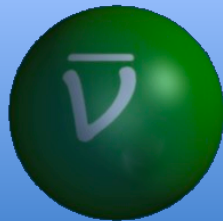
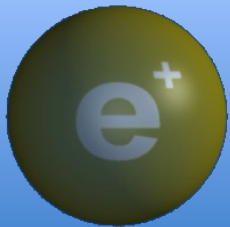


Knowing Anti-Me,
Knowing Anti-You



**THE FOLLOWING IS A SAMPLE OF QUESTIONS ABOUT ANTIMATTER,
ASKED BY STUDENTS IN LOWER SECONDARY SCHOOL:**

(Teachers may wish to elicit such questions regarding their own students' pre-conceptions about antimatter before embarking on this introductory lesson plan)

*"Antimatter?—that's extremely combustible stuff, isn't it?
'Angels & Demons' and 'Star Trek' told me so."*

*"What about warp-drive for starships—
they use matter-antimatter reactors, don't they?"*

"I read that it could be the fuel source of the future."

"OK then. Tell us— what IS antimatter?"

"...and where can I get some?"

*From the film “Angels & Demons” (2009) **

To see the video, click on the picture :



**In the lesson “Operation: Annihilate”, we look at this clip in greater detail. Here it is meant simply as an appetizer.*

Antimatter has been around in popular culture long before the release of the film “Angels & Demons” (or the 2000 Dan Brown novel on which the film is based).

The following are some examples from the television series “Star Trek”:

From Star Trek (The Original Series)

Season 3 episode "That Which Survives" (1969)



Spock: As I recall the pattern of our fuel flow, there is an access tube leading to the matter-
antimatter reaction chamber.

Scotty: Aye, there 's a service crawlway, but it 's not meant to be used while the integrator
operates.

Spock: Still, it is there and it may be possible to shut off the flow of fuel at that point.

Scotty: What with? Bare hands?

Spock: A magnetic probe.

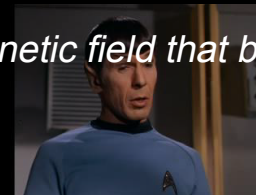
Scotty: Any matter that comes in contact with antimatter triggers the explosion. And I 'm not
even sure a man

can live in a crawlway in the energy stream of the magnetic field that bottles up the
antimatter!

Spock: I shall try.

Scotty: You'll be killed man!

Spock: Unless a solution is found quickly, that fate awaits all of us.



From Star Trek (The Original Series)

Season 1 episode “The Alternative Factor” (1967)

Kirk:

I don't follow



Spock:

*Two parallel universes —project this —one positive the other
Or more specifically, one matter, the other antimatter.*



Kirk:

*Do you know what you're saying? Matter and antimatter have
to cancel each other out —violently.*



Spock:

*Precisely. Under certain conditions —
when two identical particles of matter and antimatter meet.
Annihilation, Jim. Total, complete, absolute annihilation.*

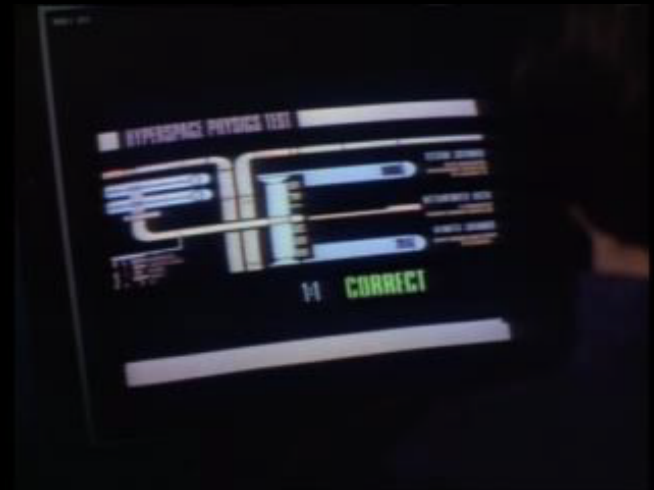


*From Star Trek (The Next Generation)
Season 1 episode “Coming of Age” (1988)*



Computer Voice:

Last question on the hyperspace physics test: “If the matter and antimatter tanks on a galaxy class starship are nine-tenths depleted, calculate the intermix ratio necessary to reach a star-base 100 light years away at warp factor 8”. Begin.



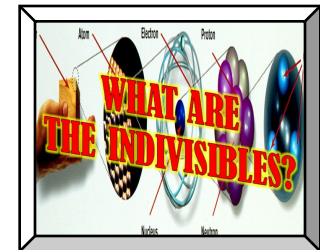
*Well, that's what film and television
have been telling us about antimatter.*

But what is the reality?

*Just **FOUR** particles make up all
of the visible matter in the Universe*

** \hat{Z}*

**For a short tutorial on fundamental particles,
see “What Are The Indivisibles?” in the
Background Materials:*



*Just FOUR particles make up all
of the visible matter in the Universe*

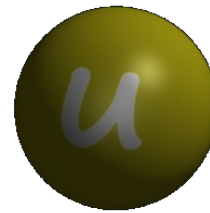
** \hat{Z}*



electro
n



neutrino

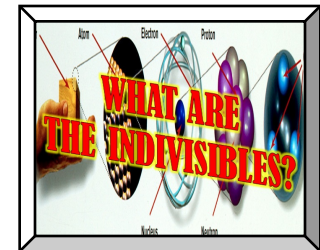


up
quark



down
quark

**For a short tutorial on fundamental particles,
see “What Are The Indivisibles?” in the
Background Materials:*



But, the Universe does have other particles up its sleeve.

For one thing, each of the matter particles has a twin.

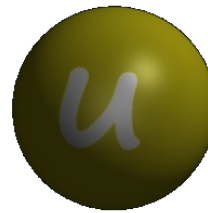
No, not an evil twin[^]



electro
n



neutrino



up
quark



down
quark

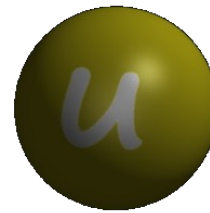
Ĵan ANTIMATTER twin.



electro
n



neutrino



up
quark



down
quark



positro
n



anti-
neutrino



anti-up
quark



anti-down
quark

It is traditional to use a little bar in the symbol for an antimatter particle to distinguish it from the symbol for its matter twin (the exception is the positron, where we use a

'A+A instead of the 'A'

*Antimatter is not the stuff of science fiction.
It exists.*

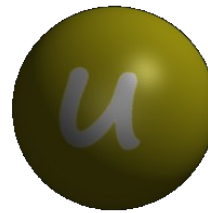
*It is the stuff (or rather, the anti-stuff) of
science fact.*



electro
n



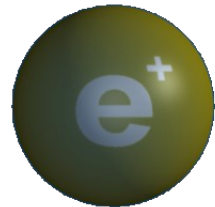
neutrino



up
quark



down
quark



positro
n



anti-
neutrino



anti-up
quark



anti-down
quark

It is traditional to use a little bar in the symbol for an antimatter particle to distinguish it from the symbol for its matter twin (the exception is the positron, where we use a

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Matter, Antimatter: What's the difference?

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There is one essential and obvious difference:

Matter, Antimatter: What's the difference?

There is one essential and obvious difference:

A particle of matter that has an ELECTRIC CHARGE has an antiparticle twin with the exact opposite charge.

If you require information on electric charge as it pertains to this lesson, see “Will You Be Charging That?” in the Background Materials:



Matter, Antimatter: What's the difference?

There is one essential and obvious difference:

A particle of matter that has an ELECTRIC CHARGE has an antiparticle twin with the exact opposite charge.

For example, if the electron has a charge of -1 ,

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Charge:
 -1



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Charge:
 -1



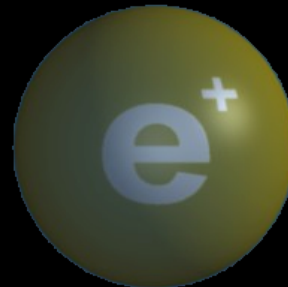
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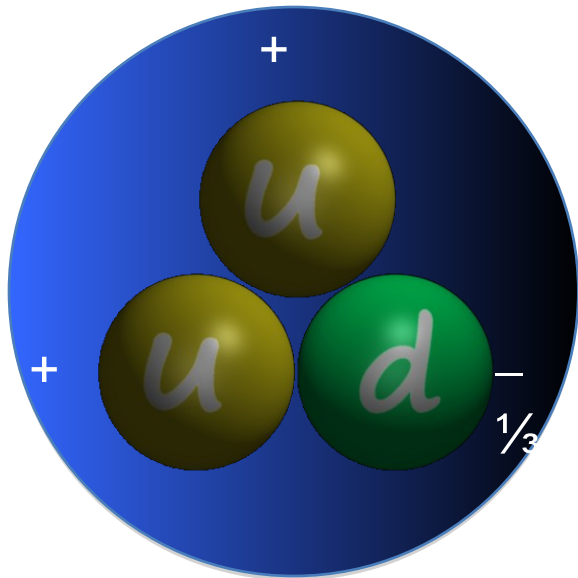
Electron
Charge:
 -1



Positron
Charge:
 $+1$

*Remember that
protons and neutrons
are made up of particular combinations
of the up and down quarks,
and that these quarks have a fractional charge ...*

PROTON *(p)*

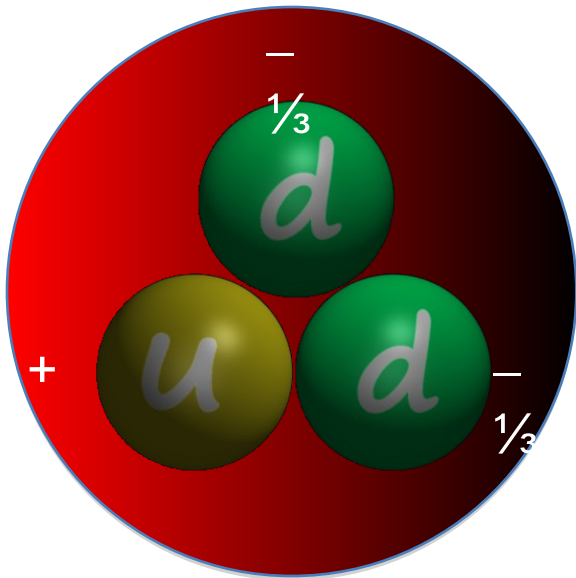


Composed of:
2 up quarks and
1 down quark

Total charge:

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

NEUTRON (*n*)



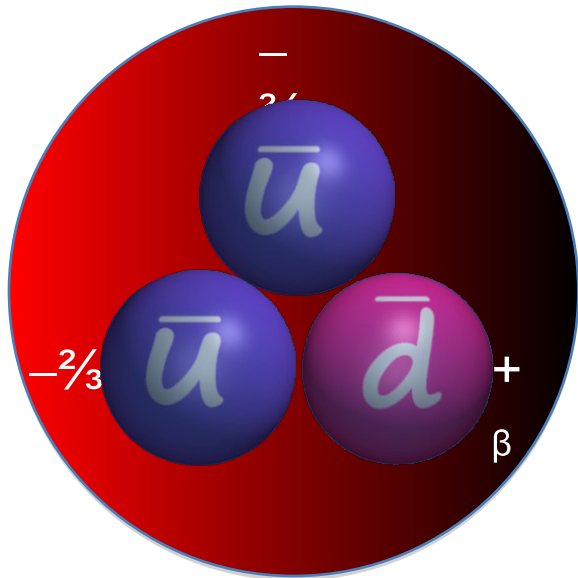
*Composed of:
1 up quark and
2 down quarks*

Total charge:
 $\frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0$

Likewise, particular combinations of the anti-up and anti-down quarks make up antiprotons and antineutrons.

Again, the anti-up and anti-down quarks have the opposite charge of their matter twins ...

ANTIPROTON (\bar{p}):

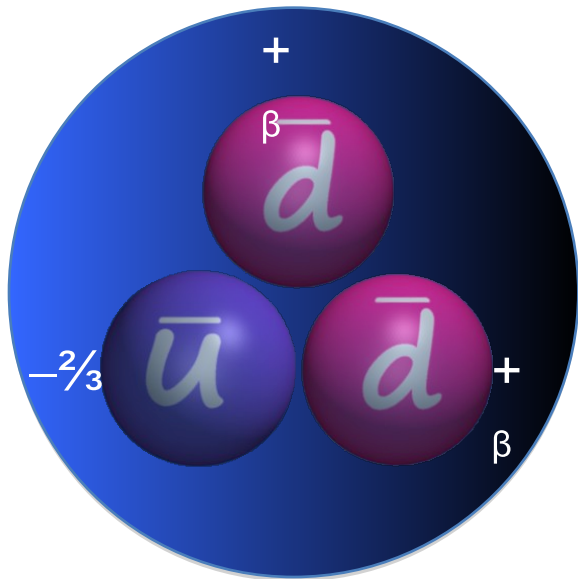


Composed of:
2 anti-up quarks and
1 anti-down quark

Total charge:

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

ANTINEUTRON (\bar{n}):



*Composed of:
1 anti-up quark and
2 anti-down quarks*

Total charge:

$$-\frac{2}{3} + \frac{1}{3} + \frac{1}{3} = 0$$

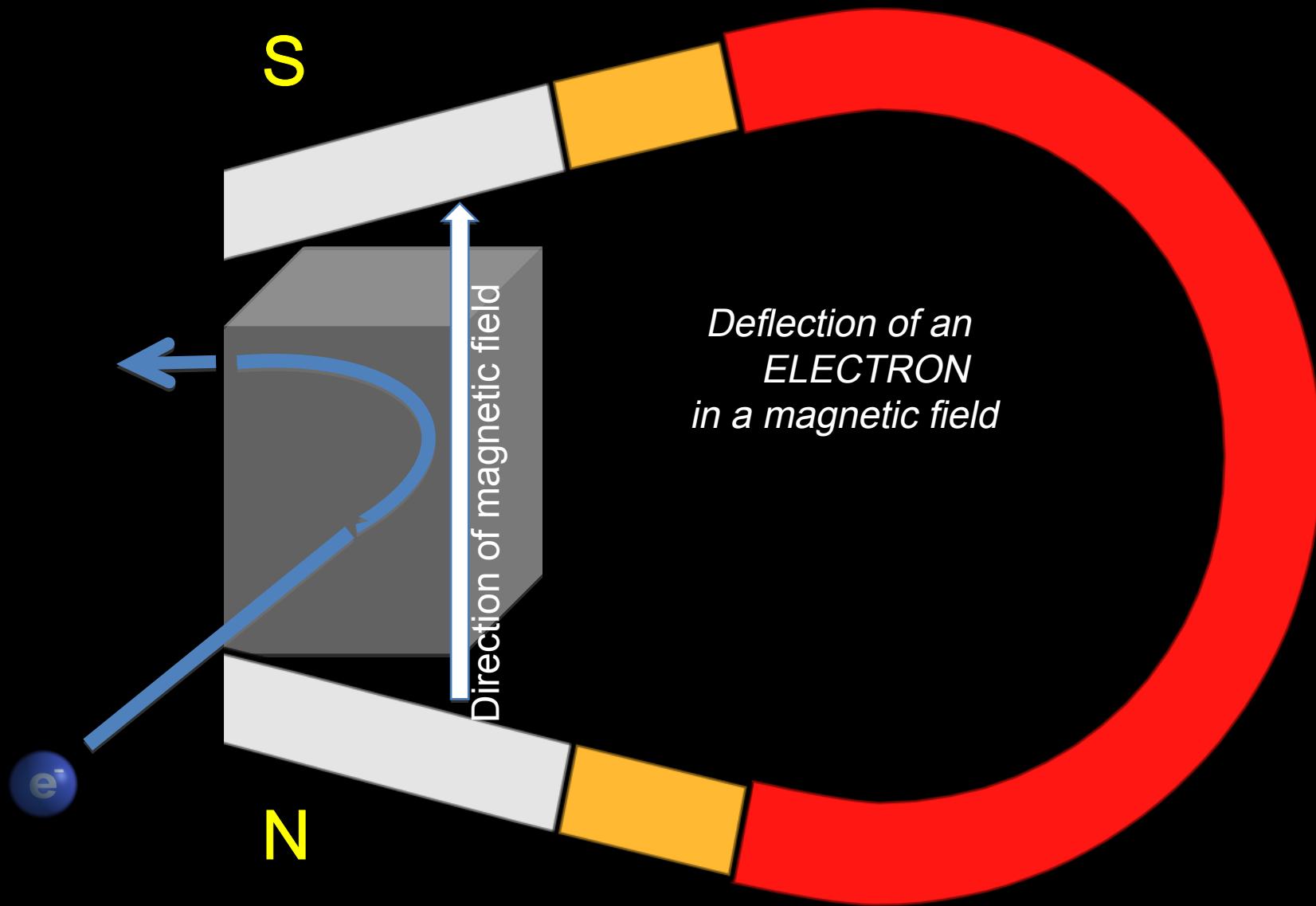
Notice that the antineutron also has zero charge. If a particle has no charge, then its antiparticle has no charge.

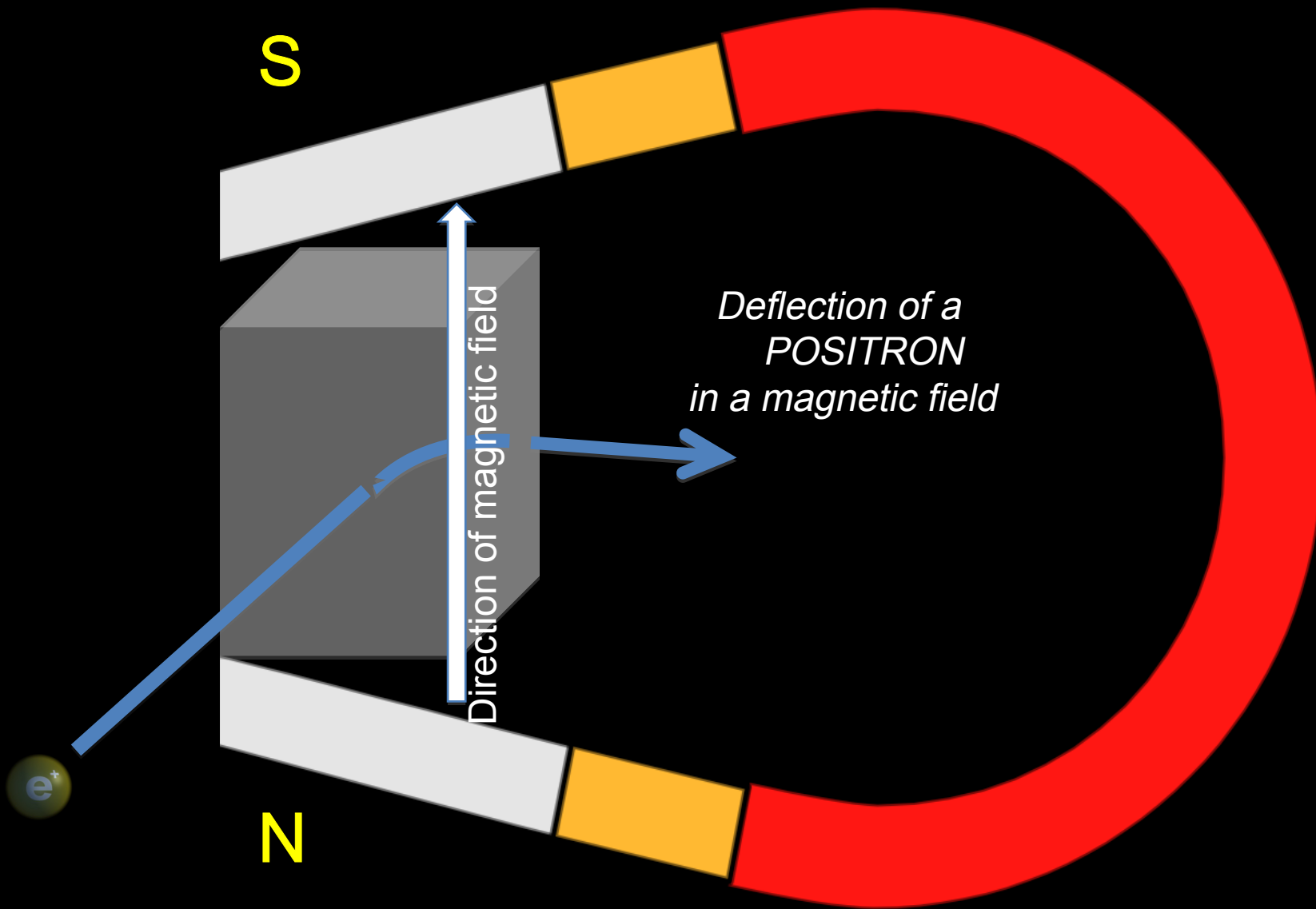
*In a magnetic field, a particle with an electric charge
will be deflected by the same amount as its antiparticle*

BUT

in opposite directions:

For example





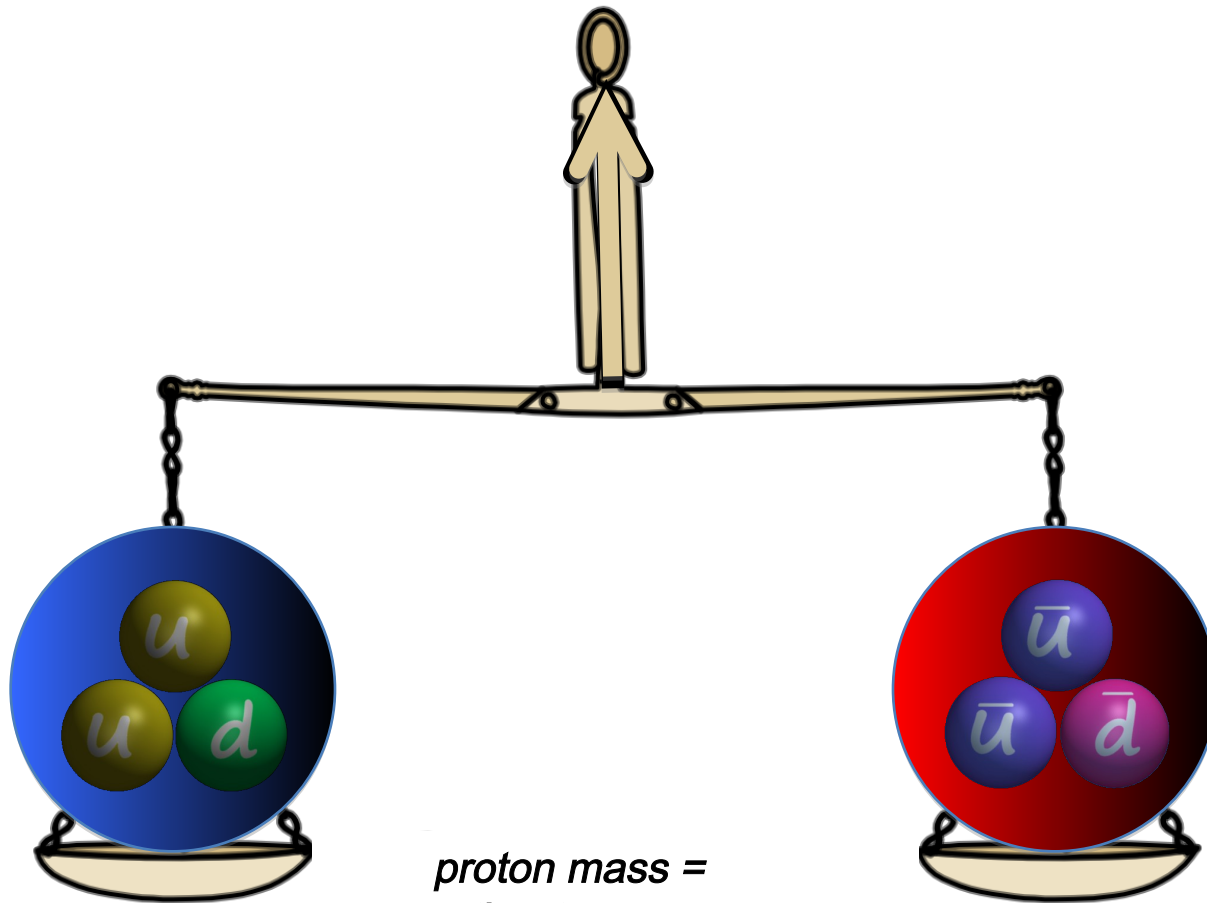
*How are Matter and Antimatter
similar?*

How are Matter and Antimatter similar?

As far as we can tell, particles and antiparticles have IDENTICAL masses.

(The fact that a particle and its antiparticle are deflected by the same amount in a magnetic field, is an indication to us that the mass of a particle and its antiparticle are identical).

For example ...



*proton mass =
antiproton mass*

*We also BELIEVE, though it has yet to be
PROVED experimentally,
that antimatter behaves IDENTICALLY to matter
under the influence of GRAVITY.*



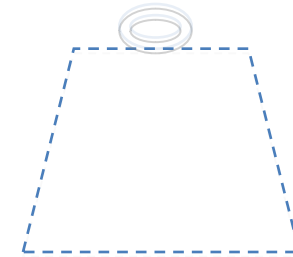
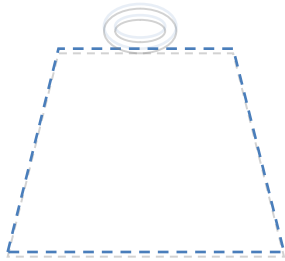
*For example,
if you were able to drop a
certain amount of
matter and antimatter
in a gravitational field,
we believe that they would
accelerate at precisely the
same rate.*





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*In addition to the fundamental antiparticles,
entire anti-atoms are possible.
In fact, human beings have already made one:*

*In addition to the fundamental antiparticles,
entire anti-atoms are possible.
In fact, human beings have already made one:*

ANTIHYDROGEN

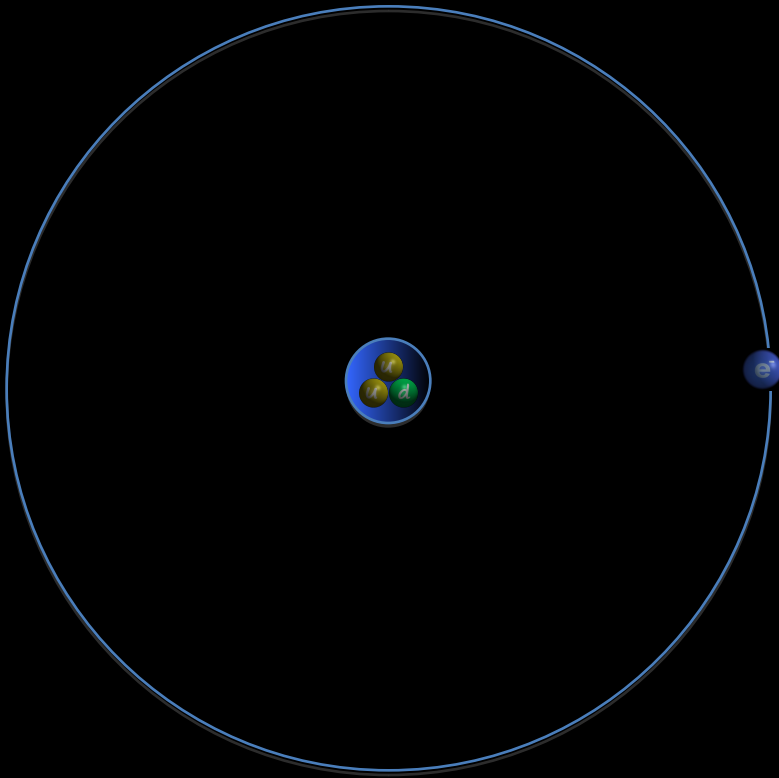
Good old HYDROGEN.

It's the simplest atom we know.

It consists of 1 proton and 1 electron.

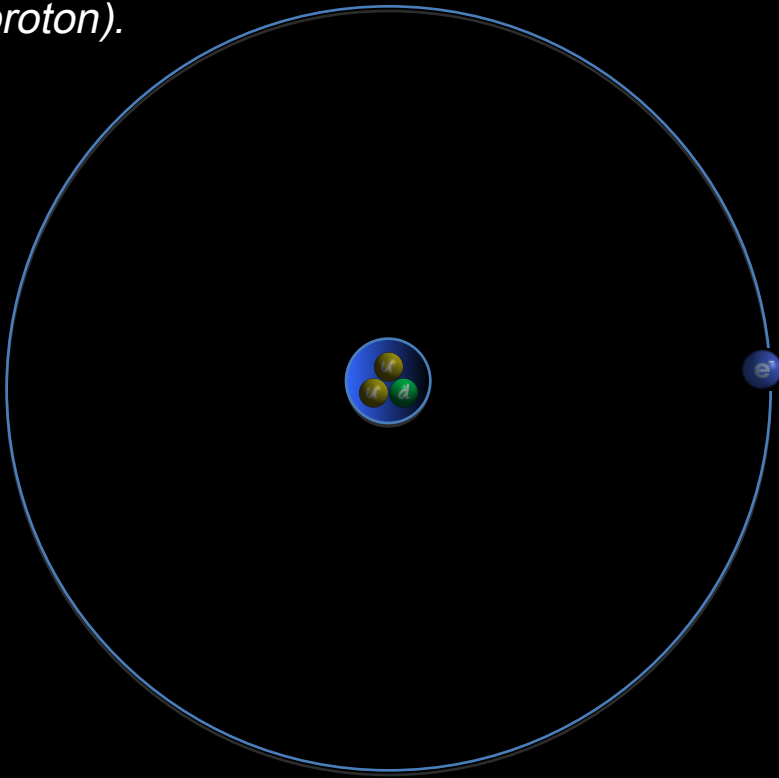
Let us picture a hydrogen atom as an electron orbiting its nucleus, a proton.

Let us picture a hydrogen atom as an electron orbiting its nucleus, a proton.



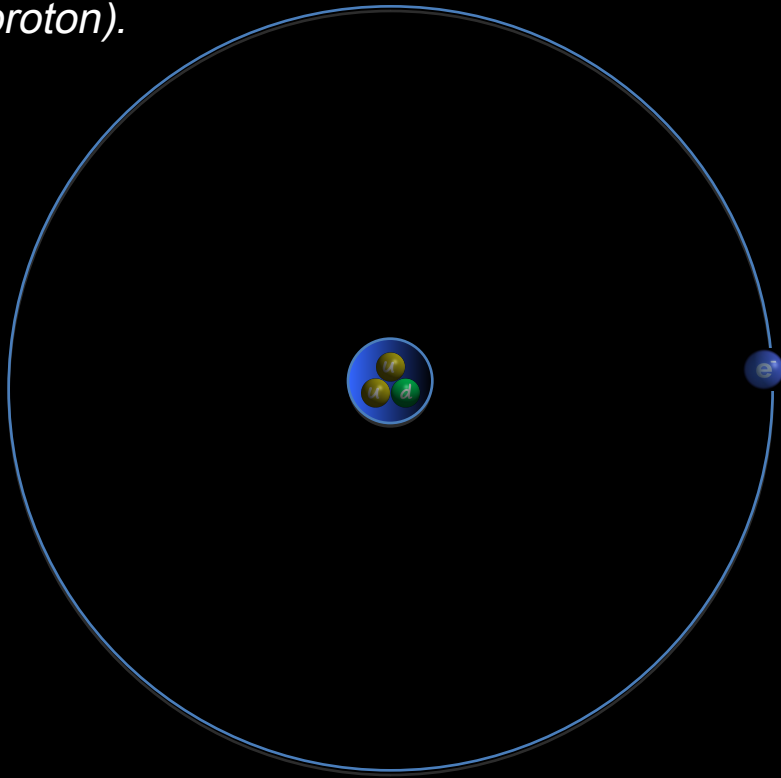
Hydrogen
(H)

Let us picture a hydrogen atom as an electron orbiting its nucleus, a proton. BUT REMEMBER—this is NOT an accurate depiction! (For one thing, in the proper scale, our electron would have to be drawn about 1 kilometer away from the proton).



Hydrogen
(H)

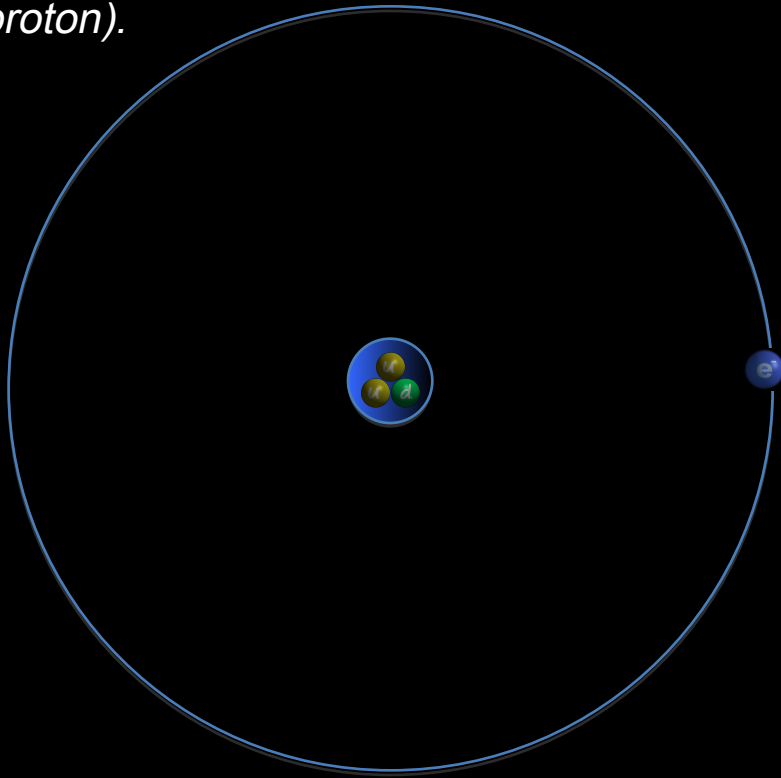
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(H)

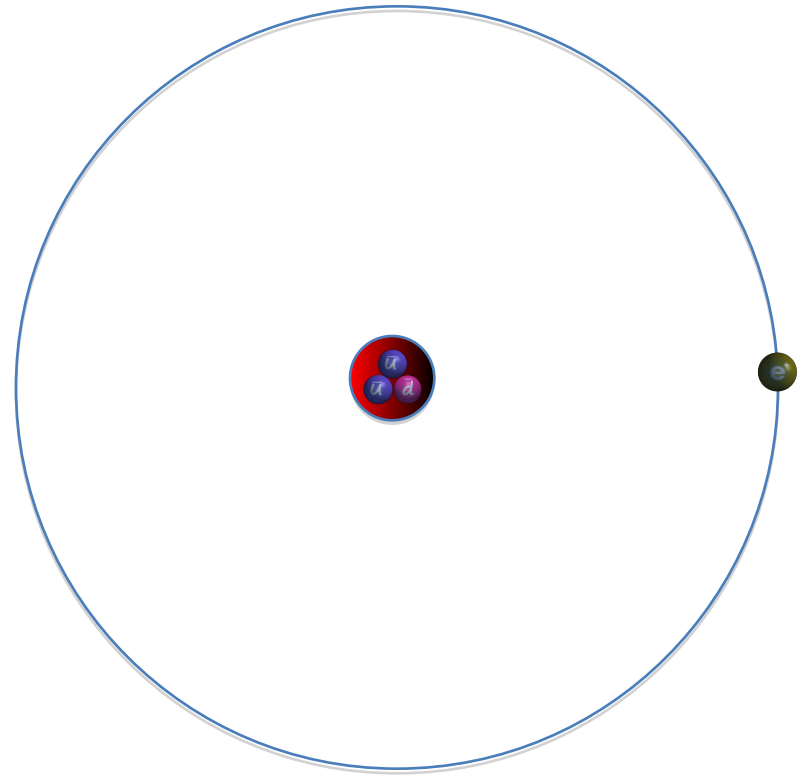
Let us now picture an antihydrogen atom as a positron orbiting its nucleus, an antiproton . (The same warnings apply!)

Let us picture a hydrogen atom as an electron orbiting its nucleus, a proton. BUT REMEMBER—this is NOT an accurate depiction! (For one thing, in the proper scale, our electron would have to be drawn about 1 kilometer away from the proton).



Hydrogen
(H)

Let us now picture an antihydrogen atom as a positron orbiting its nucleus, an antiproton. (The same warnings apply!)



Anti-
Hydrogen $\bar{\text{H}}$
($\bar{\text{H}}$)

*At CERN in 1995,
The very first atoms of ANTIHYDROGEN were made.*

*From an initial production in 1995 of just a few atoms in 3
weeks,
a few million have been produced on a worldwide basis
in the intervening years.**

*Although that may seem impressive, remember that it
takes about
600,000,000,000,000,000,000,000 antihydrogen atoms
to make just one gram.*

** See the following links to find out*

more:

[http://press.web.cern.ch/press/PressReleases/Releases1996/PR01.96EAntiHydrogen.
html](http://press.web.cern.ch/press/PressReleases/Releases1996/PR01.96EAntiHydrogen.html)

[Antihydrogen Atoms Made At Cern](http://cool-antihydrogen.web.cern.ch/cool-antihydrogen/)

<http://cool-antihydrogen.web.cern.ch/cool-antihydrogen/>

How far can we go with this?

Could we have other anti-atoms?

How about anticarbon, antinitrogen, antioxygen?

How far can we go with this?

Could we have other anti-atoms?

How about anticarbon, antinitrogen, antioxygen?

What about an entire Periodic Anti-Table?

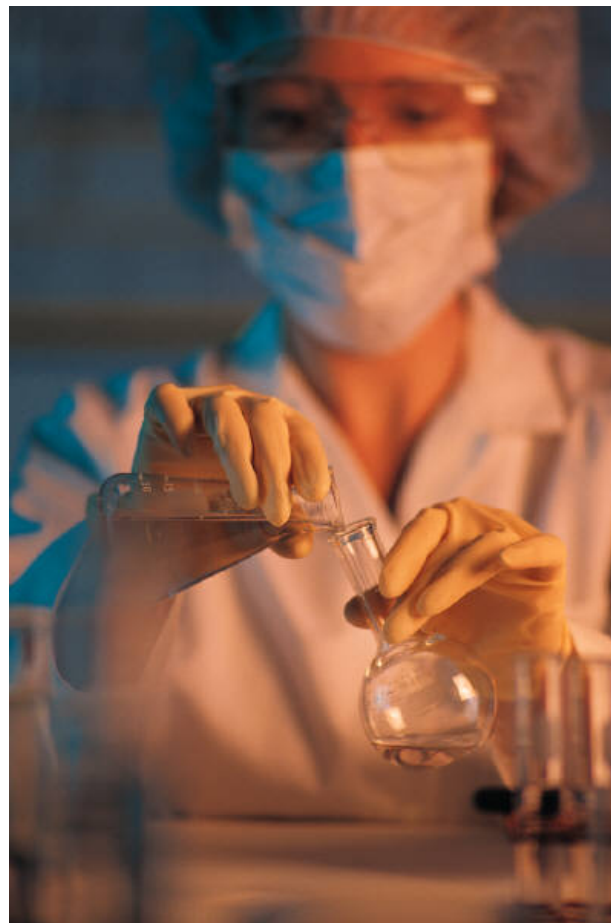
THEORETICALLY SPEAKING,
COMBINATIONS OF
POSITRONS, ANTIPROTONS AND ANTINEUTRONS
COULD GENERATE ANTI-VERSIONS OF ALL OF THE
ELEMENTS IN THE PERIODIC TABLE.

period 1																		period 2																	
H																		He																	
100.000																		4.0026																	
period 3																		period 4																	
Li																		Be																	
6.941																		9.0122																	
period 5																		period 6																	
Na																		Mg																	
22.990																		24.305																	
period 7																		period 8																	
K																		Ca																	
39.098																		40.078																	
Rb																		Sr																	
85.468																		87.62																	
Cs																		Ba																	
132.905																		137.327																	
Fr																		Ra																	
223.018																		226.025																	
period 9																		period 10																	
Sc																		Ti																	
44.956																		47.88																	
V																		Cr																	
50.942																		52.004																	
Mn																		Fe																	
54.938																		55.845																	
Co																		Ni																	
58.933																		58.693																	
Cu																		Zn																	
63.546																		65.38																	
Ga																		Ge																	
69.723																		72.64																	
As																		Se																	
74.922																		78.96																	
Br																		Kr																	
79.904																		83.80																	
period 11																		period 12																	
Y																		Zr																	
88.906																		91.224																	
Nb																		Mo																	
92.906																		95.94																	
Tc																		Ru																	
																		101.07																	
Rh																		Pd																	
																		106.91																	
Ag																		Cd																	
107.868																		112.412																	
In																		Sn																	
114.818																		118.710																	
Sb																		Te																	
121.757																		127.60																	
I																		Xe																	
126.905																		131.29																	
At																		Rn																	
210																		222																	
period 13																		period 14																	
Al																		Si																	
26.982																		28.086																	
P																		S																	
30.974																		32.06																	
Cl																		Ar																	
35.453																		39.948																	
period 15																		period 16																	
Ga																		Ge																	
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As																		Se																	
74.922																		78.96																	
Br																		Kr																	
79.904																		83.80																	
period 17																		period 18																	
Tl																		Pb																	
204.38																		207.2																	
Bi																		Po																	
208.98																		209																	
At																		Rn																	
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We also predict that
ANTIMATTER CHEMISTRY
is identical to
good old MATTER
CHEMISTRY



*Though it may annoy your chemistry teacher,
chemistry is basically the study of
what happens when bunches of atoms come together.*

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chemistry is basically the study of
what happens when bunches of atoms come together.*

As two hydrogen atoms approach each other,
their nuclei repel (why?).

This repulsion is overcome because
the electron in one atom attracts
the proton in the other atom.

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chemistry is basically the study of
what happens when bunches of atoms come together.*

As two hydrogen atoms approach each other,
their nuclei repel (why?).

This repulsion is overcome because
the electron in one atom attracts
the proton in the other atom.

The best configuration is when the atoms are bound
together .

We then have a hydrogen molecule .

AS AN EXERCISE, REPLAY THE FORMATION OF A HYDROGEN
MOLECULE,
ONLY THIS TIME USING *ANTIHYDROGEN* ATOMS.

WOULD THERE BE ANY DIFFERENCE FROM THE POINT OF VIEW OF
THE FORCES OF ATTRACTION AND REPULSION?

WOULD AN ANTIHYDROGEN MOLECULE BE FORMED?

AS AN EXERCISE, REPLAY THE FORMATION OF A HYDROGEN
MOLECULE,
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WOULD THERE BE ANY DIFFERENCE FROM THE POINT OF VIEW OF
THE FORCES OF ATTRACTION AND REPULSION?

WOULD AN ANTIHYDROGEN MOLECULE BE FORMED?

*(With respect to forces of attraction and repulsion, there is a complete
symmetry between these two cases. Thus, an antihydrogen molecule
WOULD be formed)*

Can we keep going?

Can we keep going?

*If anti-hydrogen molecules are a theoretical
possibility,*

AND

*the chemistry of antimatter is identical to that of
matter ...*

Can we keep going?

If anti-hydrogen molecules are a theoretical possibility,

AND

the chemistry of antimatter is identical to that of matter ...

Then how about bigger AND BIGGER anti-molecules?

Can we keep going?

*If anti-hydrogen molecules are a theoretical
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*Then how about bigger AND BIGGER anti-
molecules?*

AS A LITTLE THOUGHT EXPERIMENT,
TAKE THIS LINE OF THINKING AS FAR AS YOU CAN'H

And what about an Anti-You?
What would your Anti-You look like?

And what about an Anti-You?
What would your Anti-You look like?

If we took You

And what about an Anti-You?
What would your Anti-You look like?

If we took You



Insert your
photo here

And what about an Anti-You?
What would your Anti-You look like?

If we took You



Insert your
photo here

and reversed the charges of all of the particles that make you up
(in other words change your electrons to positrons, your protons to
antiprotons, and your neutrons to antineutrons),
the resulting forces would be the same .

And what about an Anti-You?
What would your Anti-You look like?

If we took You



Insert your
photo here

and reversed the charges of all of the particles that make you up
(in other words change your electrons to positrons, your protons to
antiprotons, and your neutrons to antineutrons),
the resulting forces would be the same .

These forces have given you your structure~and so, your
appearance.

So, Anti-You
would look exactly like
You.



Insert your
photo here
AGAIN

So, Anti-You
would look exactly like
You.



Insert your
photo here
AGAIN

However, if You and your Anti-You were to meet ...

So, Anti-You
would look exactly like
You.



Insert your
photo here
AGAIN

However, if You and your Anti-You were to meet ...

To gain an understanding into what would happen in such an
encounter,

go to the lesson “*Operation: Annihilate!*”.

One Final Note:

You will sometimes see an anti-object depicted as a mirror-image photo-negative of the original object.

For example:



BANANA



ANTI-
BANANA

In the Extension Lesson “*Through The Looking Glass*”, we discuss why antimatter *can* be thought of as a negative mirror-image of matter. But it should be understood that bulk antimatter would look identical to bulk matter. A depiction like the one above is simply used for *effect!*