

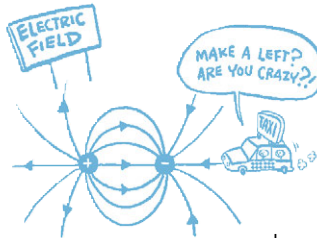
Light

Ripples in the Electromagnetic Field

What is light, precisely? Well, light is a specific kind of electromagnetic radiation. By that we mean “ripples in the electromagnetic field”.

The Electric Field: To Charge or Not to Charge, That is the Question

Let us first explain the electric field: Well, you know that things can be electrically charged, either positively or negatively. Things with similar charges repel each other, while things with opposite charges attract each other. So, electrically charged matter always feels a force, coming from all the other charged things in the universe. This force field (physicist call this a “field” because it is everywhere) is called the electric field. You can think of it as the GPS for charged particles – it tells them where to go next.



Magnets – How Do They Work?

The magnetic field is a bit more difficult to understand. Things can also carry a magnetic charge, we then call them “magnetized”. But the magnetic charge is not just a number, like the electric charge. Rather, it has a strength, and at the same time also a direction. You can think of this as a little arrow attached to the magnetized object – the arrow points away from the North Pole and towards the south pole of the magnet, and the longer the arrow the stronger the magnet. Just as electric charges try to push charged particles around, so do magnets. But

while electric charges exert a force on charged particles simply because they are charged, magnets only act with a force on them (the so-called Lorentz force) if they move. So as long as a proton sits perfectly still, a magnet cannot push it around. Only when the proton starts to move somewhere – maybe because of the electric field – will the magnets be able to change its path.

Two Sides of the Same Coin: The Electromagnetic Force

The magnetic force has been known for thousands of years, as long as people realized that needles made of certain metals always point into the same direction – the North Pole. The ancient Greeks also knew about the electric force. They observed that by rubbing amber on animal fur caused little crackling sparks (which we nowadays call “electric discharges”). In fact *ἤλεκτρον*, or “*ēlektron*”, is the ancient Greek word for amber.

But it wasn’t until the end of the 19th century, when English scientist James Clerk Maxwell found out that the two belong together. They are just two different phenomena of the same physical interaction, which we nowadays call “the electromagnetic field”. The electric and magnetic force belong together inseparably. The famous equations which made J.C. Maxwell immortal in fact state that a changing electric field causes a magnetic field – which is why a spinning electric charge behaves like a magnet (↻¹).

↻¹: “Spin” on page 187

But conversely, a changing magnetic field causes an electric field – which is why a rotating magnet is used in every kind of power plant to push electrons through wires (in other words: generate electricity).

So if you disturb the electric field, this generates a change in the magnetic field, which in turn again changes in the electric field – in the opposite direction of the initial disturbance. This is also called “Lenz’ rule”. For the magnetic field precisely the same is happening, which is why the electromagnetic field is a bit like an elastic rubber sheet: if you poke at it, it wants to get back into its original form, if possible. But this going back to its original form doesn’t happen right away, but takes some time. Which is why a disturbance in the electromagnetic field – like a ripple in the rubber sheet – will spread out, oscillating back and forth. These wave-like ripples propagate in all directions with a very specific speed. They are called “electromagnetic waves”, and the speed is the well-known speed of light.

The Electromagnetic Spectrum: Size Does Matter

Although the speed of these waves is always the same, the frequency with which they make the electromagnetic field oscillate, can be different. The faster they jitter back and forth (and thus, the shorter their wavelength), the more energy is stored in them.

The longest waves are the long radio waves. Their wavelength is above a kilometer (i.e. roughly a mile). The shortest of those are the waves we actually use in our radios: AM waves are a kilometer up to a hundred meters long, while FM waves are about one to ten meters in length. The next shorter waves are called microwaves, and their wavelength is from a meter down to a millimeter. The ones in your microwave oven are actually about 12 cm, or 4.7 in. This

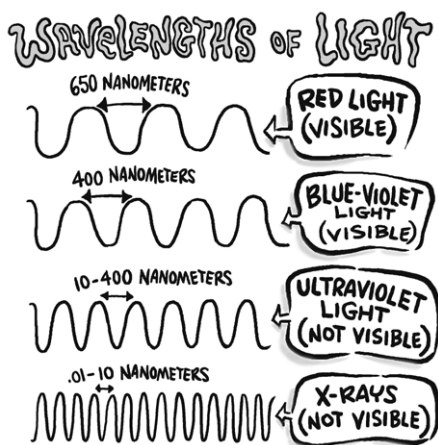
is not yet very energetic at all, but coincidentally it is precisely the energy of a quantum transition in water molecules, which is why these waves are ideal to heat up anything that contains water.

The electromagnetic waves from about one to about a hundred micrometers are called infrared (IR) radiation. This radiation is not visible to the human eye, but we can feel it, as being warm. Put your hand next to an oven or a roaring fire, and you

can feel the infrared radiation “first-hand”.

The IR ends where the visible light begins – the electromagnetic radiation from 700 nanometers (red) to about 390 nanometers (dark blue) is the visible light. Our human eyes are made so we can see this radiation. It is what we call light, and consists of those colors which you can see in a rainbow – ordered from red to blue.

We now come to more and more energetic waves. Beyond the color blue in the electromagnetic spectrum is the ultraviolet (UV) radiation. Their lengths



range down to about 10 nanometers, which is where the X-rays begin. X-rays have a wavelength down to 10 picometers (a trillionth of a meter). Although it can be quite useful in medical diagnostics, this kind of radiation is already so energetic that it can be dangerous if one overuses it.



It was around 50 years after J.C.Maxwell's ideas, that a young scientist made a remarkable discovery: He found that one cannot put arbitrarily little energy into an electromagnetic wave. Usually, the energy which is carried by it is determined by two factors: one is its wavelength, and the other one is its intensity, or its brightness.

And finally, everything with an even shorter wavelength than picometers is called γ -rays. This extremely high energy radiation reaches us from outer space, when stars explode (\nearrow^2), or when heavy atomic nuclei decay (\nearrow^3).

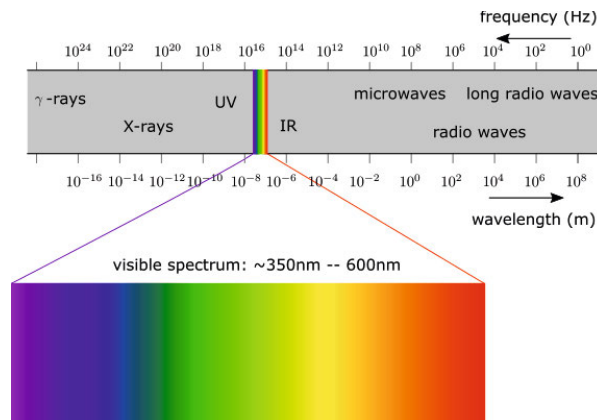
So It's a Wave – or Is It?!

From earliest times natural philosophers wondered about the nature of light. For quite some time, an idea that people had was that light consisted of tiny little particles, which were flying from objects into our eyes. However, its wave-like properties were understood around the 18th century, when natural philosophers discovered that light, just as water waves, can be refracted, aberrated and scattered. And with J.C.Maxwell in the

19th century, it became finally clear that light was a certain type of electromagnetic wave. The question of the nature of light seemed to be settled, and the idea of little “light particles” was finally buried. At least, this was what people thought these days.

Now this young scientist – his name was Albert Einstein – found that you cannot have an arbitrarily low intensity within an electromagnetic wave. Even more, the energy in a wave can only be transferred to other systems in packages of a fixed size, or quanta. These energy quanta are larger, the shorter the wavelength is. In other words, there can be two electromagnetic waves with the same energy – one very bright one with a long wavelength, and one very dim one with a short wavelength – but in

the first one there are many energy packages of small size, and in the second one there are only few packages, but each containing a lot of energy.



These energy packages are called photons. They can be thought of as tiny little particles which light (or any other kind of electromagnetic radiation) consists of. Einstein

later received the Nobel prize for this discovery, and this was the first clear example that a physical system can behave both like a wave and a particle. This is why Einstein is sometimes mentioned as one of the inventors of quantum theory (\nearrow^4).

\nearrow^2 : “Supernovae” on page 83

\nearrow^3 : “Alpha, Beta and Gamma Rays” on page 171

\nearrow^4 : “Wave-Particle Duality” on page 143

Quirky Quarks

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