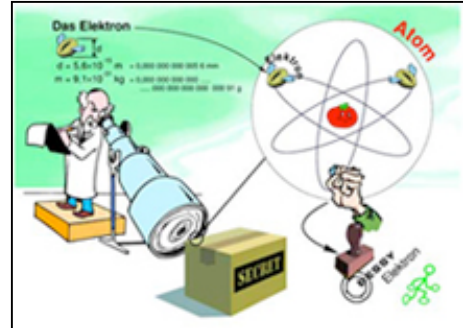


Accelerator Physics for pedestrians

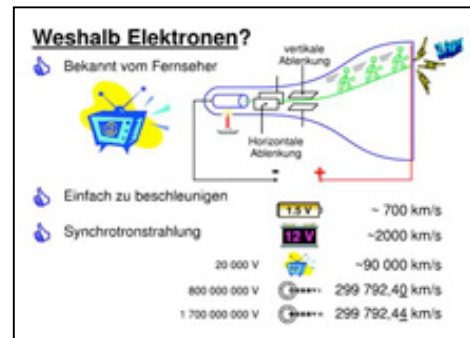
Electrons

At BESSY we accelerate electrons. Normally electrons are a part of atoms, the smallest part in which material can be splitted without changing its properties. Naturally electrons circle the nucleus of an atom. At BESSY some of these electrons are used to produce synchrotron radiation. For this, electrons are grabbed from an atom and then accelerated. standard operation at BESSY II requires roughly 12 billion (12,000,000,000) of accelerated electrons.



Why electrons?

Electrons are relatively easy to accelerate due to their high electric charge and their small mass. The best know example of an electron accelerator is the television. Within the tube of such, a device a metal rod is heated which causes electrons to be ejected out of the rod. These electrons are then accelerated by means of an electric potential (voltage). As such a simple 1.5 Volt battery is sufficient to accelerate the electrons up to a speed of 700 km/s. A normal color-TV employs 20,000 Volt, which is sufficient to accelerate the electrons to almost 90,000 km/s. At BESSY II we use 1,700,000,000 Volt which accelerates the electrons to a velocity of about 300,000 km/s, i.e., the velocity of light.



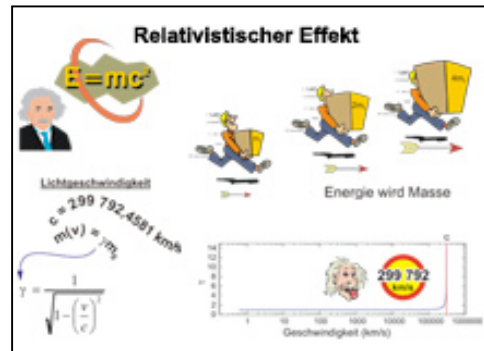
Speed

For synchrotron radiation the speed of the electrons is important. The time in which they reach their velocity is less important. The electrons at BESSY have a velocity of about 300,000 km/s, almost the velocity of light. At that speed one can fly to the moon in 1 second or, alternatively, orbit the earth 7.5 times per second.



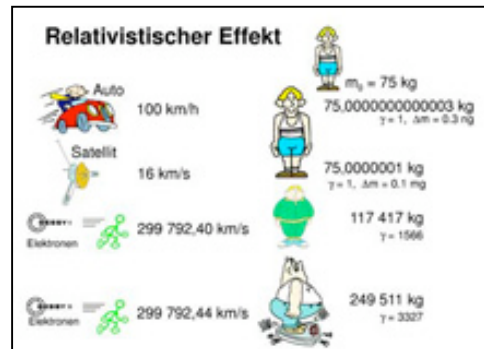
Relativity

Einstein has stated that the velocity of light is the maximum possible velocity. Particles with mass can come close to the velocity of light but can never actually reach it. If one approaches the velocity of light, the energy that normally is used for the acceleration, is converted into mass. The mass increase is expressed with the Lorenz factor gamma. In the figure the increase in mass is expressed by the growth of the box carried by the man. The Lorenz factor is important for the properties of synchrotron radiation.



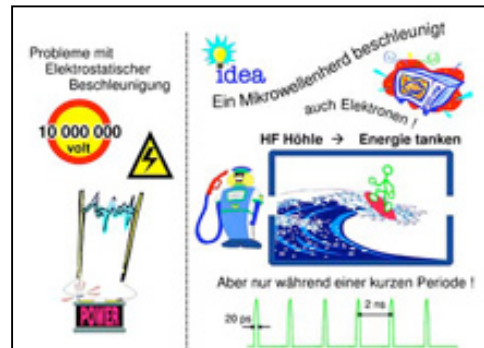
Relativistic effect

In normal life it is impossible to notice the relativistic effect. Even if we fly along on a satellite at 16 km/s our mass is not measurably increased. The electrons at BESSY, however, approach the velocity of light. Hence, the effect is strong. A person of 75 kg, moving along with the same velocity as an electron in the BESSY II storage ring, would have a mass of almost 250 tons.



Electrostatic acceleration

Due to the high voltage electrostatic acceleration like in a TV, is not practical at BESSY. As an alternative BESSY employs micro-waves or, more accurately, radio-frequent (rf) waves. The rf-waves are stored in a rf-cavity. Electrons entering this cavity at the correct moment feel an accelerating force similar to the force a surfer feels when he is surfing down a wave. Electrons can only be accelerated, however, when they enter at the maximum of the wave. They can thus only be accelerated at specific periods of time. The rf-accelerated electron-beam is therefore not continuous but consists of a train of short pulses.



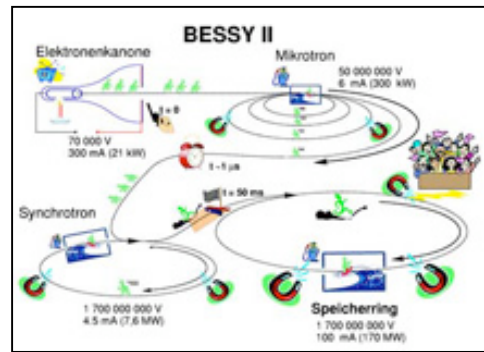
Accelerator types

For low accelerating voltage, e.g. for TV's or X-ray tubes, the electrostatic accelerator is the most economic. In the linear accelerator a lot of rf-cavities are put after each other such that an electron may be accelerated successively in each cavity. Linear accelerators have the advantage that they can accelerate a lot of current to very high energy (voltage). At high energy they become very costly, though. Linear accelerators are used for cancer-therapy. As an alternative to the linear accelerator one may also bend the electrons back to the entrance of the accelerator. The circular design shown is known as a synchrotron. BESSY employs such an accelerator scheme to accelerate the electrons.



BESSY II

BESSY II employs a TV-like device to generate a 70 kV electron beam. Before its injection into the main storage ring is accelerated in a microtron and a synchrotron to its final energy of 1.7 GeV. The accelerating process takes 50 ms and can be repeated with a repetition rate of 10 Hz. The total current in the storage ring of 100 mA can be obtained by successive injection of electrons, accelerated in multiple accelerating cycles.



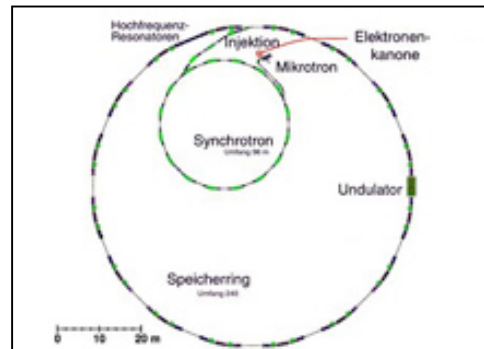
Synchrotron radiation

Note that also the storage ring is equipped with rf-cavities to compensate for energy loss due to the emission of synchrotron radiation.



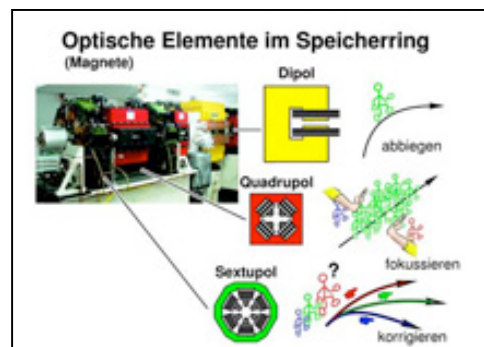
Storage ring

The storage ring is the largest component at BESSY II. Other components, important for the accelerating process, are difficult to distinguish.



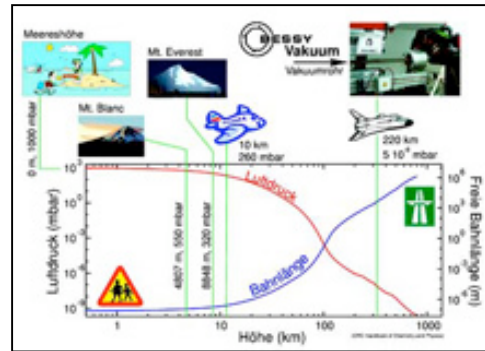
Optical elements

Magnets ensure that the electrons circle in the storage ring. Main components are the dipoles (32x), the quadrupoles (144x) and the sextupoles (112x). The dipoles enable the circular orbit of the electrons. The quadrupoles compensate the natural behavior of electrons to drift apart. Sextupoles make small corrections on the quadrupoles and are important for storing the beam over a longer period of time.



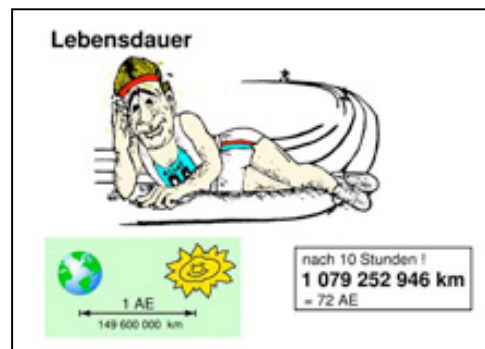
Vacuum system

Electrons may scatter on atoms in the air. To avoid this the electrons are kept in an evacuated pipe. Inside this pipe the air-pressure is 100,000,000,000 times lower than the air pressure at sea-level, i.e., roughly the pressure present at 220 km altitude (standard orbit altitude of the space shuttle). Without a vacuum system the electrons can not make one single turn in the machine.



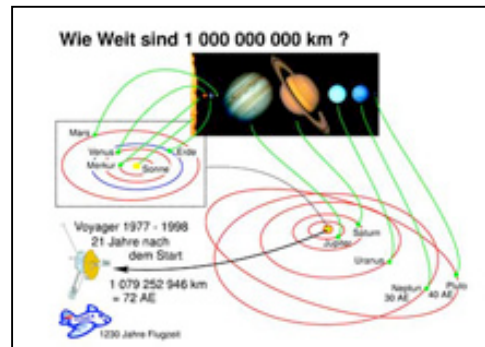
Lifetime

The amount of synchrotron radiation is proportional to the stored beam current. To keep the current high one has to reduce the loss of electrons. BESSY II is designed to permit a lifetime of 8 to 10 hours. Since the electrons move with the velocity of light (~300,000 km/s) they travel a distance of 1,000,000,000 km, i.e. 72 times the distance from the sun to the earth.



What are 1,000,000,000 km?

The distance of 1,000,000,000 km may be compared to the size of our solar system. The earth orbits the sun at a distance of 149,600,000 km (= 1AE). The most outer planet, Pluto, orbits the sun at a distance of 40 AE. The satellite Voyager is at present (Sept. 1998) at a distance of 72 AE from the earth. The Voyager started its journey in 1977 and, hence, took 21 years to reach this point. A common aircraft would take 1230 years of non-stop flying to reach this point.



Support

The previous slides gave a much too simple view of the BESSY machine. BESSY II is a high-tech device where a lot of sophisticated support-devices must function properly. This slide names some of those in detail.

