

Building a Universe from Scratch

An Introduction to Particle Physics

Rob Clemenson – Royal Holloway, University of London

robertclemenson@kes.essex.sch.uk

Matter

Matter - Stuff which has weight

Almost everything you can touch, smell, and see is made of matter. (Solids, liquids, and gasses).

E.g. Rocks, frogs, and soup



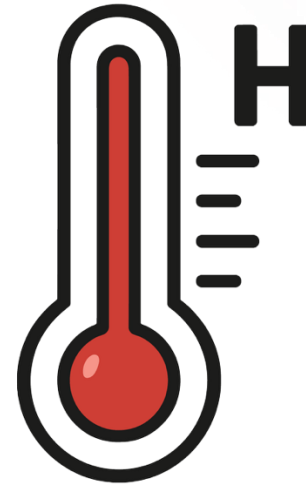
Question: Can you think of anything you can feel or see that *isn't* matter?

Energy

Energy - Something that makes matter move or change

Light and heat are types of energy. We can feel heat and see light.

E.g. Light, heat, motion



Looking Closer at Matter...

Take three Particle Physicists

We are all made out of matter



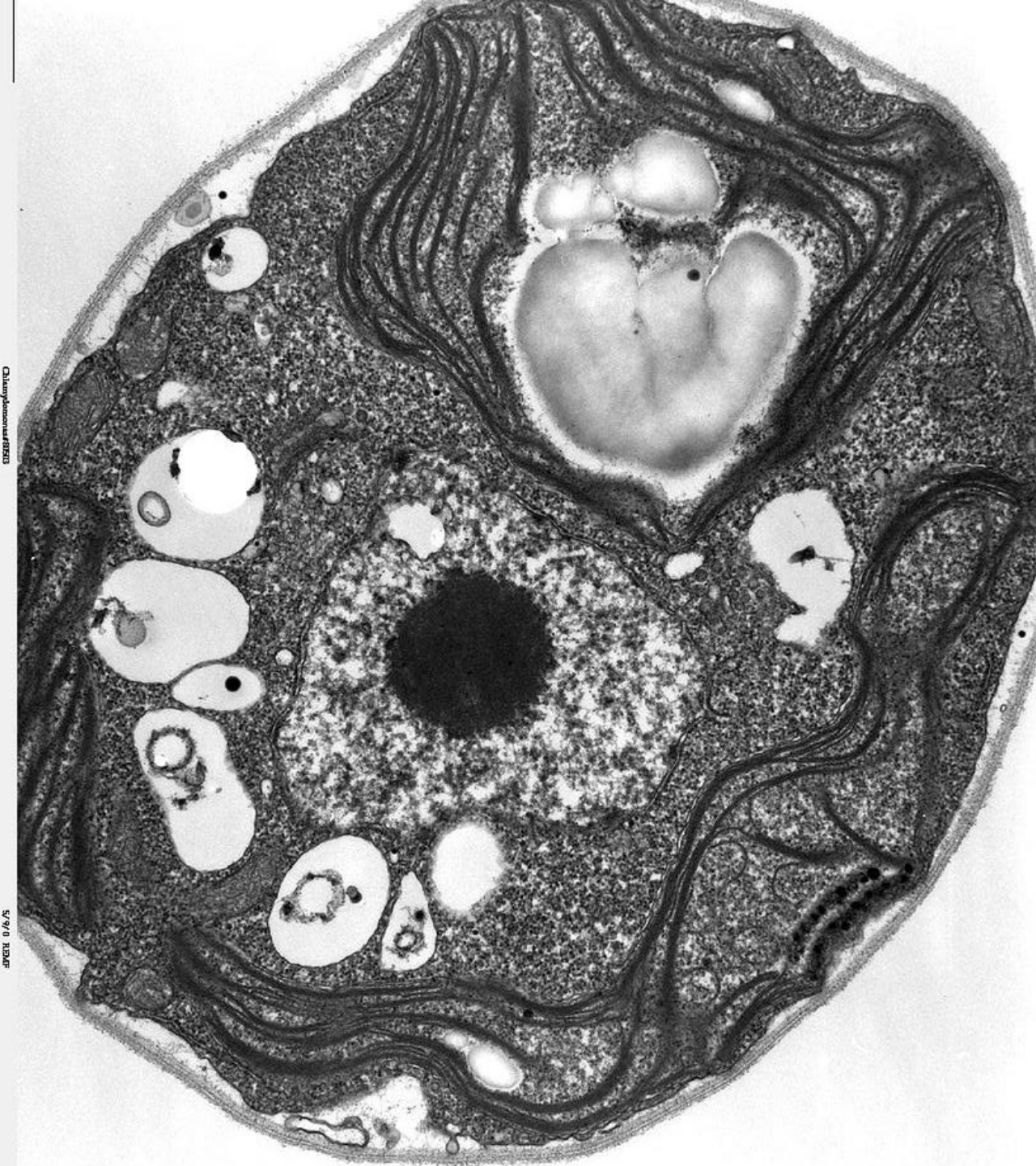
Looking Closer at Matter...

Take three Particle Physicists

We are all made out of matter

Let's zoom in a little!

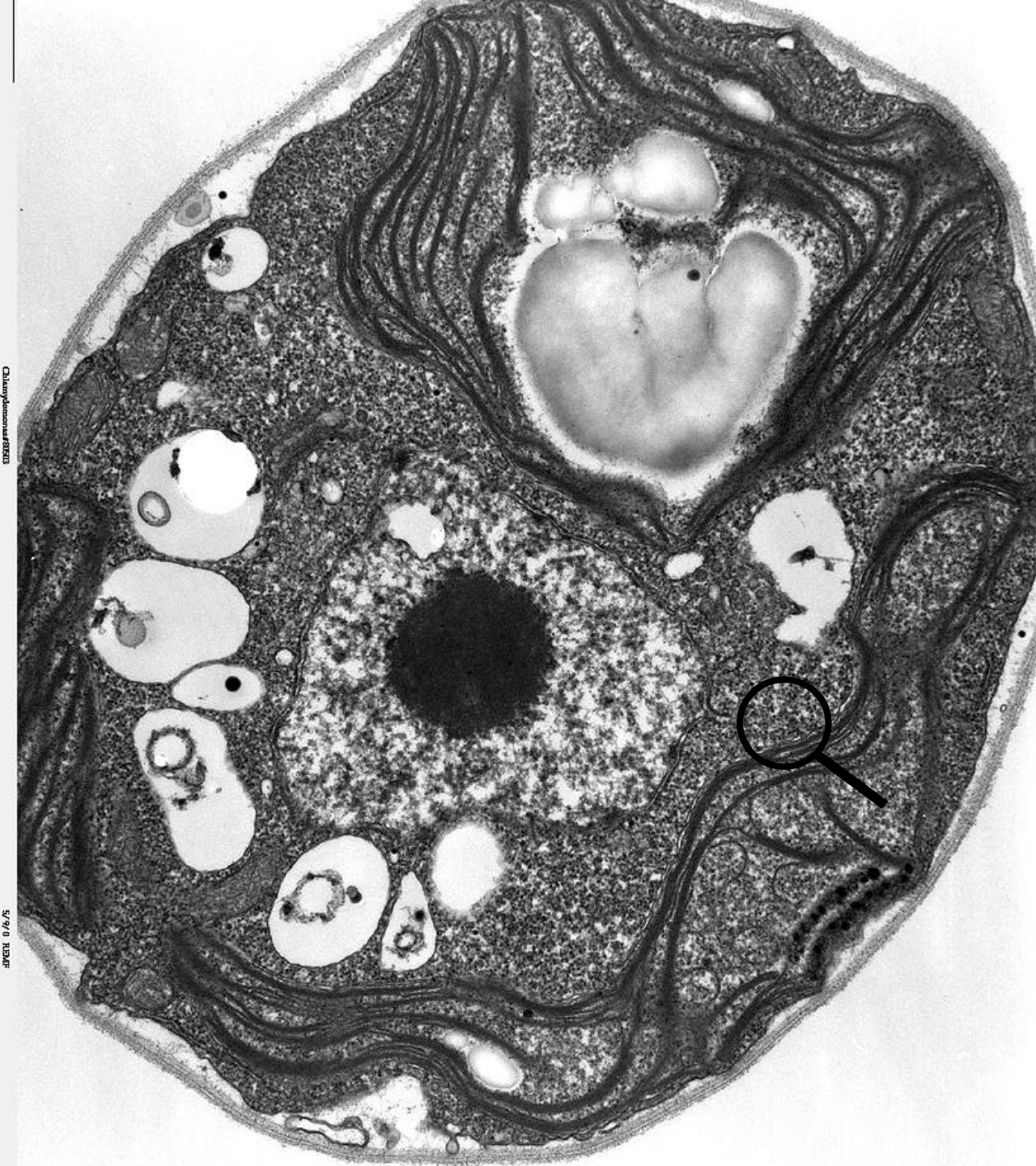




Looking Closer at Matter...

Human Cells

All living matter is made of up '*cells*'

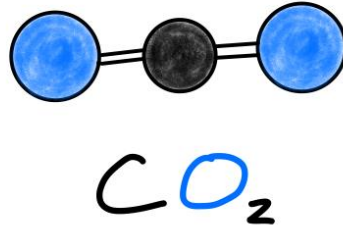
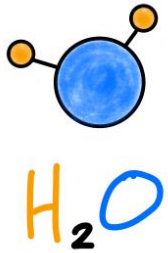


Looking Closer at Matter...

Human Cells

All living matter is made of up '*cells*'

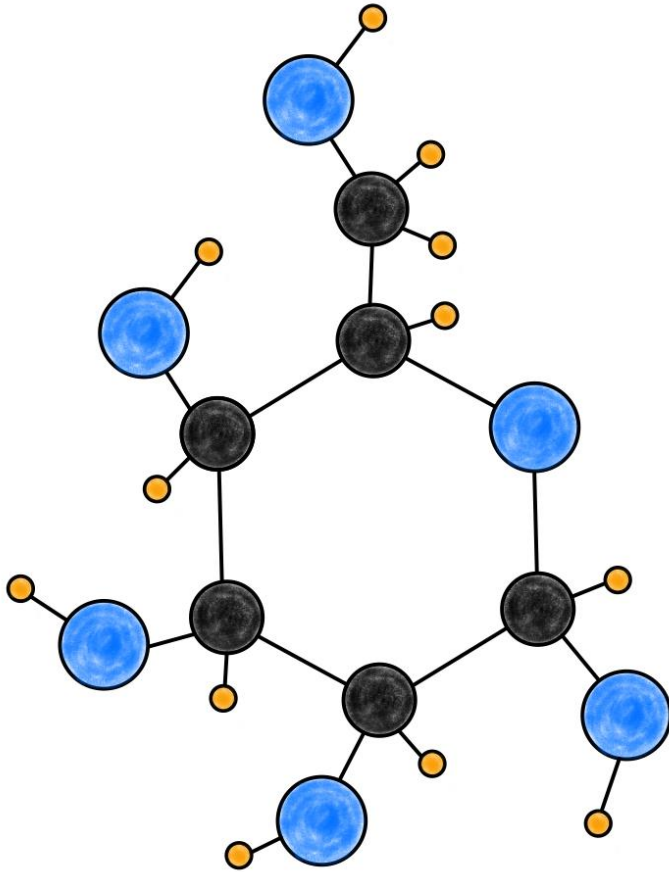
Let's zoom in even more!

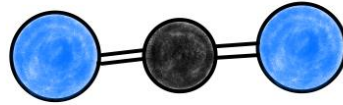
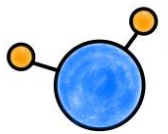


Looking Closer at Matter...

Molecules

Also called '*chemical compounds*'.
These are combinations of the different elements found in the **periodic table**.



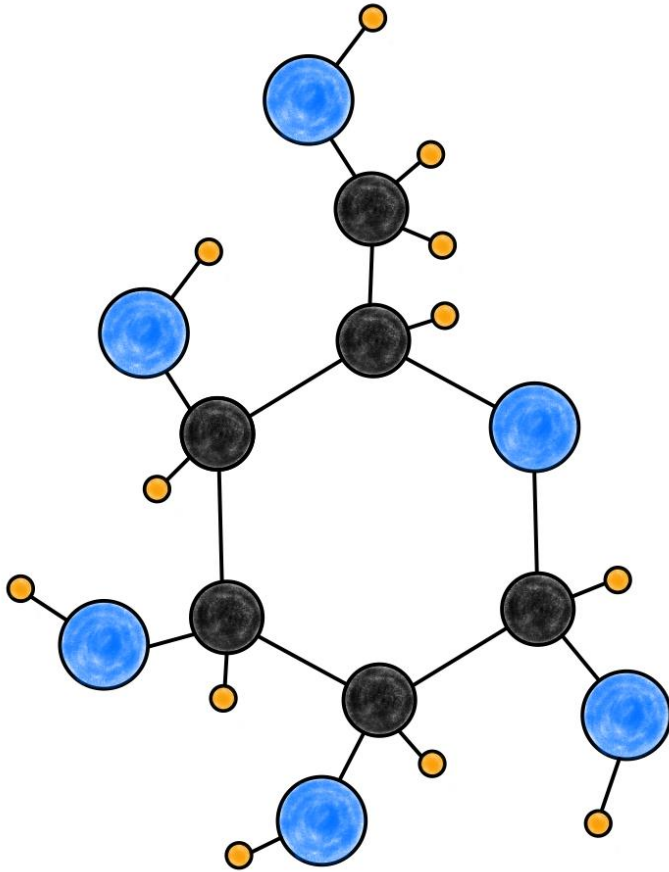


Looking Closer at Matter...

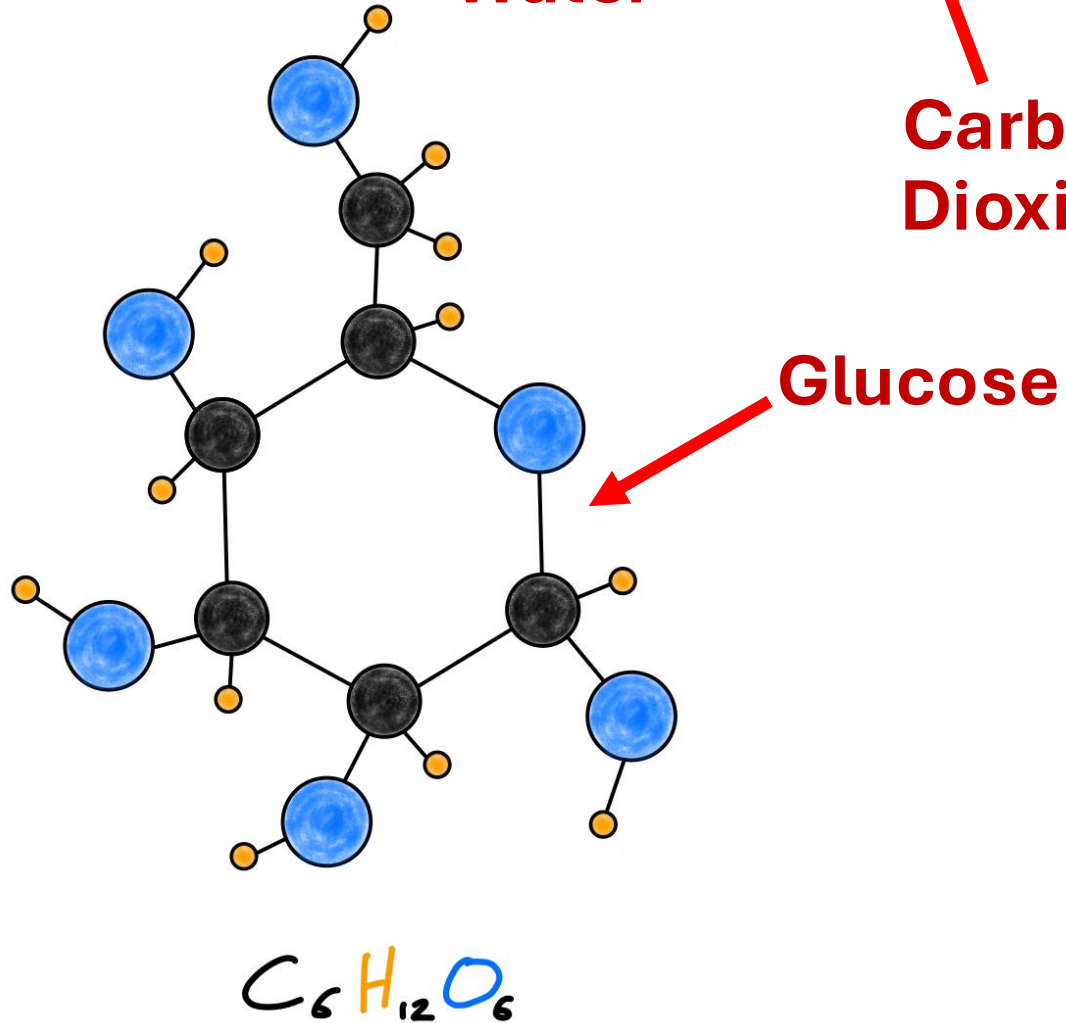
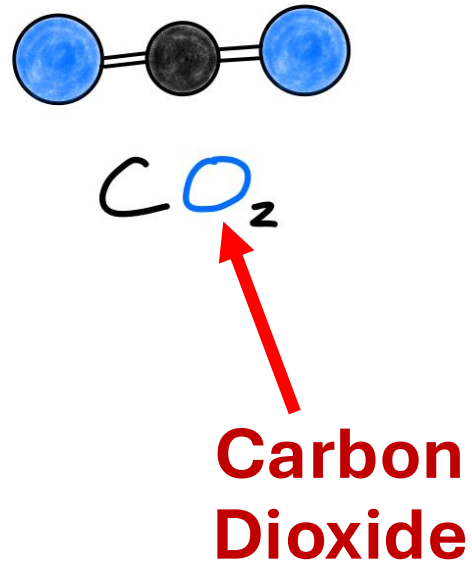
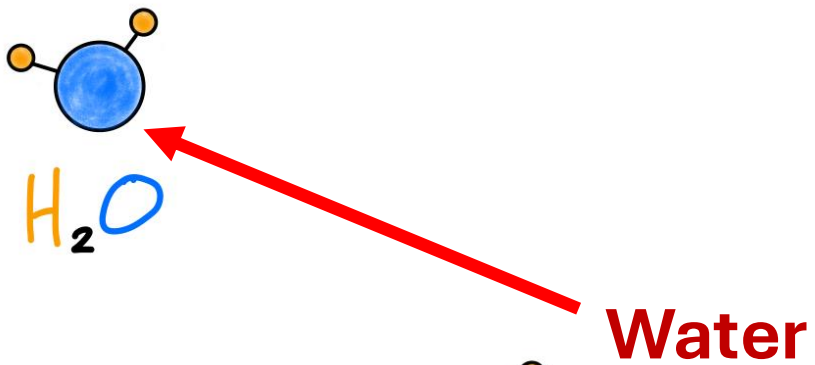
Molecules

Also called '*chemical compounds*'.

These are combinations of the different elements found in the **periodic table**.



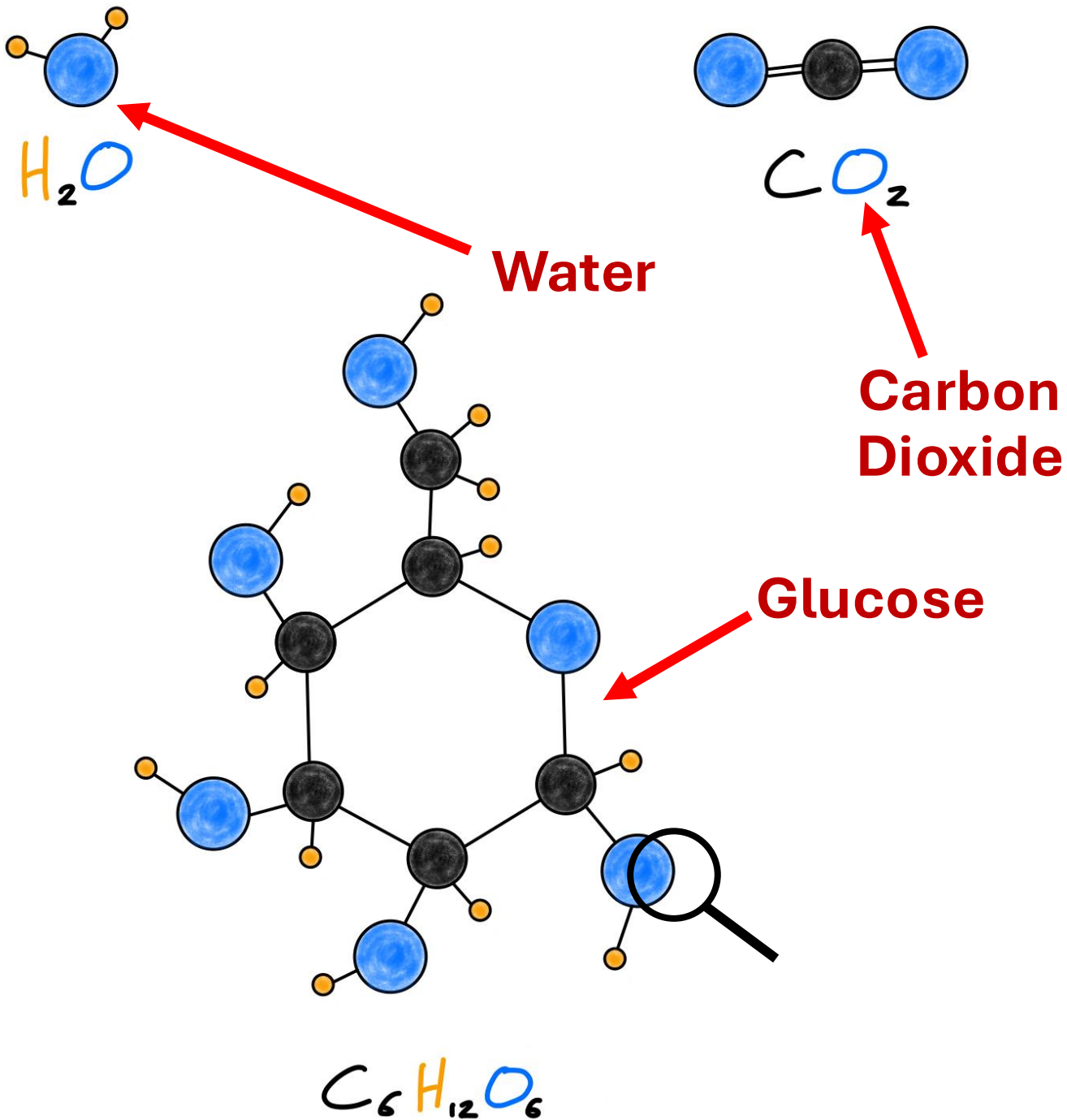
Question: Can you name any of the chemical compounds shown here?



Looking Closer at Matter...

Molecules

Also called '*chemical compounds*'.
These are combinations of the
different elements found in the
periodic table.



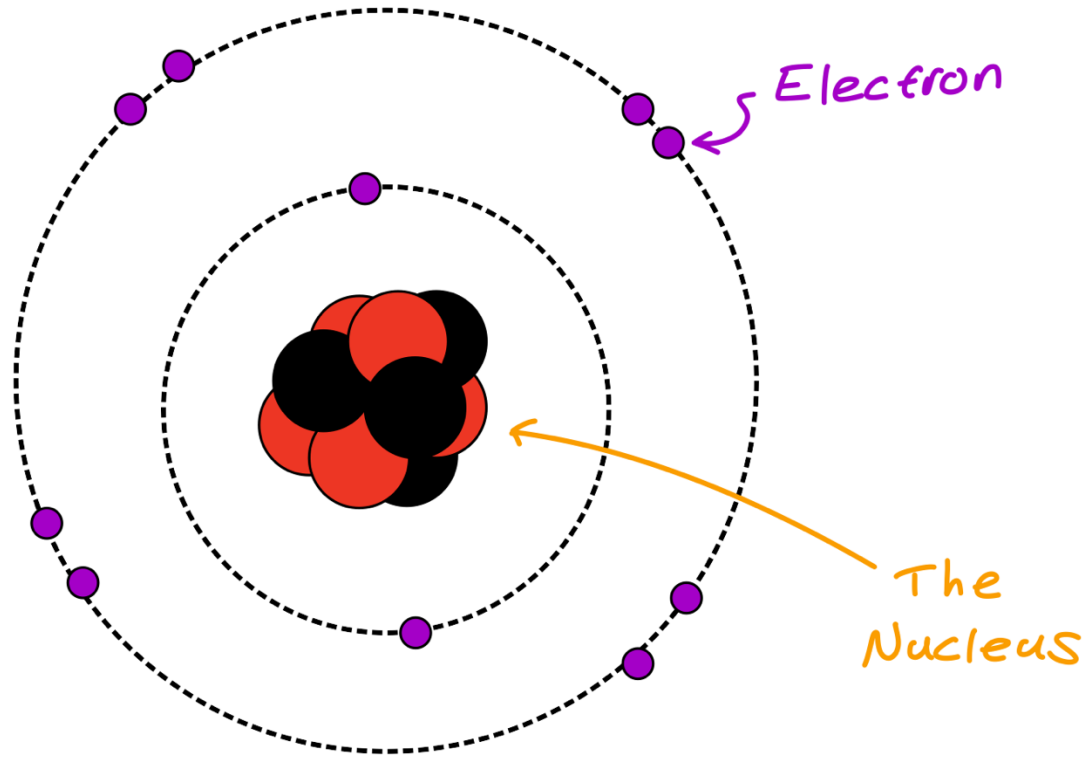
Looking Closer at Matter...

Molecules

Also called '*chemical compounds*'.
These are combinations of the different elements found in the **periodic table**.

Let's zoom in even more!

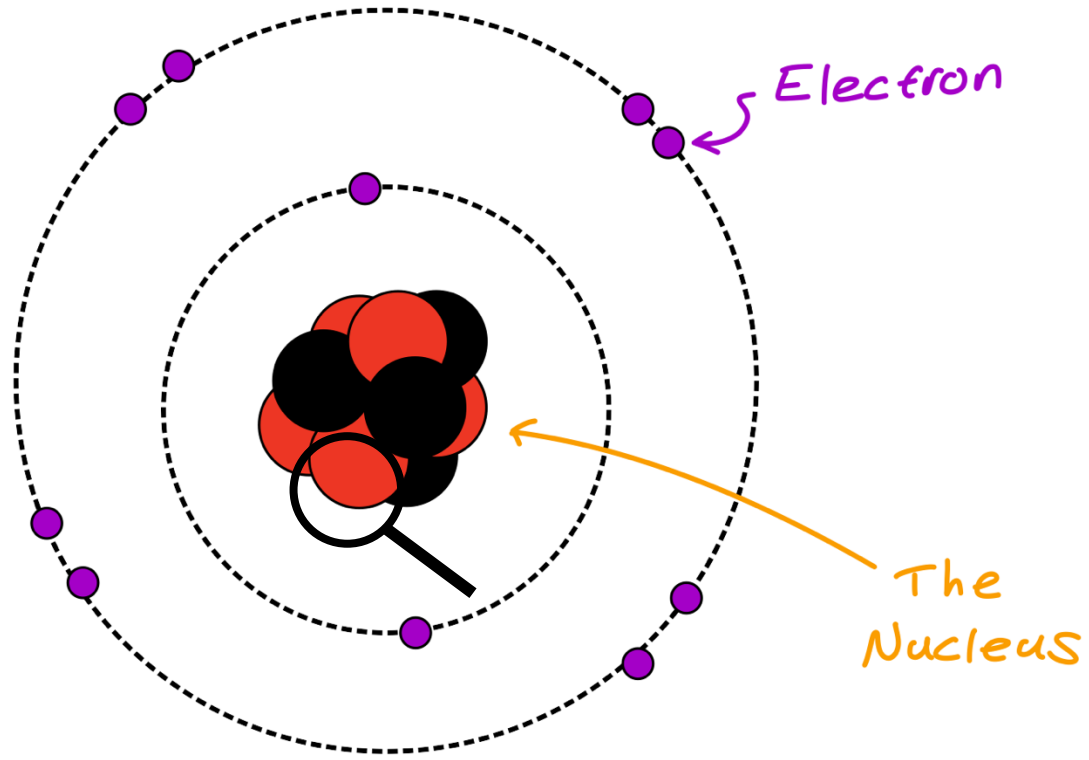
Looking Closer at Matter...



Atoms

All the 'stuff' we see on Earth is made out of atoms.

Looking Closer at Matter...

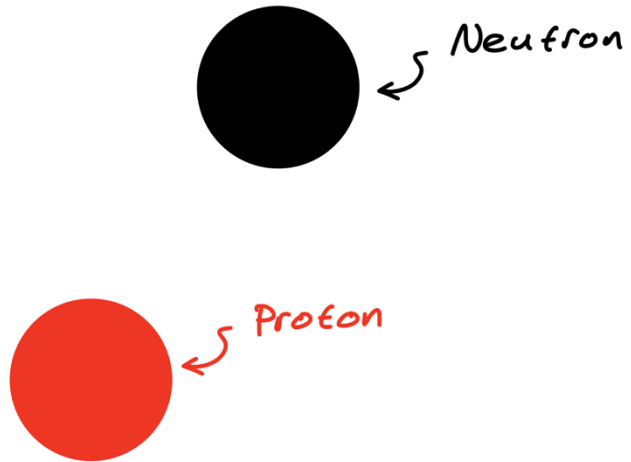


Atoms

All the 'stuff' we see on Earth is made out of atoms.

Let's look even closer...

Looking Closer at Matter...



Protons & Neutrons

The center of an atom is made out of particles called 'Protons' and 'Neutrons'.

All the different kinds of matter are organized in the **periodic table**.

Some elements near the dashed staircase are sometimes called *metalloids*

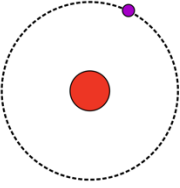
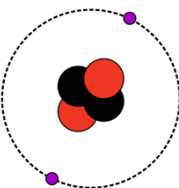
A Side Note on the Chemical Elements...

Group ►	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18															
Period ▼																																	
Nonmetals 1	1 H																		2 He														
Metals 2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne															
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar															
4	19 K	20 Ca											21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr					
5	37 Rb	38 Sr											39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe					
6	55 Cs	56 Ba	La to Yb	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn														
7	87 Fr	88 Ra	Ac to No	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og														
	s-block (plus He)		f-block	d-block										p-block (excluding He)																			
Lanthanides			<table><tr><td>57 La</td><td>58 Ce</td><td>59 Pr</td><td>60 Nd</td><td>61 Pm</td><td>62 Sm</td><td>63 Eu</td><td>64 Gd</td><td>65 Tb</td><td>66 Dy</td><td>67 Ho</td><td>68 Er</td><td>69 Tm</td><td>70 Yb</td></tr></table>																	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb																				
Actinides			<table><tr><td>89 Ac</td><td>90 Th</td><td>91 Pa</td><td>92 U</td><td>93 Np</td><td>94 Pu</td><td>95 Am</td><td>96 Cm</td><td>97 Bk</td><td>98 Cf</td><td>99 Es</td><td>100 Fm</td><td>101 Md</td><td>102 No</td></tr></table>																	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No																				

Some elements near the dashed staircase are sometimes called *metalloids*

All the different kinds of matter are organized in the **periodic table**.

Hydrogen atoms are a single electron orbiting a single proton

Group ► 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Period ▼

Nonmetals 1 H

Metals 2 Li Be 3 4
11 Na Mg 12
19 K Ca 20
37 Rb Sr 38
55 Cs Ba 56 La to Yb
87 Fr Ra 88 Ac to No

Transition metals
(sometimes excluding group 12)

Some elements near the dashed staircase are sometimes called *metalloids*

Noble gases 2 He

s-block (plus He) f-block d-block p-block (excluding He)

Lanthanides 57 La 58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb

Actinides 89 Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No

A Side Note on the Chemical Elements...

All the different kinds of matter are organized in the **periodic table**.

Hydrogen atoms are a single electron orbiting a single proton

Helium atoms are two electrons orbiting two protons and two neutrons

All the different kinds of matter are organized in the **periodic table**.

Hydrogen atoms are a single electron orbiting a single proton

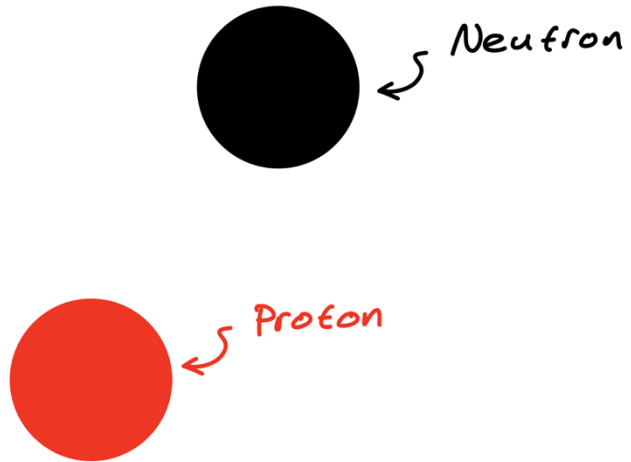
Helium atoms are two electrons orbiting two protons and two neutrons

Carbon atoms are six electrons orbiting six protons and six neutrons

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period																		
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca											31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr											49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	La to Yb										81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	Ac to No										113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
	s-block (plus He)		f-block		d-block								p-block (excluding He)					
			Lanthanides		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
			Actinides		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

Back to zooming!....

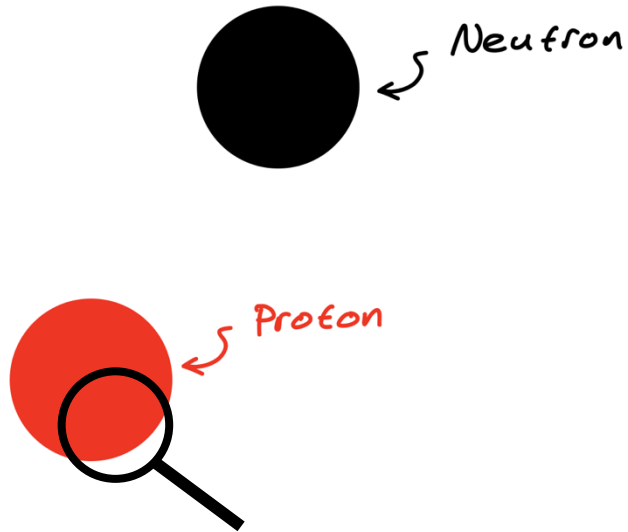
Looking Closer at Matter...



Protons & Neutrons

The center of an atom is made out of particles called 'Protons' and 'Neutrons'.

Looking Closer at Matter...

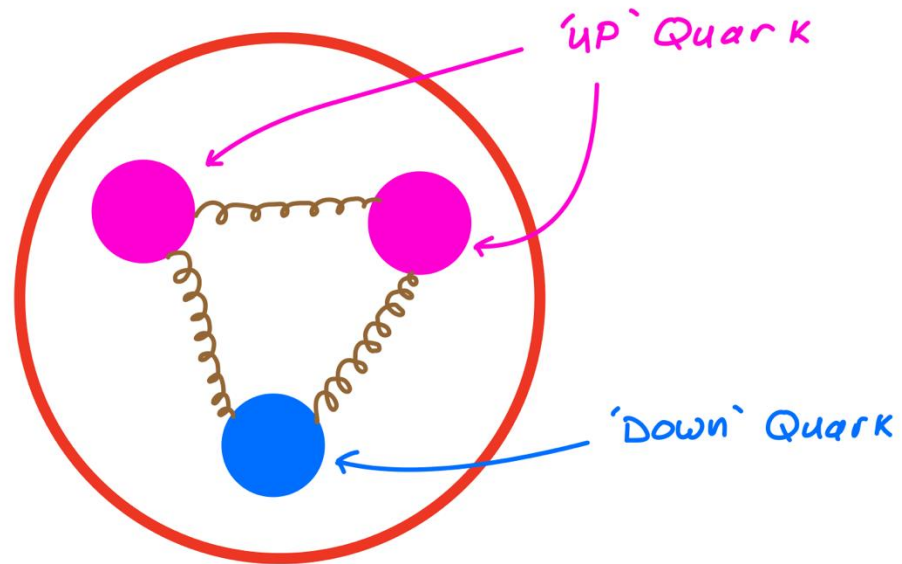


Protons & Neutrons

The center of an atom is made out of particles called 'Protons' and 'Neutrons'.

Another zoom in...

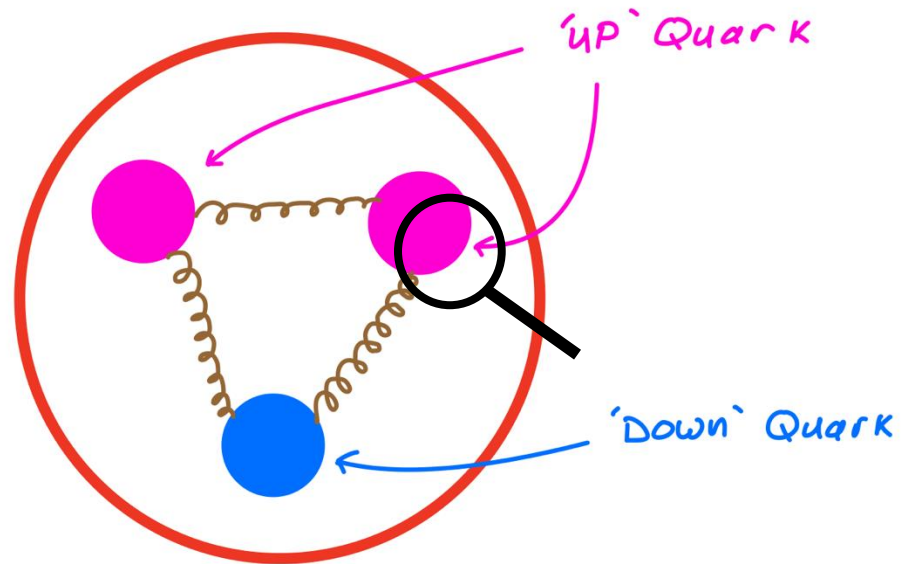
Looking Closer at Matter...



Quarks

Protons and Neutrons are made up of 'quarks'.

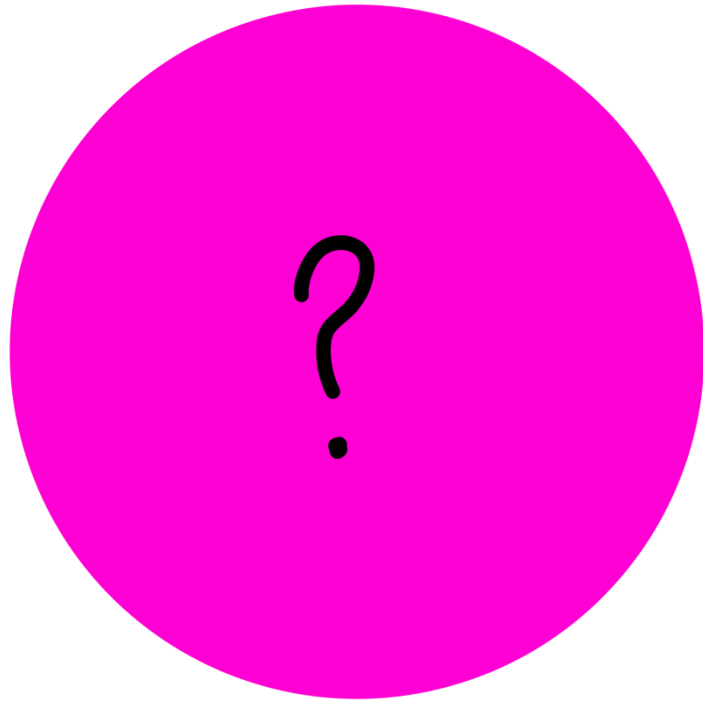
Looking Closer at Matter...



Quarks

Protons and Neutrons are made up of 'quarks'.

But what are quarks made of?!



Looking Closer at Matter...

Beyond Quarks?

“But what are quarks made of?!”

We don't know!

Quarks, '***just are***'!

Q U A R K S	<div><div>UP</div><div>mass $2,3 \text{ MeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$</div><div>u</div></div>	<div><div>CHARM</div><div>$1,275 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$</div><div>c</div></div>	<div><div>TOP</div><div>$173,07 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$</div><div>t</div></div>	<div><div>GLUON</div><div>0 0 1</div><div>g</div></div>	G A U G E B O S O N S	<div><div>HIGGS BOSON</div><div>$126 \text{ GeV}/c^2$ 0 0</div><div>H</div></div>
	<div><div>DOWN</div><div>$4,8 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$</div><div>d</div></div>	<div><div>STRANGE</div><div>$95 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$</div><div>s</div></div>	<div><div>BOTTOM</div><div>$4,18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$</div><div>b</div></div>	<div><div>PHOTON</div><div>0 0 1</div><div>γ</div></div>		
	<div><div>ELECTRON</div><div>$0,511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$</div><div>e</div></div>	<div><div>MUON</div><div>$105,7 \text{ MeV}/c^2$ -1 $\frac{1}{2}$</div><div>μ</div></div>	<div><div>TAU</div><div>$1,777 \text{ GeV}/c^2$ -1 $\frac{1}{2}$</div><div>τ</div></div>	<div><div>Z BOSON</div><div>$91,2 \text{ GeV}/c^2$ 0 1</div><div>Z</div></div>		
	<div><div>ELECTRON NEUTRINO</div><div>$<2,2 \text{ eV}/c^2$ 0 $\frac{1}{2}$</div><div>ν_e</div></div>	<div><div>MUON NEUTRINO</div><div>$<0,17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$</div><div>ν_μ</div></div>	<div><div>TAU NEUTRINO</div><div>$<15,5 \text{ MeV}/c^2$ 0 $\frac{1}{2}$</div><div>ν_τ</div></div>	<div><div>W BOSON</div><div>$80,4 \text{ GeV}/c^2$ ± 1 1</div><div>W</div></div>		
	L E P T O N S					

What other things *‘just are’*?

*‘The Standard Model of
Elementary Particles’*

If you were cooking up a Universe
from scratch, this would be you list
of ingredients.

The Particle Physicists Mantra:

“To discover the basic building blocks of all the matter in the Universe, and to understand how these building blocks fit together.”



Q U A R K S	UP mass 2,3 MeV/c ² charge 2/3 spin 1/2 		CHARM 1,275 GeV/c ² 2/3 1/2 		TOP 173,07 GeV/c ² 2/3 1/2 		GLUON 0 0 1 		HIGGS BOSON 126 GeV/c ² 0 0 	
	DOWN 4,8 MeV/c ² -1/3 1/2 		STRANGE 95 MeV/c ² -1/3 1/2 		BOTTOM 4,18 GeV/c ² -1/3 1/2 		PHOTON 0 0 1 		G A U G E B O S O N S	
	ELECTRON 0,511 MeV/c ² -1 1/2 		MUON 105,7 MeV/c ² -1 1/2 		TAU 1,777 GeV/c ² -1 1/2 		Z BOSON 91,2 GeV/c ² 0 1 			
	ELECTRON NEUTRINO <2,2 eV/c ² 0 1/2 		MUON NEUTRINO <0,17 MeV/c ² 0 1/2 		TAU NEUTRINO <15,5 MeV/c ² 0 1/2 		W BOSON 80,4 GeV/c ² ±1 1 			
	L E P T O N S									

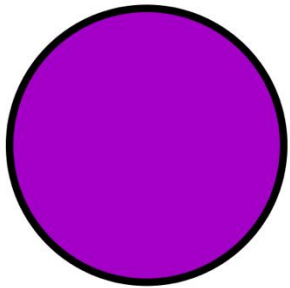
So... is that it?

Does ‘*The Standard Model*’ tell us about all the different kinds of matter in the Universe?

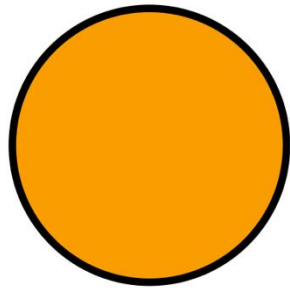
Question: Is that everything? Can you name a kind of matter not shown here?

Not even nearly!

Anti-matter

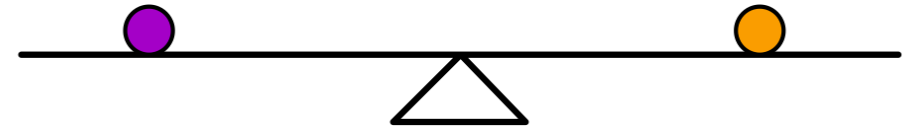


Electron

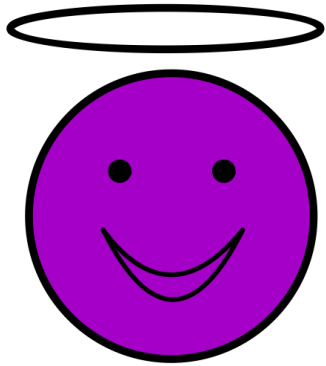


*Anti-Electron
"positron"*

Anti-matter weighs the same as normal matter, but some properties are reversed.



Anti-matter



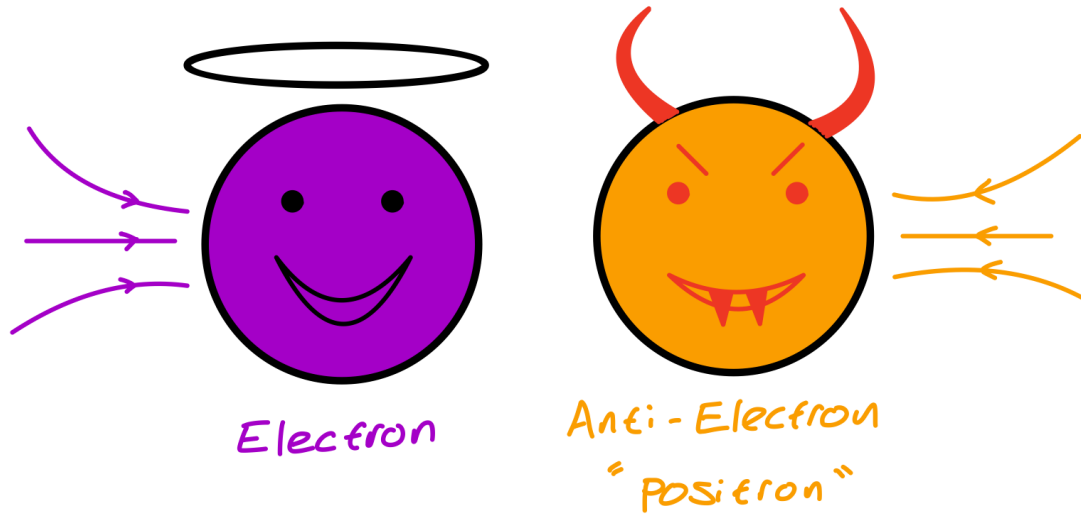
Electron



*Anti-Electron
"positron"*

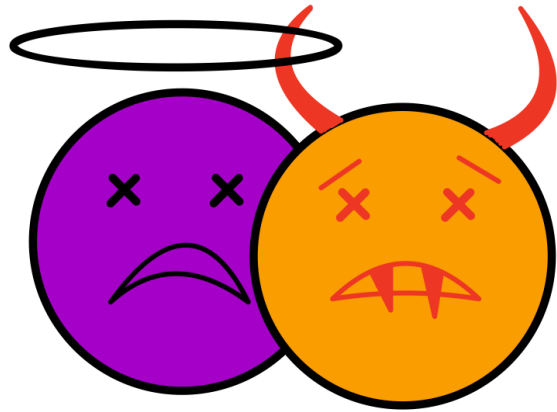
Anti-matter is a bit like matter's evil twin!

Anti-matter

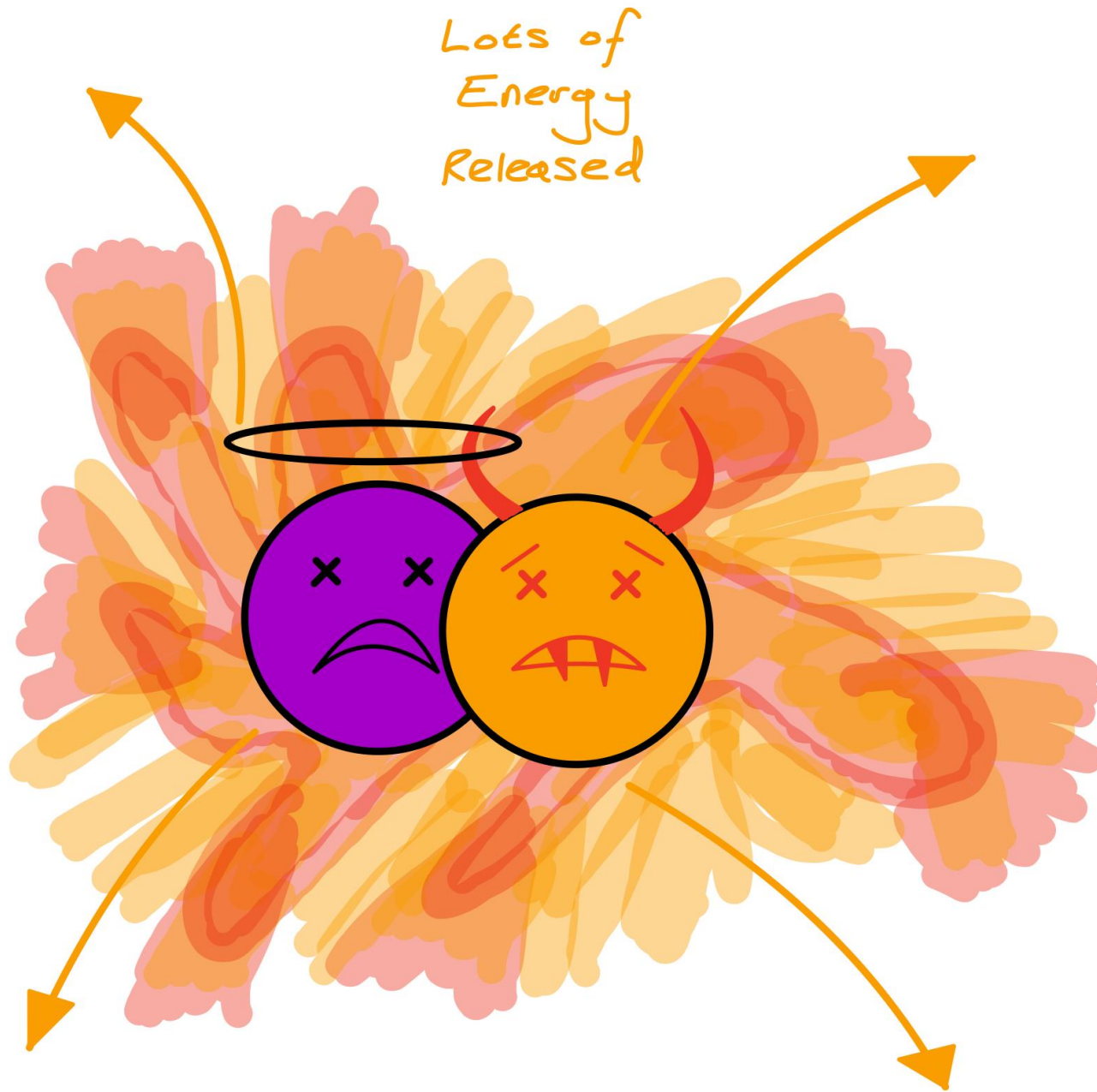


What happens when matter and anti-matter meet?

Anti-matter

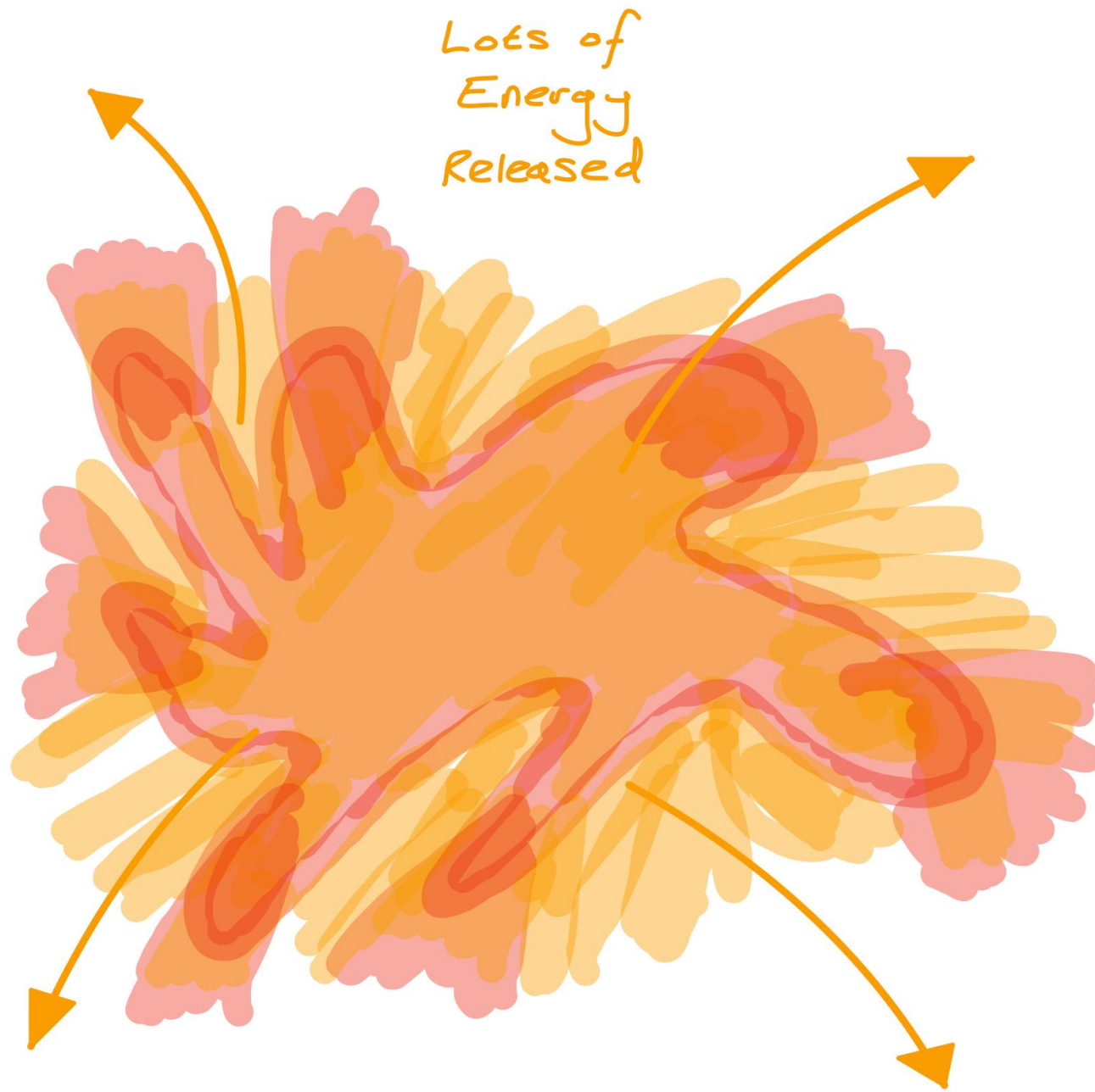


When matter and anti-matter touch,
they **ANNIHILATE**.



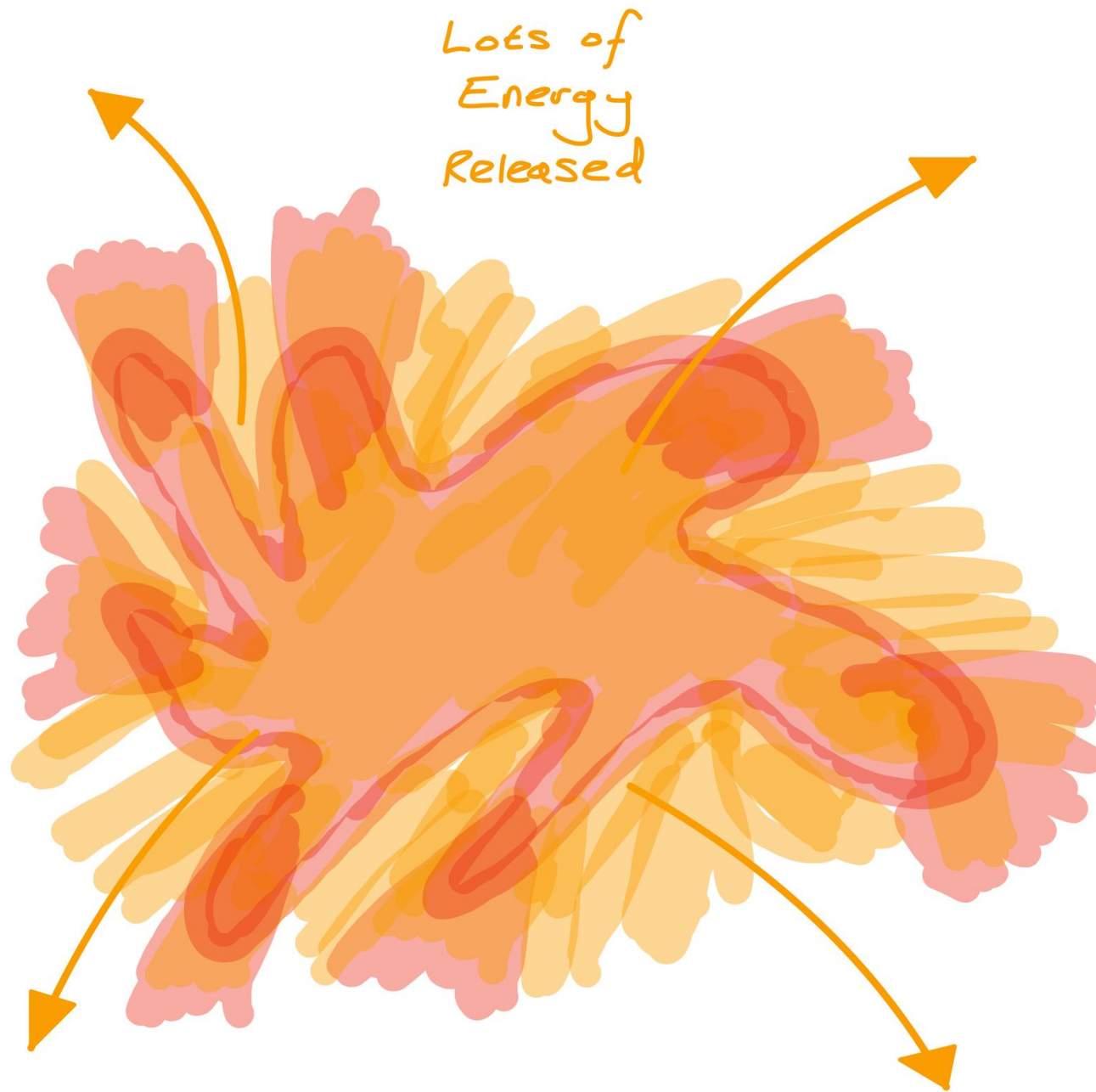
Anti-matter

Annihilation destroys the particles, and causes **HUGE** amounts of energy to be released.



Anti-matter

Annihilation destroys the particles, and causes **HUGE** amounts of energy to be released.



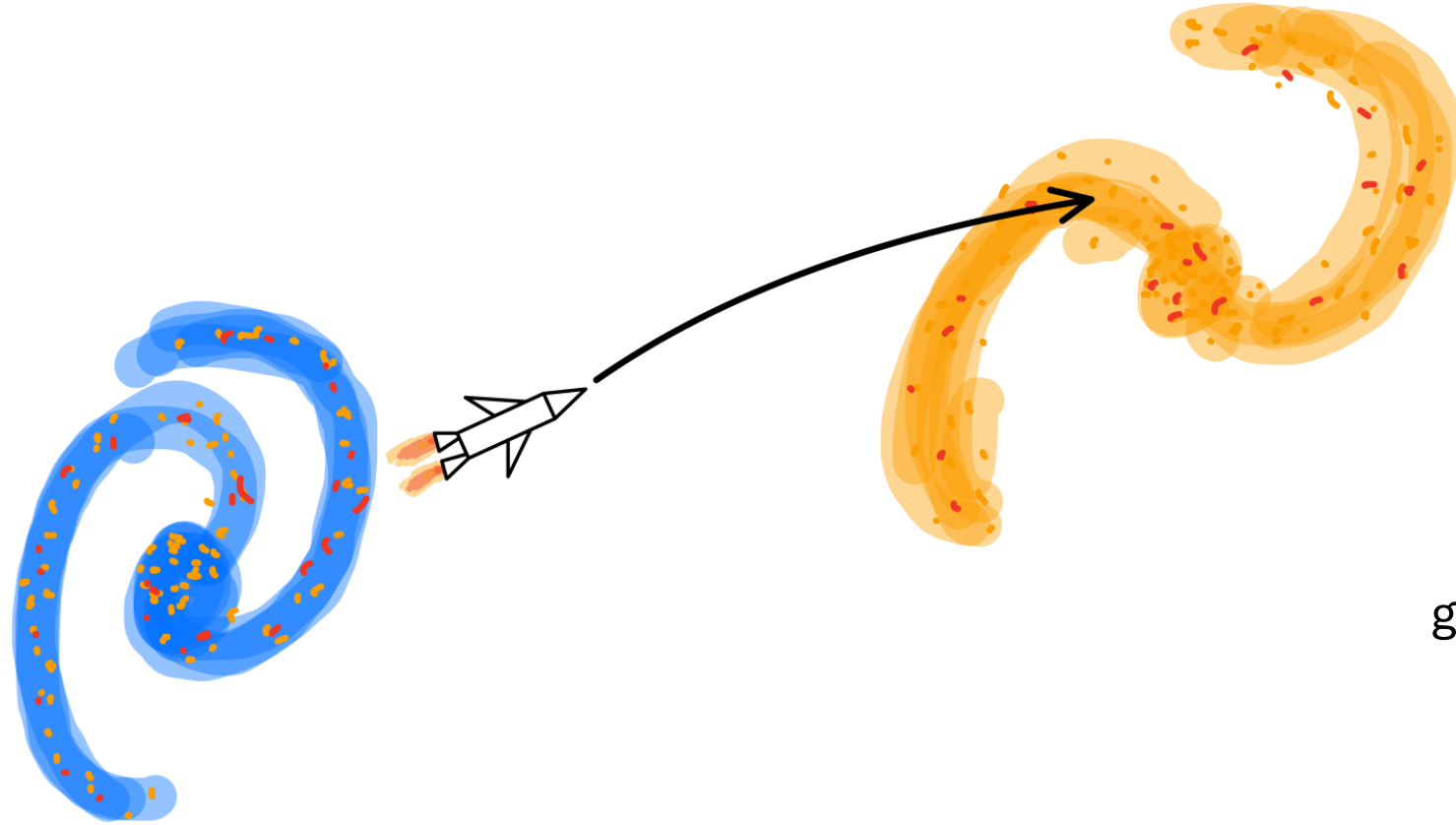
Anti-matter

How much Energy?

We need Einstein's famous formula:

$$E = mc^2$$

"Energy = mass annihilated, times the speed-of-light squared"



Anti-matter

If humans ever develop the technology to travel to other galaxies, we will probably need anti-matter to power our spacecraft.

Question: What is a galaxy?

Anti-matter Generator

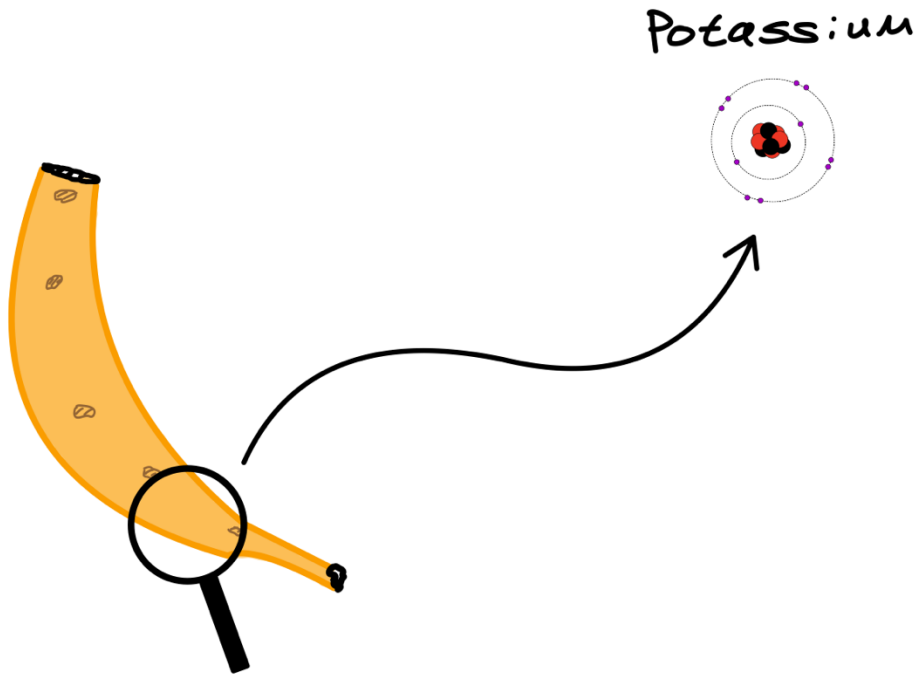
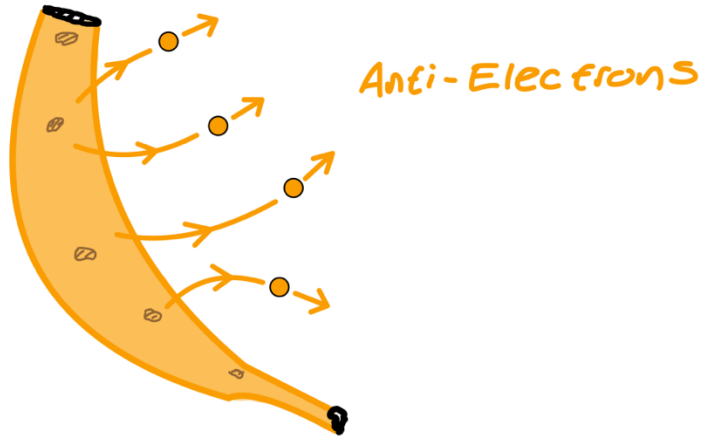
Who will volunteer to help me take out my anti-matter generator?

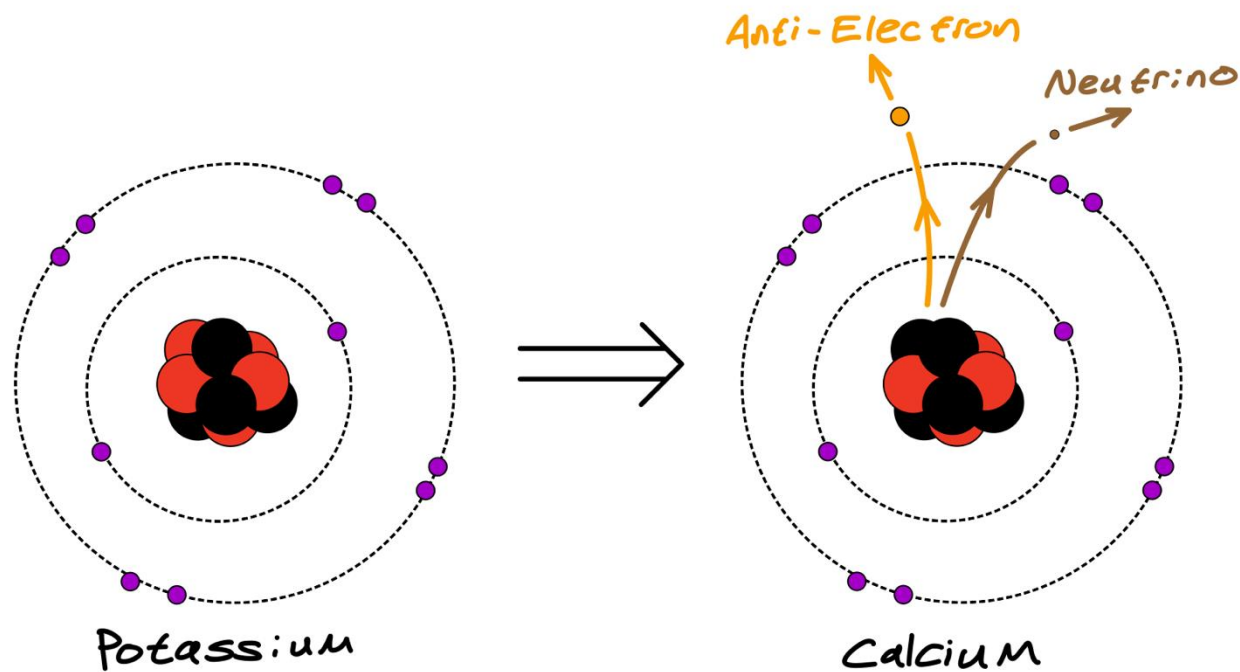
Anti-matter

The Science of our 'Anti-matter Generator'

Bananas emit **anti-electrons**!

This is because they contain potassium atoms, which are slightly radioactive.





Anti-matter

The Science of our 'Anti-matter Generator'

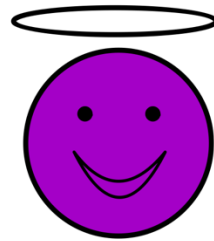
The radioactive potassium atoms decay into calcium atoms.

In this process, they release a very tiny amount of anti-matter!

QUARKS	<div>UP mass 2,3 MeV/c² charge 2/3 spin 1/2 </div>	<div>CHARM 1,275 GeV/c² 2/3 1/2 </div>	<div>TOP 173,07 GeV/c² 2/3 1/2 </div>	<div>GLUON 0 0 1 </div>	<div>HIGGS BOSON 126 GeV/c² 0 0 </div>	
	<div>DOWN 4,8 MeV/c² -1/3 1/2 </div>	<div>STRANGE 95 MeV/c² -1/3 1/2 </div>	<div>BOTTOM 4,18 GeV/c² -1/3 1/2 </div>	<div>PHOTON 0 0 1 </div>	GAUGE BOSONS	
	<div>ELECTRON 0,511 MeV/c² -1 1/2 </div>	<div>MUON 105,7 MeV/c² -1 1/2 </div>	<div>TAU 1,777 GeV/c² -1 1/2 </div>	<div>Z BOSON 91,2 GeV/c² 0 1 </div>		
	<div>ELECTRON NEUTRINO <2,2 eV/c² 0 1/2 </div>	<div>MUON NEUTRINO <0,17 MeV/c² 0 1/2 </div>	<div>TAU NEUTRINO <15,5 MeV/c² 0 1/2 </div>	<div>W BOSON 80,4 GeV/c² ±1 1 </div>		

So... is *that* it??

Does the matter in the Standard Model + anti-matter cover everything there is in the Universe?



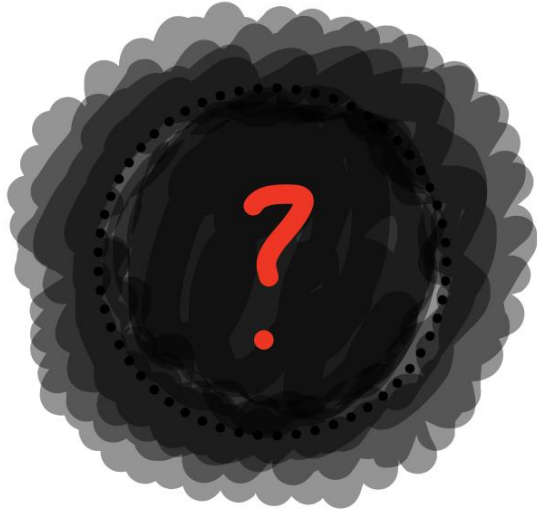
Electron



Anti - Electron
"positron"

Question: Is there more '*stuff*' in the Universe than we have discussed so far?

Still nowhere near!

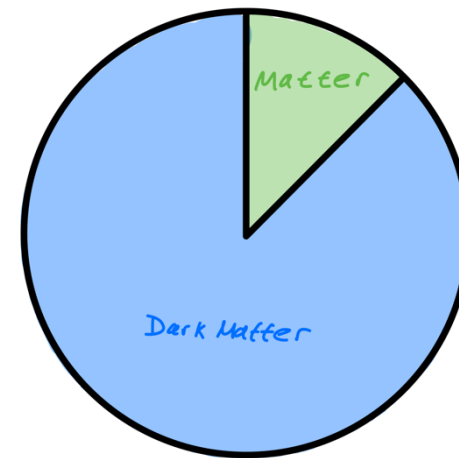


Dark Matter

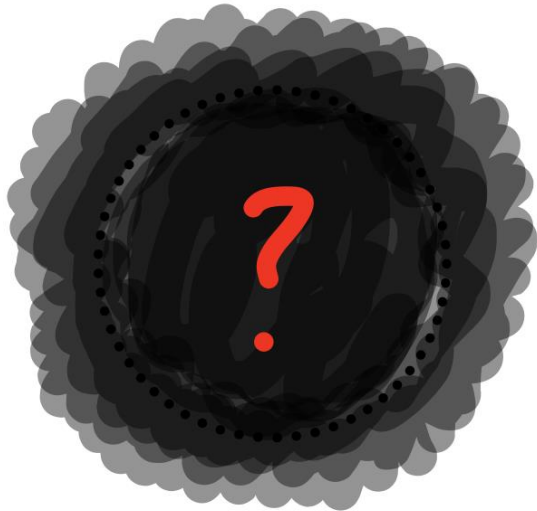
Dark Matter

About 85% of all of the matter in the Universe is totally mysterious, and completely invisible.

We call this '***Dark Matter***'.



Dark Matter



Dark Matter

**If it's invisible, how do we know
it's there?**

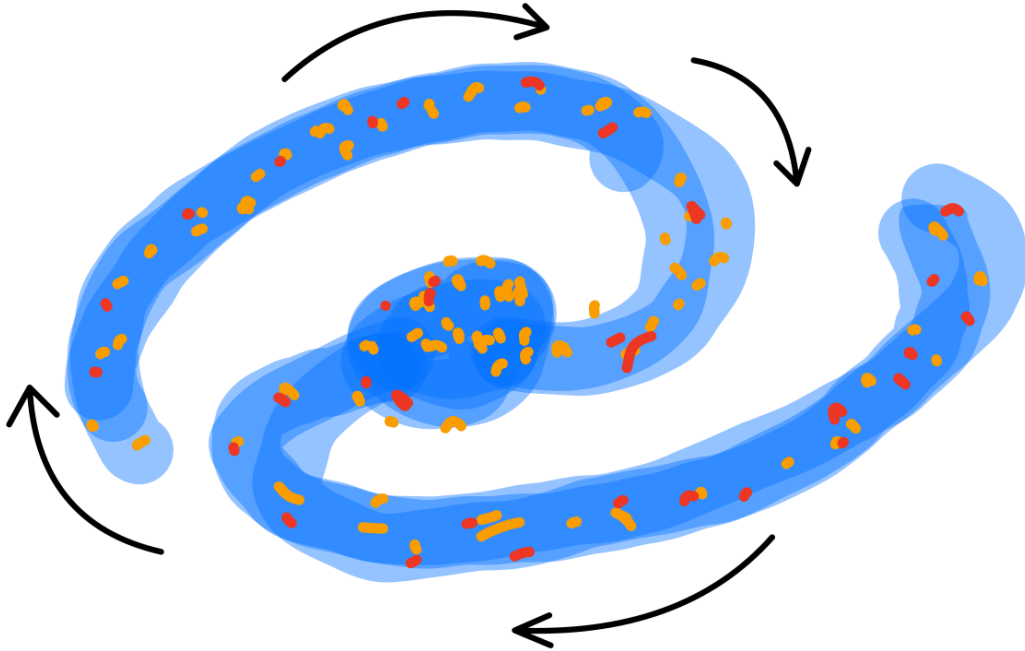


Dark Matter

We know from looking at all the galaxies in the night sky!


Question: What is the name of the galaxy we live in?

Dark Matter



The way galaxies spin means there is a lot of extra weight in addition to the stars and planets we can see.

This extra weight comes from
Dark Matter.



**Some real
galaxies!**

Our galaxy contains over one
hundred billion stars!

Question: How many galaxies are there in the Universe?

“How do I become a Particle Physicist?”

- Work hard in Science and Maths lessons.
- Be curious and ask questions.
- Learn to enjoy solving tough ‘*problems*’.
- Believe in yourself! Anyone can be a scientist!

Questions!

Ask me anything you like!

If you don't want to ask me a question right now, you can send me an email to my KES address

I really want to hear your questions about the Universe!

robertclemenson@kes.essex.sch.uk

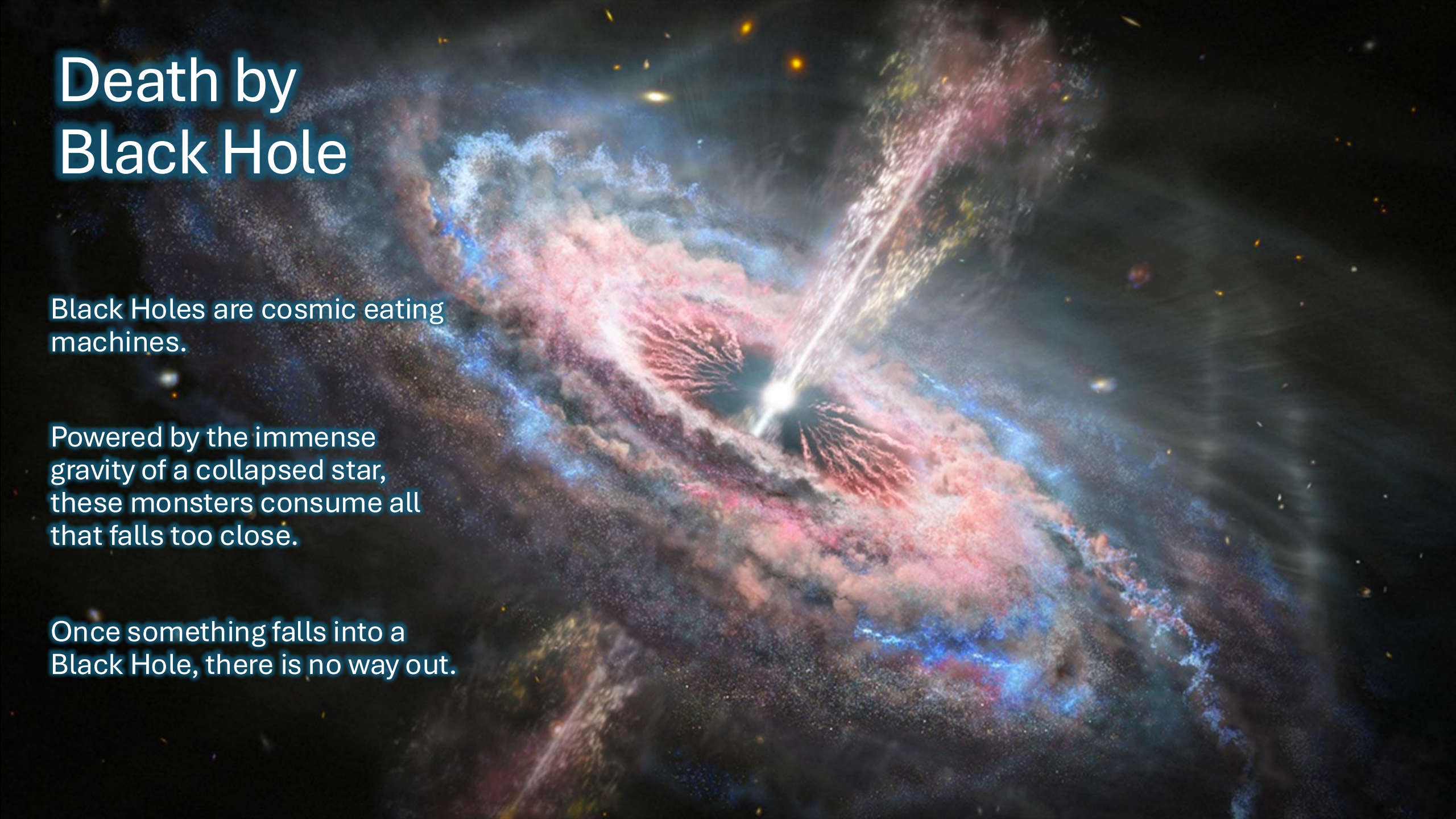
(Bonus Slides)

Death by Black Hole

Black Holes are cosmic eating machines.

Powered by the immense gravity of a collapsed star, these monsters consume all that falls too close.

Once something falls into a Black Hole, there is no way out.



Death by Black Hole



Black Holes are cosmic eating machines.

Powered by the immense gravity of a collapsed star, these monsters consume all that falls too close.

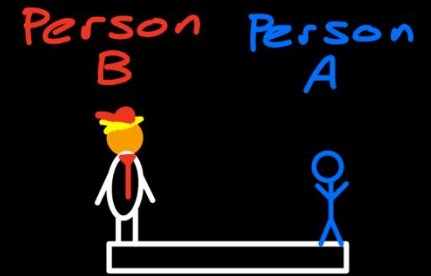
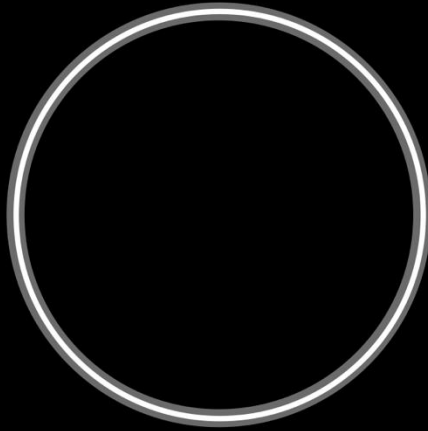
Once something falls into a Black Hole, there is no way out.

Black Holes are also natural time machines...

Time passes more slowly for people trapped near the horizon of a Black Hole.

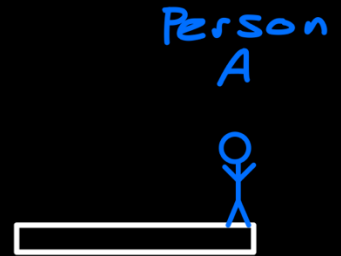
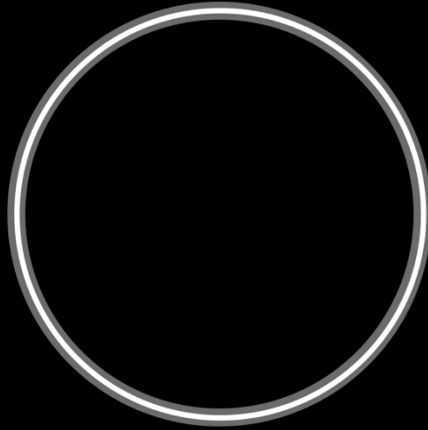
Death by Black Hole

Person A pushes Person B
into a black hole.



Death by Black Hole

Person A pushes Person B
into a black hole.



Let's consider how this
looks to each person
involved...

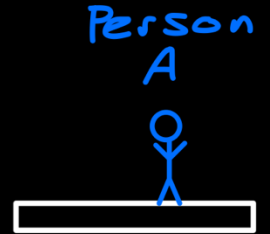
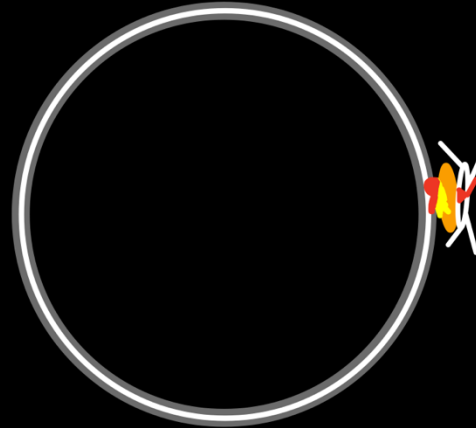
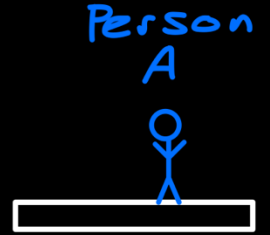
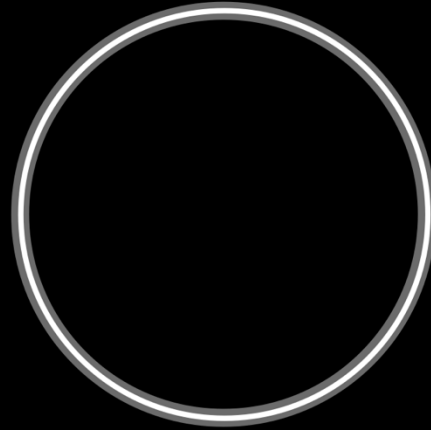
Death by Black Hole

Person A's POV

From Person A's POV,
person B never crosses
the event horizon.

Instead, Person B smears
along the horizon,
become flatter and flatter
over billions of years.

Person A's P.O.V



Death by Black Hole

Person B's POV

From Person B's POV, they pass through the horizon without much difficulty.

If the black hole is very small, they will be 'spaghettified' by the fall.

As Person B looks back at Person A, A begins to age rapidly.

