The subatomic structure of matter

Annotated learning unit

Key Idea I
Matter is everything that can be touched, practically or theoretically.

Matter is everything that can be touched. For example, a table, a chair, we humans, everything is matter. Everything that can be touched, practically or theoretically, is matter. Even air is matter. Indeed, this might sound a little bit strange, but we touch air all the time. We might not notice it every time, but on a windy day, one can easily see that we can touch the air and thus it is also matter.

Everyday examples of matter

Air as a less concrete example of matter

But what is matter? How can we picture what matter is made of?

Key Idea II
Reality is described through models. For example the model of particle physics.

Key Idea III
In the model of particle physics, there are atoms, which may combine to form compounds.

This question has been with us for more than 2500 years. At that time, as now, we can only use models to explain and describe nature. For we always describe reality through models. In ancient Greece, the thinker *Democritus* set the best models so far to describe what matter is. According to this model, matter consists of indivisible units, which he called atoms. In Greek, "*átomos*" means indivisible and that's how Democritus imagined these atoms. Everything consists of tiny, indivisible atoms that can connect with each other.

Multiple references to the model aspect of particle physics as one of the main pillars of the learning unit

Embedding in historical context and etymological explanation

Key Idea IV
In this model, atoms are divided into two areas:the nucleus-space and the orbital- space.

This model is now very old, but as it has been proven to be very accurate, it is still used in particle physics. However, we have already discovered that atoms are not indivisible! Indeed, atoms can be divided into two areas. According to the model of particle physics, we can distinguish a tiny nucleus-space and a relatively large orbital-space all around.

Linguistic accuracy: “nucleus-space” instead of ~~the nucleus~~, “orbital-space” instead of ~~the atomic shell~~

Qualitative distinction of the two areas by means of a typographic illustration of the atomic model

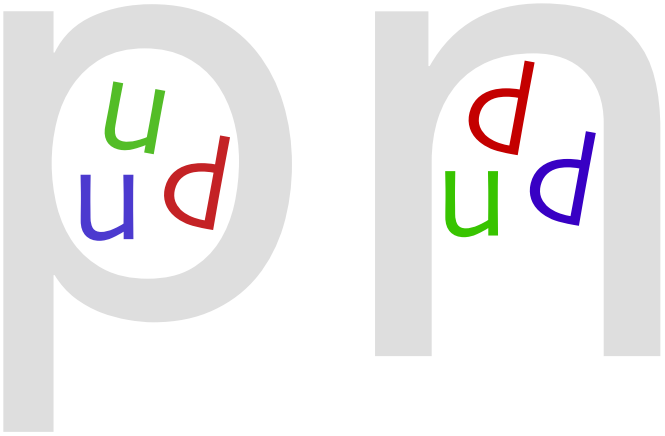
Key Idea V
In the nucleus-space, protons and neutrons are located.

Key Idea VI
Protons and neutrons are particle systems, which are made of quarks.

Key Idea VII
Quarks are indivisible. In this model, these are called elementary particles.

In the tiny nucleus-space, so-called protons and neutrons are located. These are particle systems that are only found in the nucleus-space. According to the model, these protons and neutrons are each made of three particles. These particles are called quarks. And according to the current state of research, they are indivisible. Therefore, in the model of particle physics, they are called elementary particles.

Linguistic accuracy: protons and neutrons as “particle systems, which are made of particles” instead of ~~particles containing particles~~



Typographic illustration of proton and neutron as particle systems

Elementary particles are drawn in colour, while particle systems are grey. Red, green, and blue are reserved for quarks, to set up the notion of colour charge

Key Idea VIII
In the orbital-space, it is likely to find electrons.

Key Idea IX
Electrons are indivisible. In this model, these are called elementary particles.

In the huge orbital-space, it is likely to find other particles, called electrons. As far as we know, these electrons, like quarks, are indivisible. They are, therefore, also called elementary particles. These electrons are always located somewhere in the orbital-space, while the quarks are always found in the nucleus-space.

Linguistic accuracy: “in the orbital-space, it is likely to find electrons” instead of ~~electrons are in the atomic shell~~

nucleus-space	orbital-space
*u*d	e

After all, an atom, as *Democritus* hat imagined it more than 2500 years ago, is not indivisible. But it is made of indivisible particles. But it is made of indivisible particles. It is made of the quarks that form the protons and neutrons in the nucleus-space and of the electrons that can be found somewhere in the orbital-space.

Short summary and final review on *Democritus*

Key Idea X
In this model, apart from particles, there is only empty space.

According to the model of particle physics, apart from these tiny, indivisible particles, there is only empty space. Nothingness. Everything, the table, the chairs, we humans, the earth, everything is made of an incredible amount of elementary particles and much more emptiness.

Introduction of empty space as “opponent” of elementary particles

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