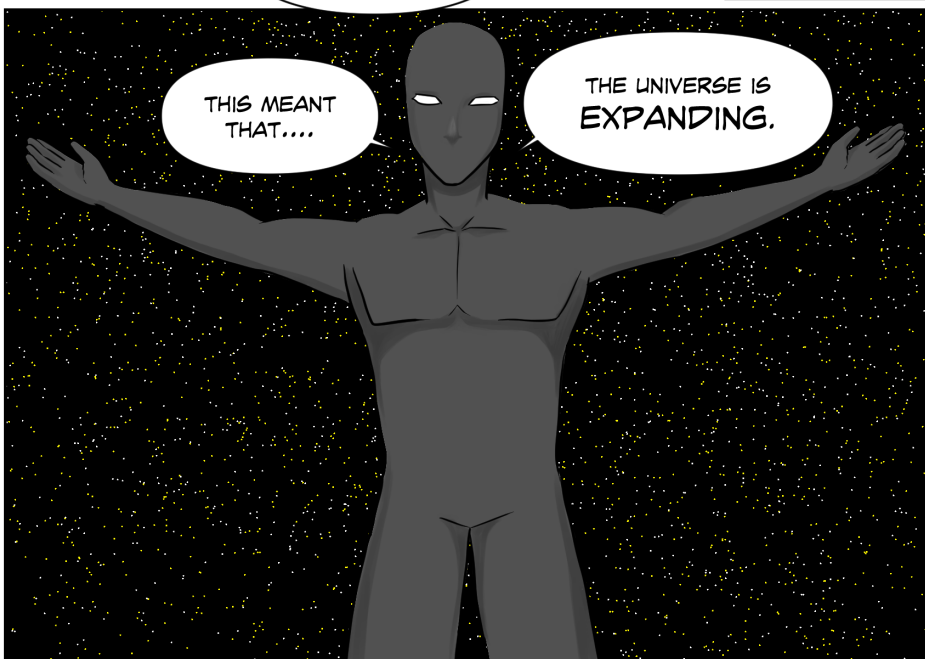
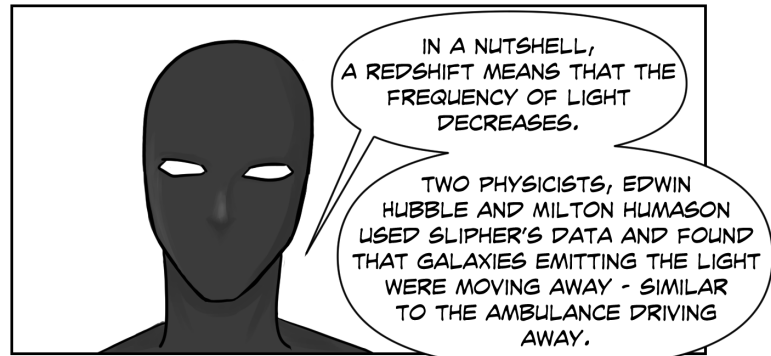
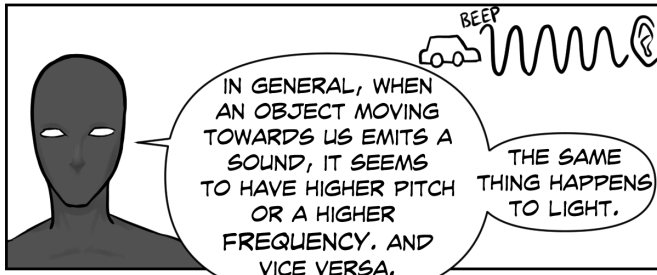
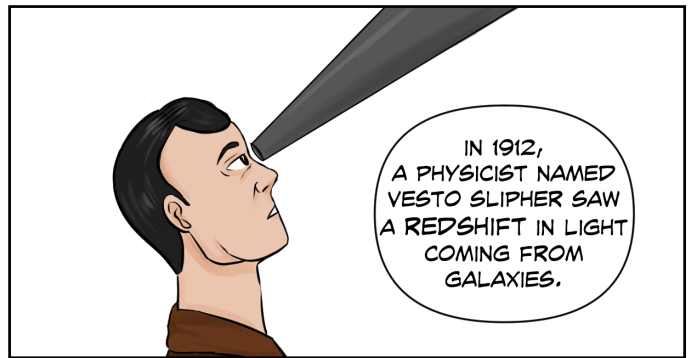
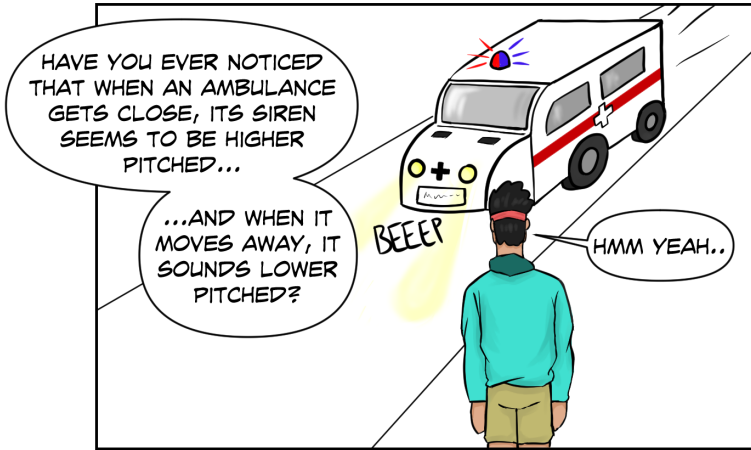
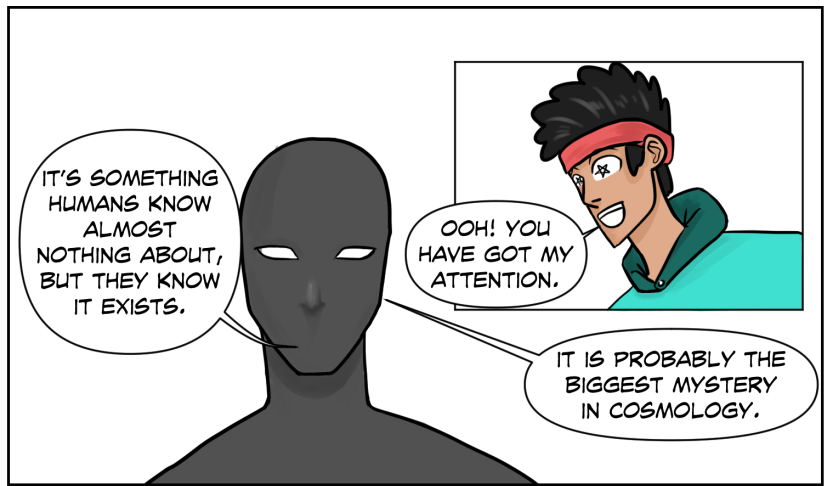
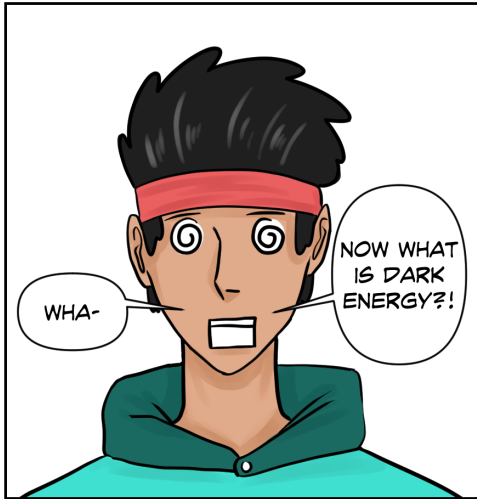


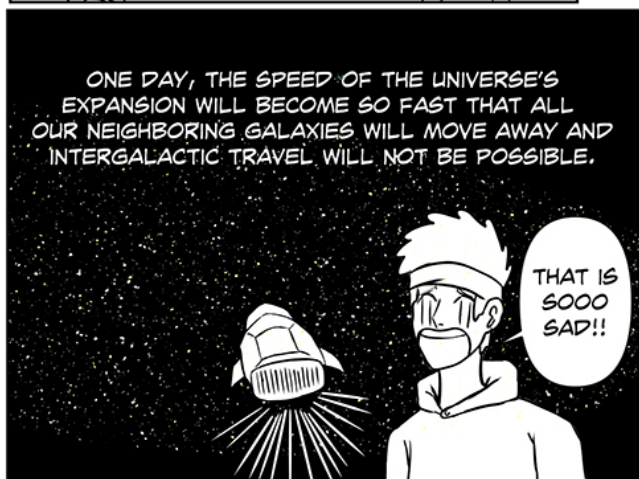
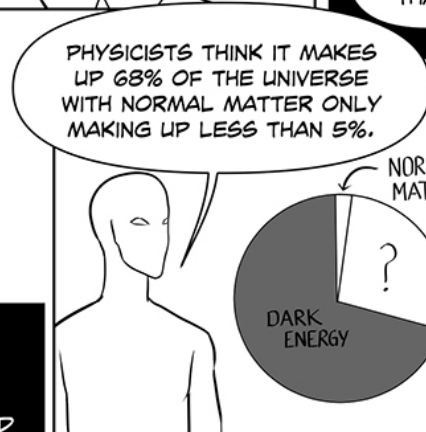
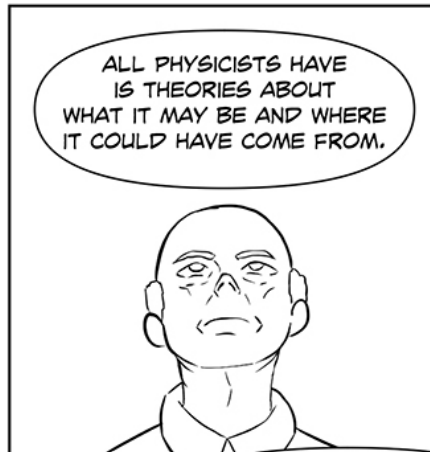
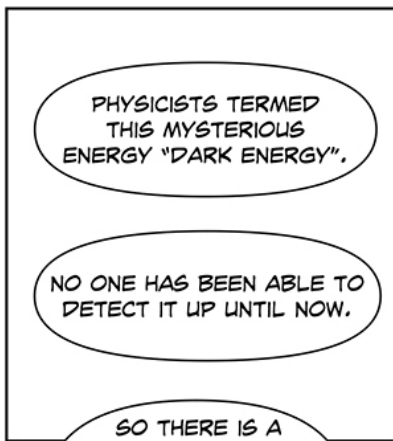
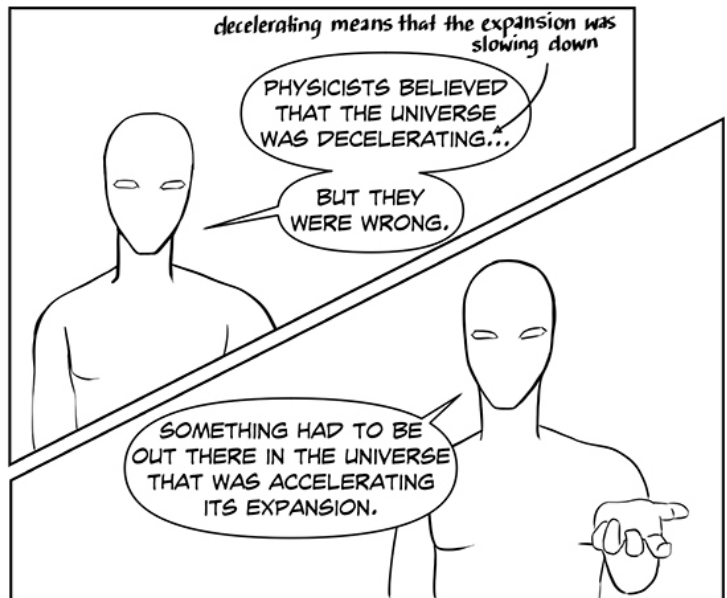
OOH! WHAT IS IT?? IT MUST BE AS INTERESTING AS ANTIMATTER IF YOU WANT ME TO PAY ATTENTION.



IT SURELY WILL BE.

WE WILL LEARN ABOUT DARK ENERGY AND DARK MATTER.



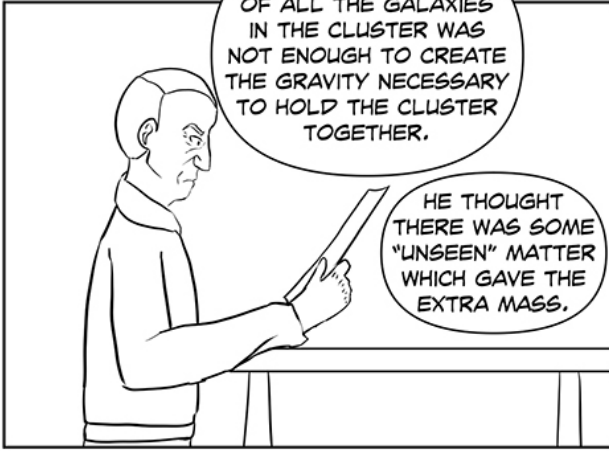
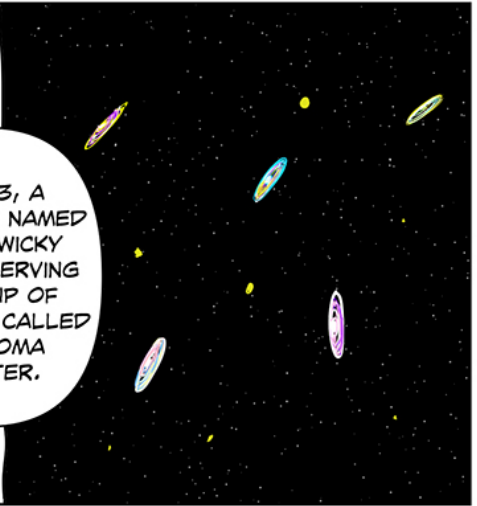




DARK MATTER TOO IS ANOTHER MYSTERY OF THE UNIVERSE.



IN 1933, A PHYSICIST NAMED FRITZ ZWICKY WAS OBSERVING A GROUP OF GALAXIES CALLED THE COMA CLUSTER.



THE ACTUAL MASS OF ALL THE GALAXIES IN THE CLUSTER WAS NOT ENOUGH TO CREATE THE GRAVITY NECESSARY TO HOLD THE CLUSTER TOGETHER.

HE THOUGHT THERE WAS SOME "UNSEEN" MATTER WHICH GAVE THE EXTRA MASS.



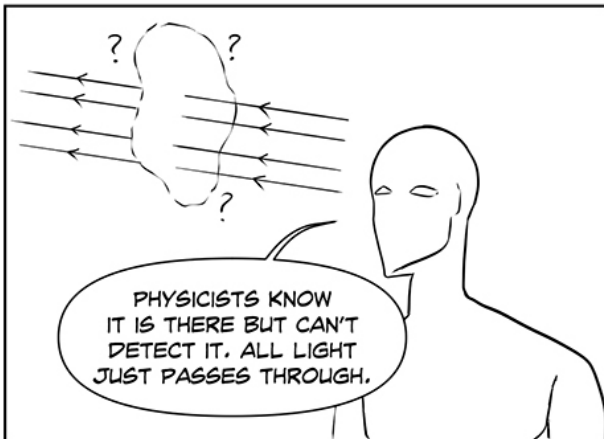
THIS CREATED THE NOTION OF DARK MATTER-SOMETHING THAT HELPED KEEP CLUSTERS TOGETHER.

THIS IS JUST A REPRESENTATION

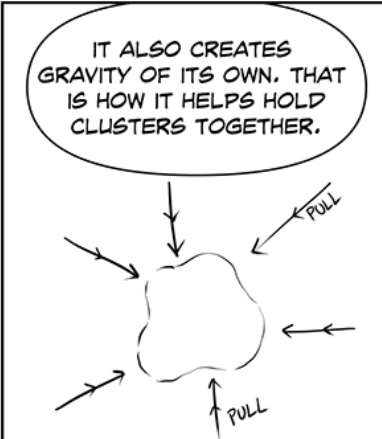


WOAH.

SO WHAT DO PHYSICISTS KNOW ABOUT DARK MATTER CURRENTLY?



PHYSICISTS KNOW IT IS THERE BUT CAN'T DETECT IT. ALL LIGHT JUST PASSES THROUGH.

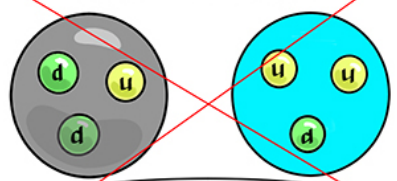


IT ALSO CREATES GRAVITY OF ITS OWN. THAT IS HOW IT HELPS HOLD CLUSTERS TOGETHER.

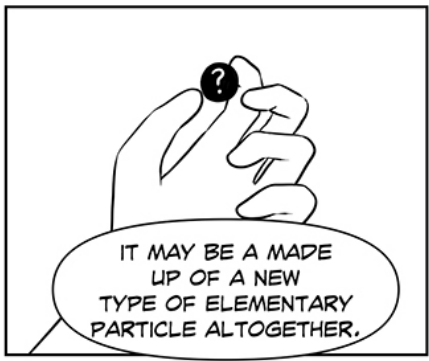


THAT'S ALL? IT REALLY IS A MYSTERY.

PHYSICISTS ALSO THINK THAT A LARGE PART OF DARK MATTER IS NON-BARYONIC..



WHICH MEANS IT IS NOT MADE UP OF PROTONS AND NEUTRONS.



IT MAY BE A MADE UP OF A NEW TYPE OF ELEMENTARY PARTICLE ALTOGETHER.



A NEW PARTICLE?!



THE DETECTION OF DARK MATTER PARTICLE IS VERY DIFFICULT, SINCE IT BARELY INTERACTS WITH ANYTHING.

BUT THE SEARCH IS ON AND WILL NOT STOP. PHYSICISTS AROUND THE WORLD ARE WORKING TOWARDS THIS GOAL.



BUT IT IS STILL A MYSTERY!

I WISH I KNEW WHAT IT WAS!!



WHO SAID IT IS A MYSTERY?



I AM THE TIMEKEEPER OF THE UNIVERSE. OF COURSE I KNOW ALL ITS SECRETS.

LET'S GO BEYOND HUMAN DISCOVERY.