Subatomic Particles

in collaboration with

developed by

A. Quantum fields

From the main room, follow the ***purple path*** *on the right. Talk to the scientist in the first room to get instructions on how to shrink down to the quantum dimension.*

Once there, collect the subatomic particles using the 'Particle Extractor'.

Task A1 Make sure to collect all the particles and write them into the correct row of the table below:

Group	Quantum Fields	Particle and Anti-Particles
Matter Particles	Up Quark Quantum Field	
	Down Quark Quantum Field	
	Electron Quantum Field	
	Neutrino Quantum Field	
Messenger Particles	Photon Quantum Field	
	Gluon Quantum Field	
	Weak Quantum Field	

Did you know

In Minelabs we represent the quantum fields as clouds. In reality, quantum fields do not look like this. Each type of quantum field extends throughout space and time. A quantum field is everywhere and always present.

Elementary particles are disruptions of the quantum fields. You can compare this with fog. The quantum fields fill the entire space like a fog. A particle is formed by compressing the mist somewhere to form a droplet. Elementary particles are thus like droplets in the mist.

Go back into your normal size when you collected all the particles. Talk to the scientist. When you have completed the task, you can continue in the next room.

B. Matter Particles

Task B1 Fill out the sentences below.

- Some quantum fields produce two particles at a time. These are combinations of a **matter particle** and an ___________**-matter particle.**

Talk to the scientist and start experimenting with the given particles. Observe how the particles interact with each other.

- Place an electron right next to its anti-particle. When a particle and an anti-particle touch each other, then ____. The particles disappear and in their place two ________________ appear.

Task B2 Write the combinations of matter particles you obtained from the quantum field in the table.

Matter particle	____________**-matter particle**

Did you know

Now you know that quantum fields are constantly forming particles, you could ask yourself: "Will the matter in the Universe only increase?"

No, because matter and anti-matter particles are always formed in pairs at the same time. They immediately annihilate each other and disappear immediately. During the Big Bang, the matter particles that were formed back then survived and still exist around us! Scientists think that the space between the particles expanded so fast that the matter particles became isolated from the anti-matter particles. They probably did not get the chance to annihilate.

C. Messenger Particles

Some quantum fields only produce one particle at a time. These are messenger particles. The messenger particles convey messages between other particles on how they should behave or interact. Depending on the type of messenger particle, this message can be '**attraction**' →←, '**repulsion**' ←→ or '**change**' ⇆.

Messenger particle
Photon
Gluon
Weak Boson

D. The Gluon and the Strong Interaction

Go to the next room, talk to the scientist and get introduced to the gluon and its strong interactions. You will obtain all the possible gluons and quarks.

Task D1 Place three gluons and two types of quarks in the crafting table, like the pattern on the wall. What is the result from the various combinations of quarks? Try to produce new particles and write the recipes in the table below. Is there a pattern in the colour of the quarks you combine?

Quark	3 Gluons	Quark	Result
Up Quark Red	*3 Gluons*	*Anti Up Quark Red*	*Pion Null*

Task D2 Select the correct option in the sentence below.

- The gluon is *a matter particle / messenger particle* from the *strong / weak* interaction. The message of the gluon is always *attraction / repulsion* between *quarks / electrons*, you can say it 'glues' them firmly together

In Minelabs the quarks always have one specific colour, but the gluon has an icon with many different colours. In reality, the quarks and gluons themselves are not coloured, but they have a **color charge.**

Task D3 Select the correct option in the sentences below.

- With two quarks and gluons you can make ______________________________________.
- If one quark has a certain **color charge** (red, green or blue) then the other quark has to be ______________________________________.
- The resulting color of the combination of quarks and gluons is _____________________.

After finishing the above tasks, you can go to the next room. There will be a blackboard on the wall, which shows you the next recipes. Talk to the scientist to get your next tasks.

Task D4 Place 3 gluons and 3 quarks of different types on the crafting grid. Which combinations of quarks results in useful recipes? Write down as many possible in the table below.

Quark	3 Gluons	Quark	Quark	Result
Red down quark	*3 Gluons*	*Blue up quark*	*Green up quark*	*Proton*

When you combine a color charge with its anti-color, you obtain a color neutral '**white**' particle. For example, if you combine a blue quark with an anti-blue quark (yellow colour in the game), you get a 'white' particle as a result. All the pions thus have a neutral, white color. When you put three quarks together, their colors should also combine to the neutral, white color.

Task D5 Fill out the sentences below.

- With three quarks and gluons you can make ______________________________.
- You can always make a combination of the colors _______________,
  _________________ and __________________ to obtain matter particles.

Did you know

You may have noticed that you cannot place quarks in the Minelabs world. That's because a color charge can never occur alone. Only a particle with a combination of colors that is white can exist and be placed in the Minelabs world

After finishing the above task, you can enter the next room. Talk to the scientist to get informed about your next task. Task D6 is optional.

Did you know

- In Minelabs, we coloured the quarks with red, green and blue, the anti-quarks are coloured in cyan, magenta and yellow. This corresponds to the **color charge** property of the quarks. Quarks also have another charge, the **electrical charge**. In the bonus task below, *task D6*, you will investigate the electric charge of the quarks

- The electrical charge of an up quark is **+2/3**, the down quark has an electrical charge of **-1/3**. The anti-particles have opposite charges, for both the color and the electric charge. The electric charge of an anti-up quark is -2/3 and an anti-down quark has charge +1/3.

- When combine charged particles, the resulting charge is the sum of the loads.

Task D6 Enter the names and electrical charges of the combined particles in the table below.

	Particle 1	Particle 2	(Particle 3)	Result
Name	*Up Quark*	*Anti-up Quark*		*Pion Null*
Charge	*+2/3*	*-2/3*		*=0*
Name				
Charge				
Name				
Charge				
Name				
Charge				
Name				
Charge				

E. The Weak Boson and the Weak Interaction

After completing the previous tasks correctly, you can continue in the next room about the weak boson. Talk to the scientist, you receive some weak bosons and some matter particles.

The **weak boson** is a **messenger particle.** The message of the weak boson is **'change'** ⇆. The weak boson causes particles to change into other particles. This phenomenon is called the **weak interaction.**

You can combine matter particles into weak pairs. The two particles in a weak pair will change into each other under the influence of the weak interaction.

Task E1 Place a weak boson with a matter particle on the crafting table. Complete the table below.

Matter particle	**Weak partner**
Up quark	
Electron	
Anti-up quark	
Positron	

Did you know

Is it not strange that particles can change? This bizarre change is the basis of radioactivity.

Task E2 Complete the sentences below.

- When a matter particle absorbs or emits a weak boson, the matter particle changes into its ______________________________.
- The message of the weak boson is ______________________.
- This phenomenon is described as the ____________ interaction.

F. The Photon and the Coulomb Interaction

After completing the tasks for the weak boson, you can talk to the scientist again. You will receive electrons and protons.

The photon is the messenger particle of the electromagnetic force, which is responsible for the phenomena of electricity and magnetism. The photon carries a message between particles with an electric charge, such as the electron. The message of the photon is '**attraction**' →← or '**repulsion**' ←→ between electrical charges. Electrons have an electric charge of **-1**, while protons have an electric charge of **+1**.

Did you know

In Minelabs we do not consider magnets or magnetic forces. We limit ourselves to the forces between electric charges – this force is called the Coulomb force.

Task F1 Place the electrons and protons on the ground and investigate how they influence each other

Did you know

You can't see this in Minelabs (or in real-life), but the charged particles exchange photons. An electron pulls photons from the ever-present quantum field and throws the photons away. When another electron captures the photon, it receives the message of repulsion. The photon disappears back into the quantum field. It is as if the electrons are having a snowball fight: they continuously pick up snowballs (photons) from a snow carpet (quantum field), and after the snowball is broken, the snow disappears back into the snow carpet.

Task F2 Do the particles attract or repel each other?
Complete the sentences below with **'attraction' →←** or **'repulsion' ←→**.

- When the photon is exchanged between particles that are both positive, the message is ______________________________.
- When the photon is exchanged between particles that are both negative, the message is ______________________________.
- When the photon is exchanged between particles of opposite electrical charge (one positive and one negative), the message is ______________________________.

G. The Standard Model

Go to the next room. Take a look at all of the particle pinboards on the wall. If you interact with them, you will see more information about each of the particles.

Task G1 Complete the table below. What is the symbol, the possible color- or electrical charge, the weak partner or the message of the particles?

The different matter particles

	Up quark	Down quark	Electron	Neutrino
Icon				
Color Charge				
Electrical charge				
Weak partner				

The different messenger particles

	Gluon	Photon	Weak boson
Icon			
Color charge			
Electrical charge			
Message			

H. The Gravitational Force

Walk to the next room. You will find a model of our solar system there.

There is no known messenger particle for gravity. The gravitational force is therefore not transferred by a particle, but works in a completely different way than the other forces.

Task H1 Talk to the scientist, complete the sentence below.

- The gravitational force attracts particles that have ____________________, you can say that this is the charge for the gravitational force.

Task H2 Complete the sentence bellow with **'attraction' →←**, **'repulsion' ←→** or **'change' ⇆**.

- Just like the strong interaction, the message for the gravitational force is always _____________________________.

Did you know

The gravitational force is caused by mass, such as that of an apple, planet or star.

This is the same mass as in Newton's second law, force equals mass times acceleration.

$$\vec{F} = m\,\vec{a}$$

Is this not weird? One 'mass' is the charge of the gravitational force, the other 'mass' is inertia or 'how hard it is to move something'. Einstein though this was no coincidence, and built his theory of General Relativity on this weird equivalence.

This theory describes gravity as the curving of 'space-time'. If you have some mass, such as an apple, planet or star, this will curve this 'space-time'. Another mass will then experience this curvature and adjusts its motion. The other mass will fall towards the first mass (that apple, planet or star). Of course, this goes both ways: both masses fall towards each other and feel an effective attractive force between them.

You finished the lesson about Subatomic Particles! You can either talk to the scientist and get back to the start or just continue experimenting.