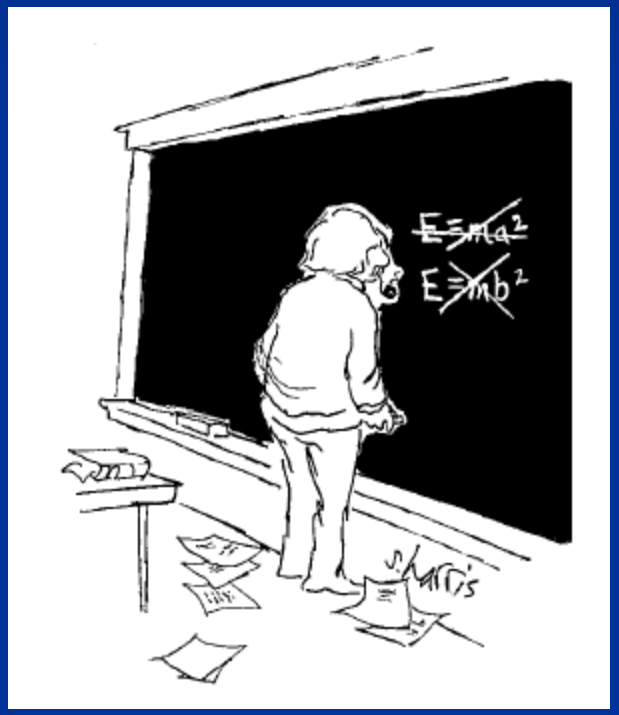
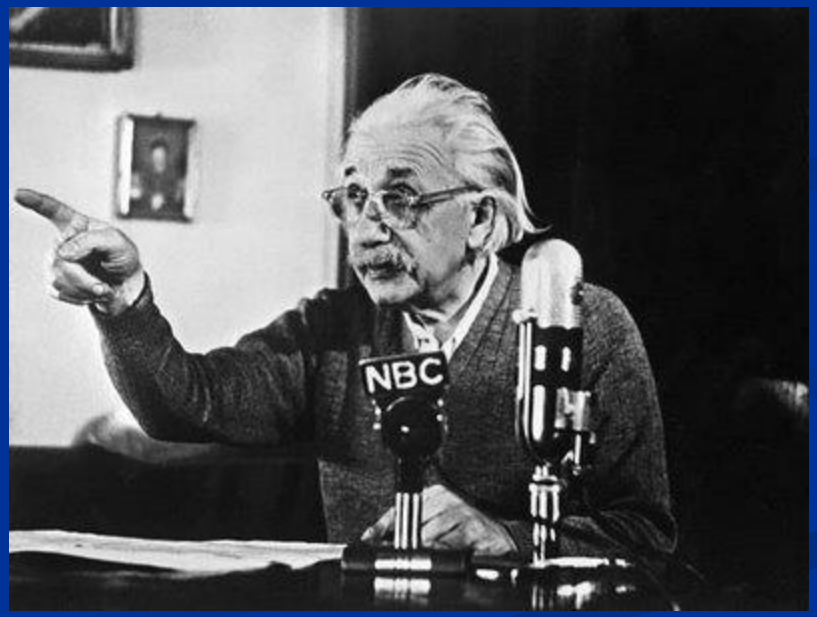
Special Theory of Relativity





7th Lecture

Relativistic Mass

If we assume a body with mass m is moving with a constant velocity, v.

Using the relationship between Relativistic Energy - Momentum:

$$E^2 = p^2c^2 + m_o^2c^4$$

Where, $E = mc^2$ and, $p = mv$

$$(mc^2)^2 = (mv)^2c^2 + m_o^2c^4$$

$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Experimental Proofs :

The first verification of the increase in mass with velocity came from the experimental work of Kaufmann in 1902 and 1906 and particularly, that of Bucherer in 1909. They were working on something entirely unrelated to relativity – or so they thought. It had been known for some time that certain substances, radium for one, were constantly shooting off three different types of small particles, or rays. Such substances are called **radioactive**. They were investigating the particular type of radiation known as beta rays and were attempting to determine just what these were. In doing so, they found the velocities with which individual particles making up the radiation were ejected from radioactive substances, the amount of electric charge on each and the mass of each.

The velocities were found to be comparable to the velocity of light; they also found that the higher the velocity, the greater the mass of the particle. Hence, they obtained many different beta particles, each with a different mass. They found that rest mass was the same for each particle.

Experimental Proofs :

This result constituted the first experimental proof of ,

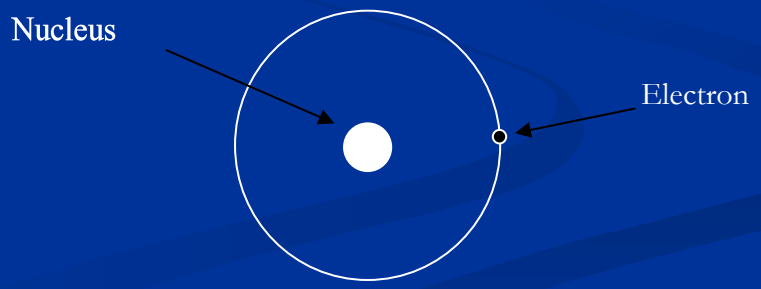
$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Equation and the first verification of the special theory of relativity.

Sommerfeld's theory of Atomic Orbits:

This verification of the mass increased predicted by the STR was proposed by Sommerfeld in 1916.

Previous to this time, the Bohr Theory (1913) had pictured the atom as consisting of a **nucleus at the centre** with the **electrons moving in circles about the nucleus**.



Experimental Proofs :

Sommerfeld's theory of Atomic Orbits…

However, Sommerfeld showed that it was more correct to assume that, in general, the electron paths were not circles but **ellipses**, and that the electron **revolved about the nucleus**, which was situated at the one of the foci of the ellipse, in the same way that planets revolve around the Sun as in the following figure.

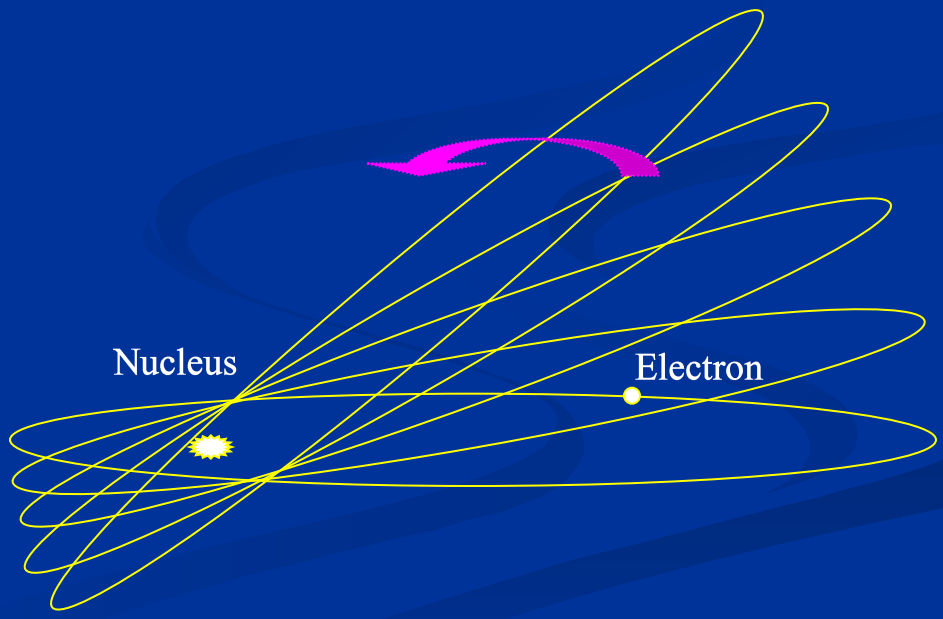
It had been shown by Kepler in 1609 that when a planet revolves around the Sun, the velocity of the planet changes from a minimum to maximum, that amount of the variation depending on the flatness, or ellipticity, of the orbit. Now, since the velocity changes, the mass increase formula says that the mass of the electron should change and the greater the variation in velocity, the greater will be this change in mass.

Experimental Proofs :

Sommerfeld's theory of Atomic Orbits…

Average velocity of the electron in its orbit about the nucleus is about one one-hundredth the velocity of light, so that for a fairly flat orbit the change in velocity, and consequent change in mass, is small but detectable.

Sommerfeld showed mathematically that the net effect of this change in mass is that the electron will not keep revolving around the nucleus in the same elliptical path over and over again like the Earth does around the Sun, but the ellipse will slowly rotate and the electron will describe a **Rosette Patten** as shown.

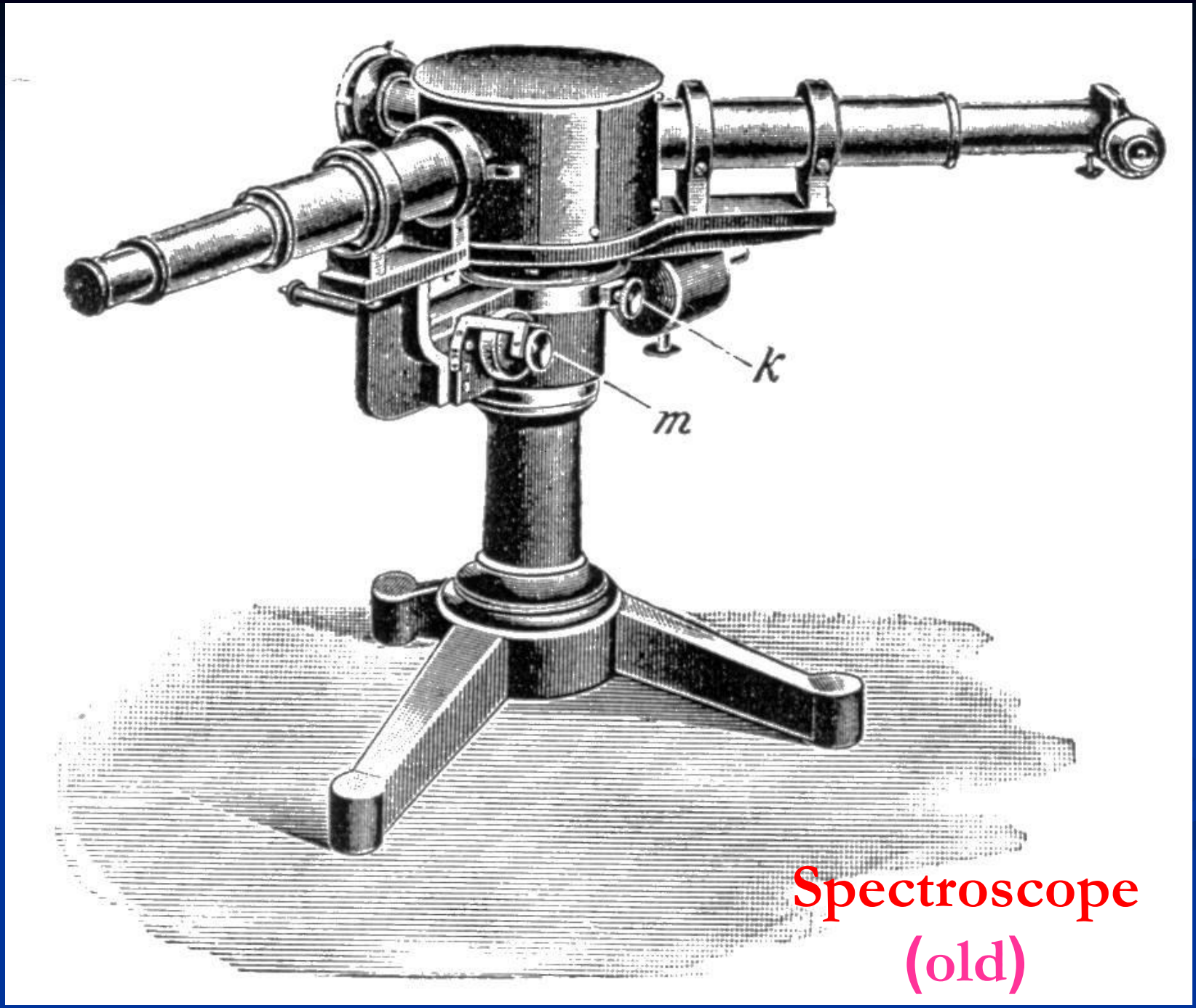


Experimental Proofs :

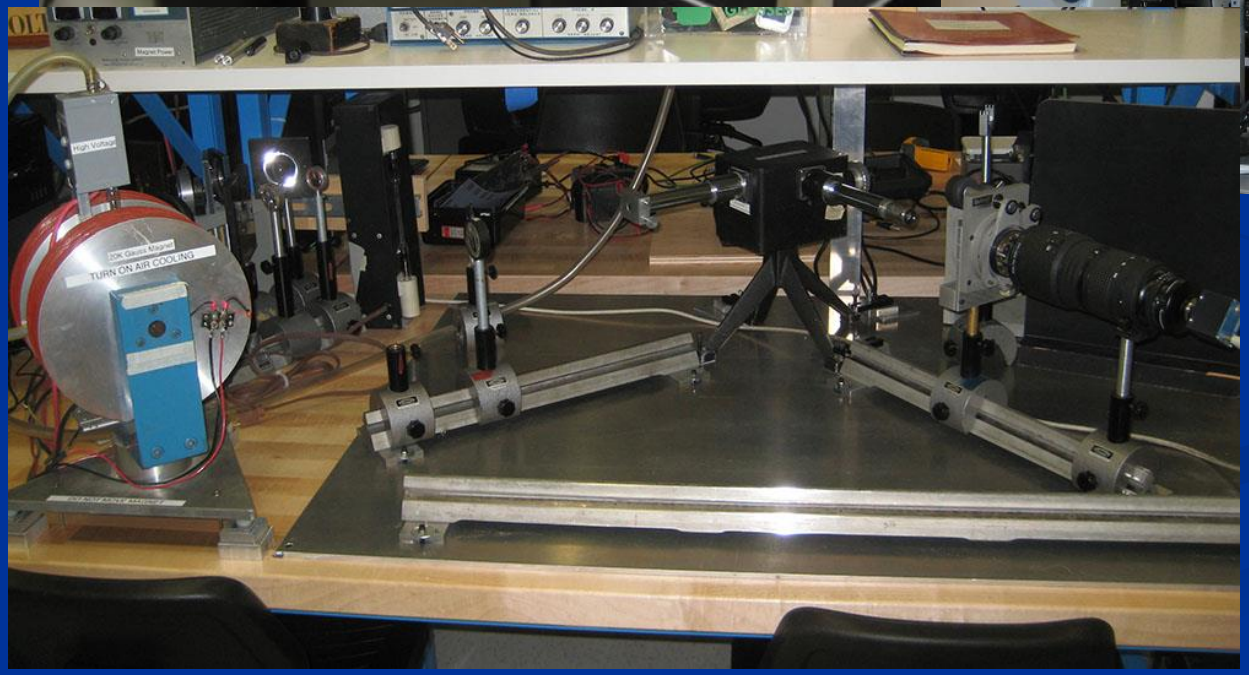
Sommerfeld's theory of Atomic Orbits…

It might seem at first glance as if it is impossible to determine the path of a single electron about a nucleus, since not only do we have no way of chopping off a single atom from a substance, but it would be impossible to see such an atom – even with the most powerful microscope we have.

In experimental work a prism by itself is insufficient for creating the best possible spectrum, since much greater precision is needed. An instrument called a spectroscope is used which contains a prism plus other necessary devices to help gain this high precision. The spectrum produced by a spectroscope shows a number of lines called Spectral Lines, which are scattered throughout the various colours of the spectrum.



Spectroscope
(old)

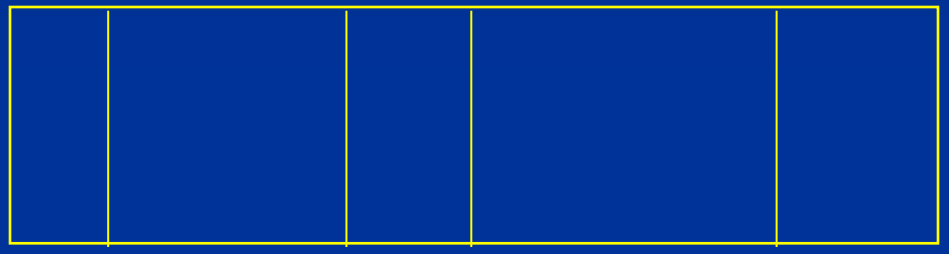


Spectroscope (Modern)

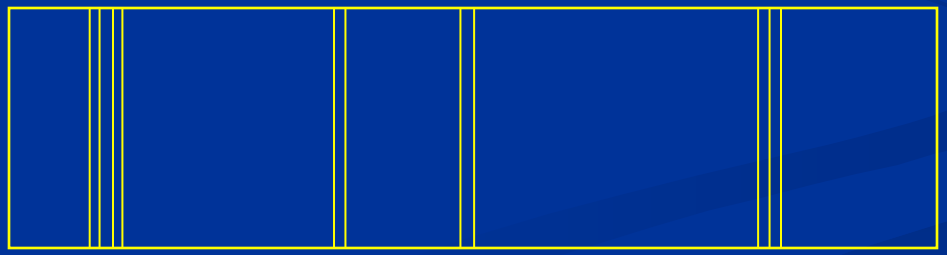
Experimental Proofs :

Sommerfeld's theory of Atomic Orbits…

Sommerfeld showed that if the path of the electron about the nucleus is an ellipse, these lines will consists of a number of single lines such shown in the following diagram.



Also, for a rosette-shaped orbit these individual lines should really be split, as shown in the following diagram.

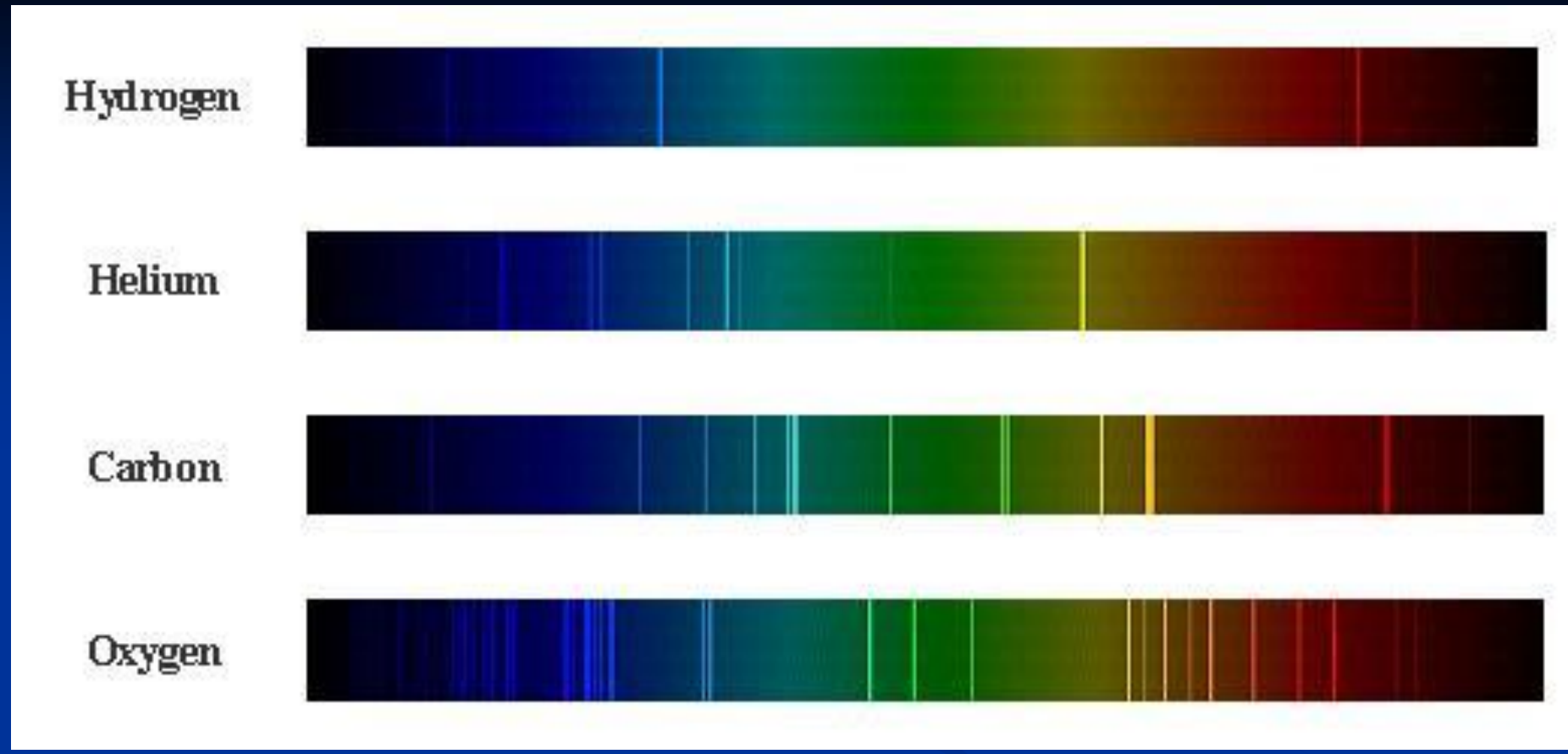


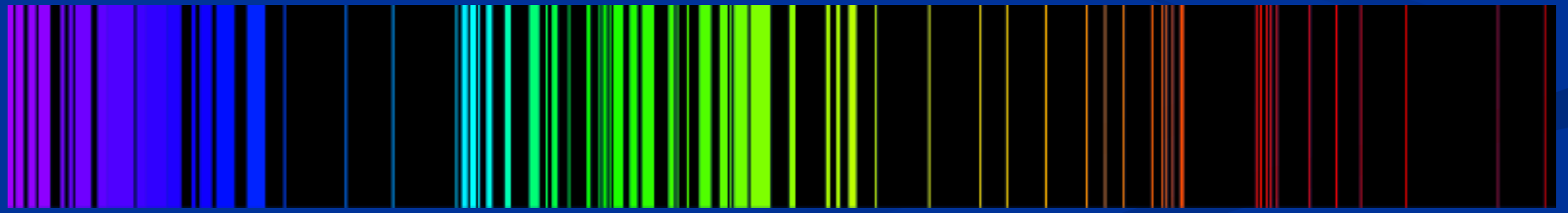
Experimental Proofs :

Sommerfeld's theory of Atomic Orbits…

If the spectral lines were single, then the path of the electron was an ellipse, and the mass of the electron did not change its revolution about the nucleus. But if the spectral lines were split into two or more, it would mean that the electron path was a rosette, as a result of the variation in the electron's mass, and would verify the mass-increase effect predicted by the STR.

The splitting of the spectral lines was first observed and announced by **Paschen** in **1916**, when he was investigating the **spectrum of Helium**. It is interesting to note that one month after Paschen published his discovery, the sommerfeld theory was published which predicted the splitting of the spectral lines on the basis of the STR and again the mass-increase effect of the STR was verified.


Hydrogen
Helium
Carbon
Oxygen



Experimental Proofs :

Atomic Accelerators :

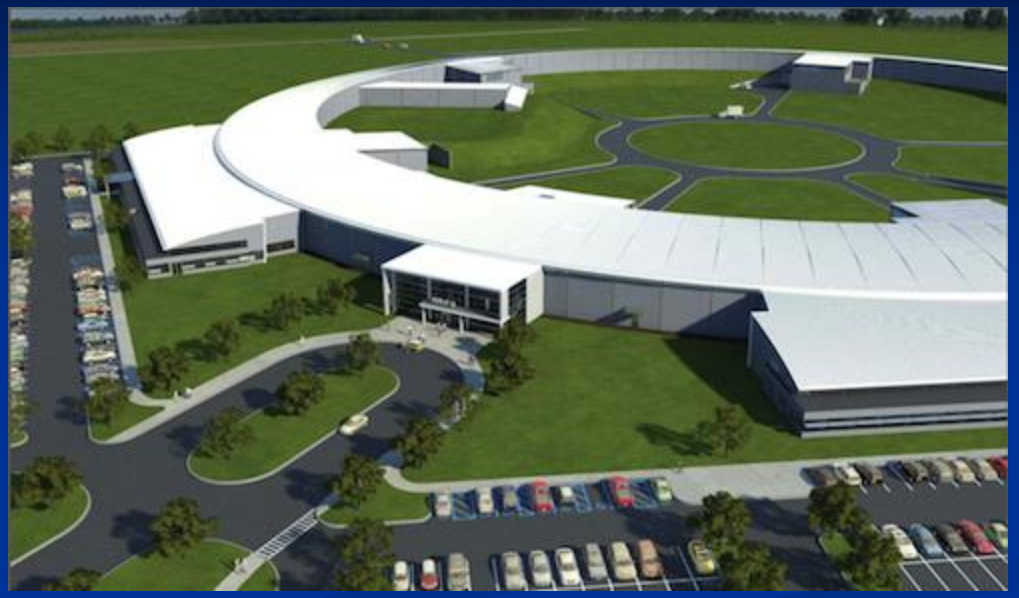
Additional examples of the mass increase with velocity have come from the spectacular results of the giant atom smashing machines which have been built to investigate the structure of the atomic nucleus. The primary purpose of these machines is to accelerate various atomic particles to high velocities; the more powerful the machine, the higher the velocities; and the higher the velocities, the greater the mass of the particles becomes, according to the mass increase formula.

These machines are called **particle accelerators**.

Experimental Proofs :

Atomic Accelerators…

Early in 1952 the **Brookhaven National Laboratory** announced its success in accelerating protons (nuclei of H atoms) up to 0.95 c. As a result the mass of the proton was increased to about **three times** its original mass.

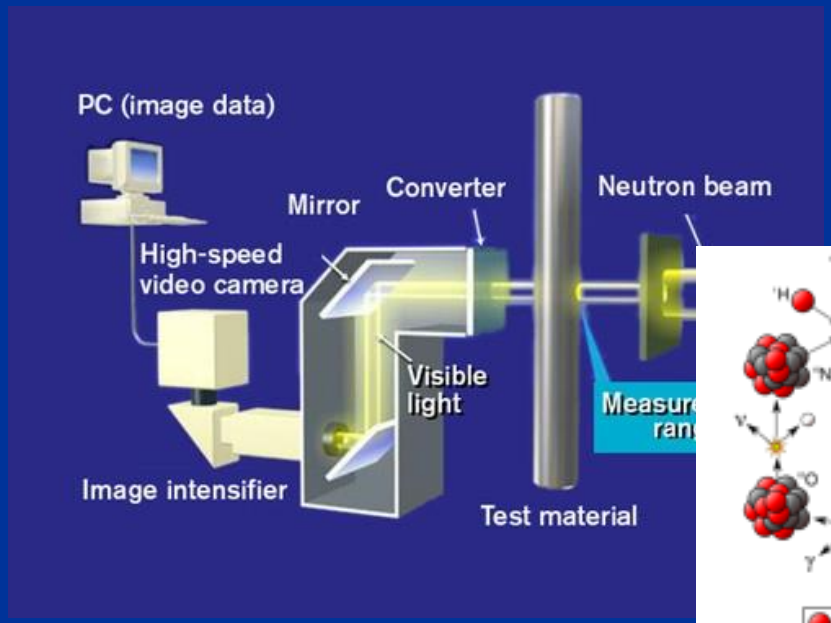


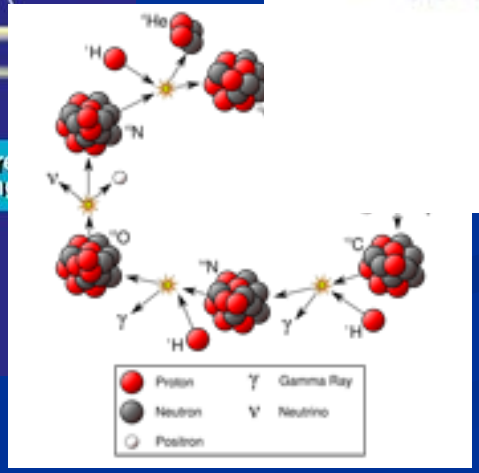
And in June 1952 the **California Institute of Technology** announced it had succeeded in accelerating electrons to 0.9999999 c. The corresponding mass increase was about **900 times** its original mass.

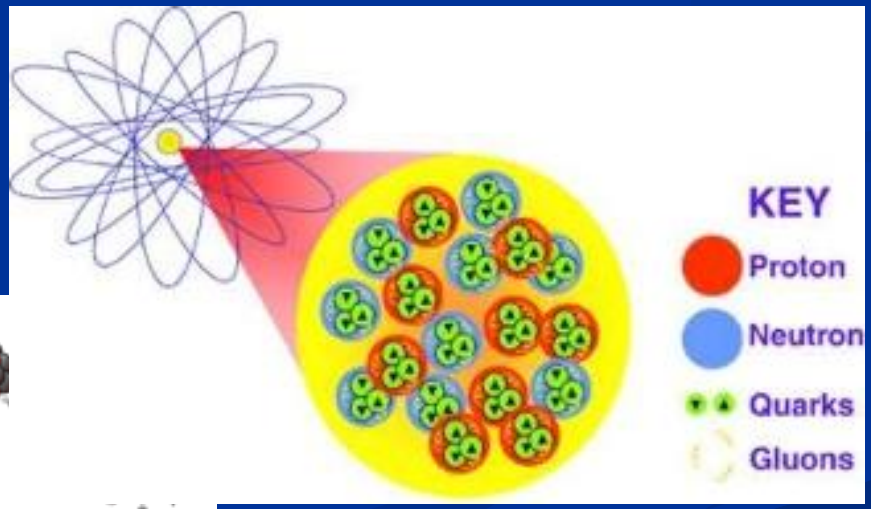
Experimental Proofs :

Atomic Accelerators…

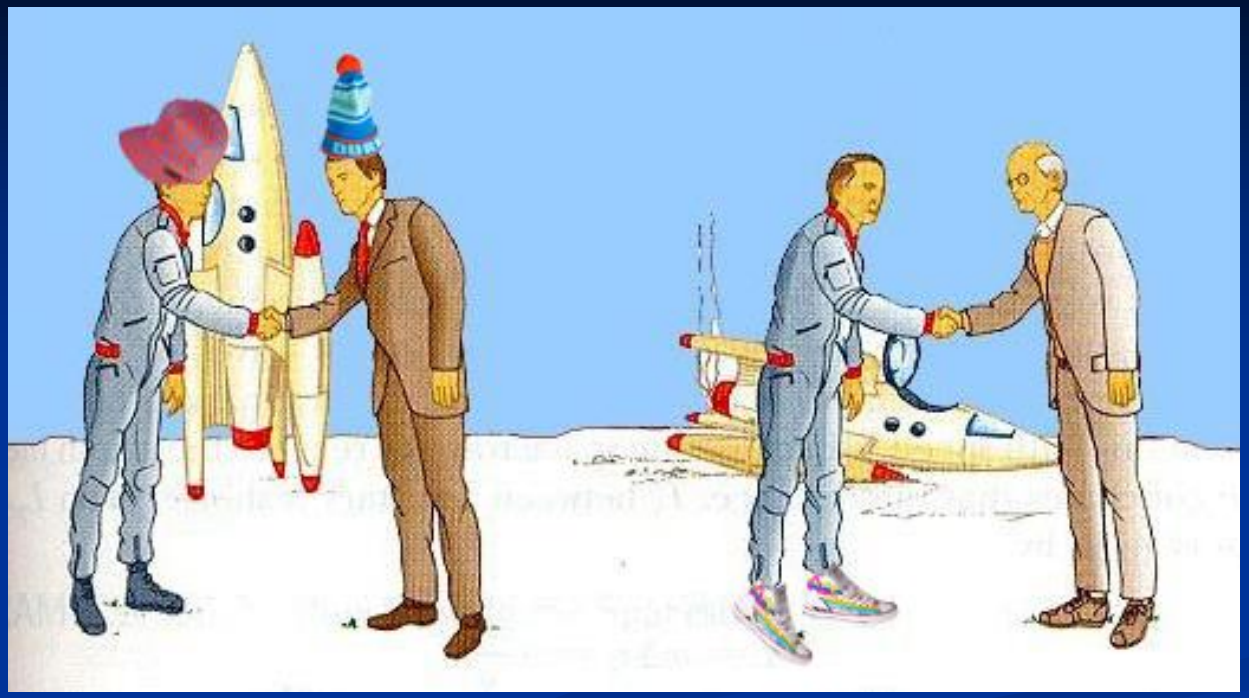
The energy of atomic accelerators throughout the world is continually being increased, with the results that the atomic particles used for bullets in Nuclear Physics research will have large and larger effective masses as their velocities come closer and closer to the velocity of light.







Twin Paradox



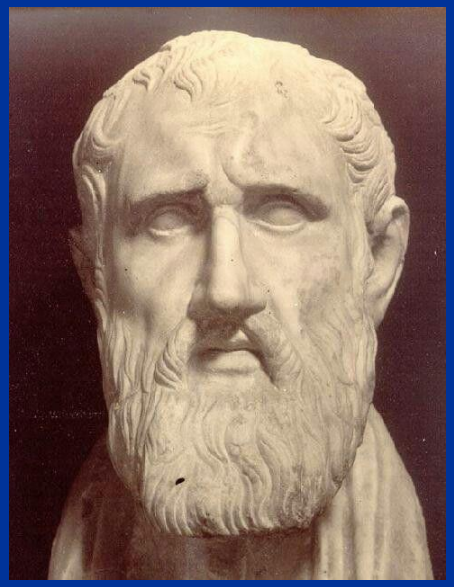
Paradox :

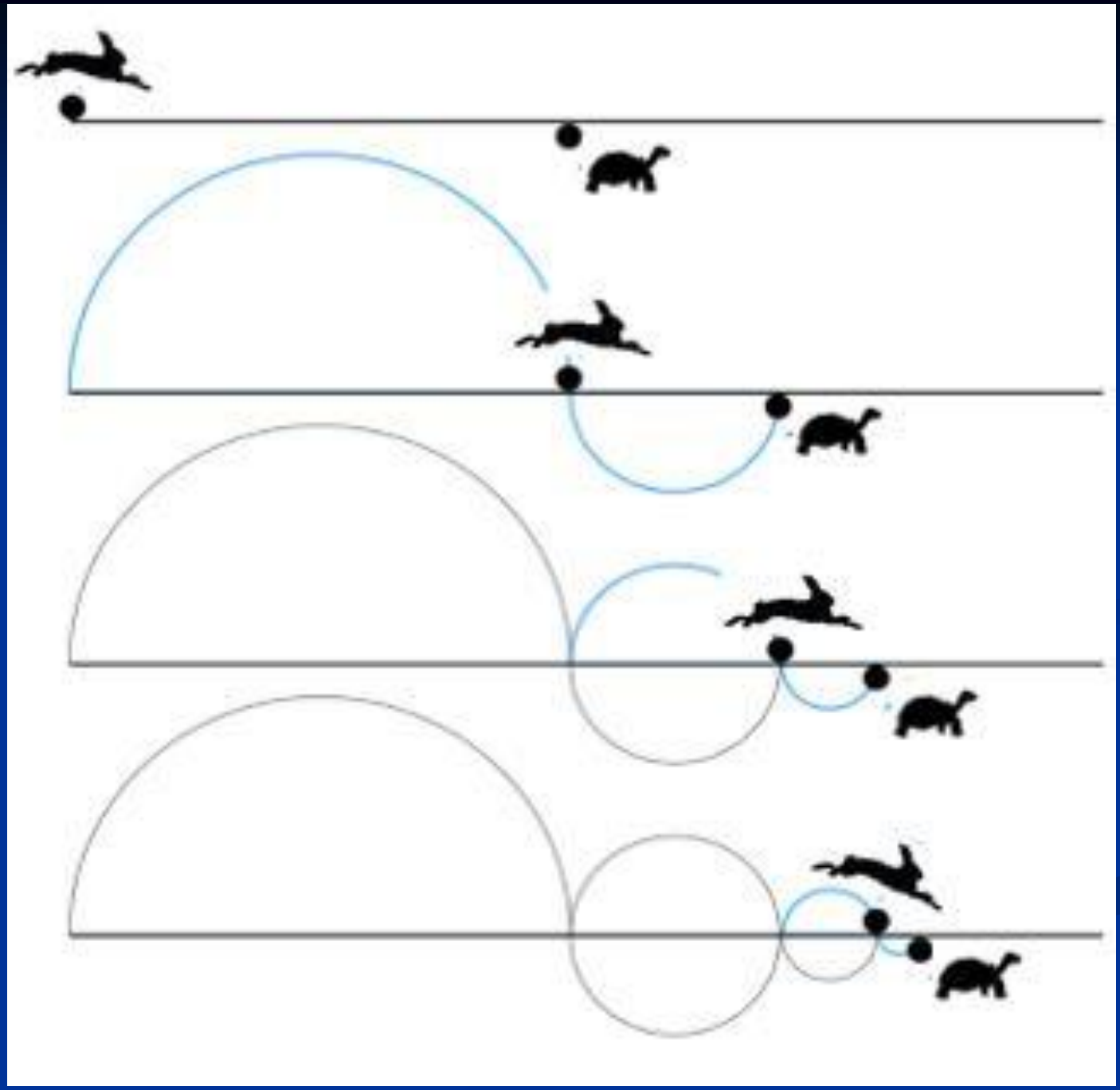
A paradox is a statement or group of statements that leads to a contradiction or a situation which defines intuition.

The term is also used for an apparent contradiction that actually expresses a non-dual truth!

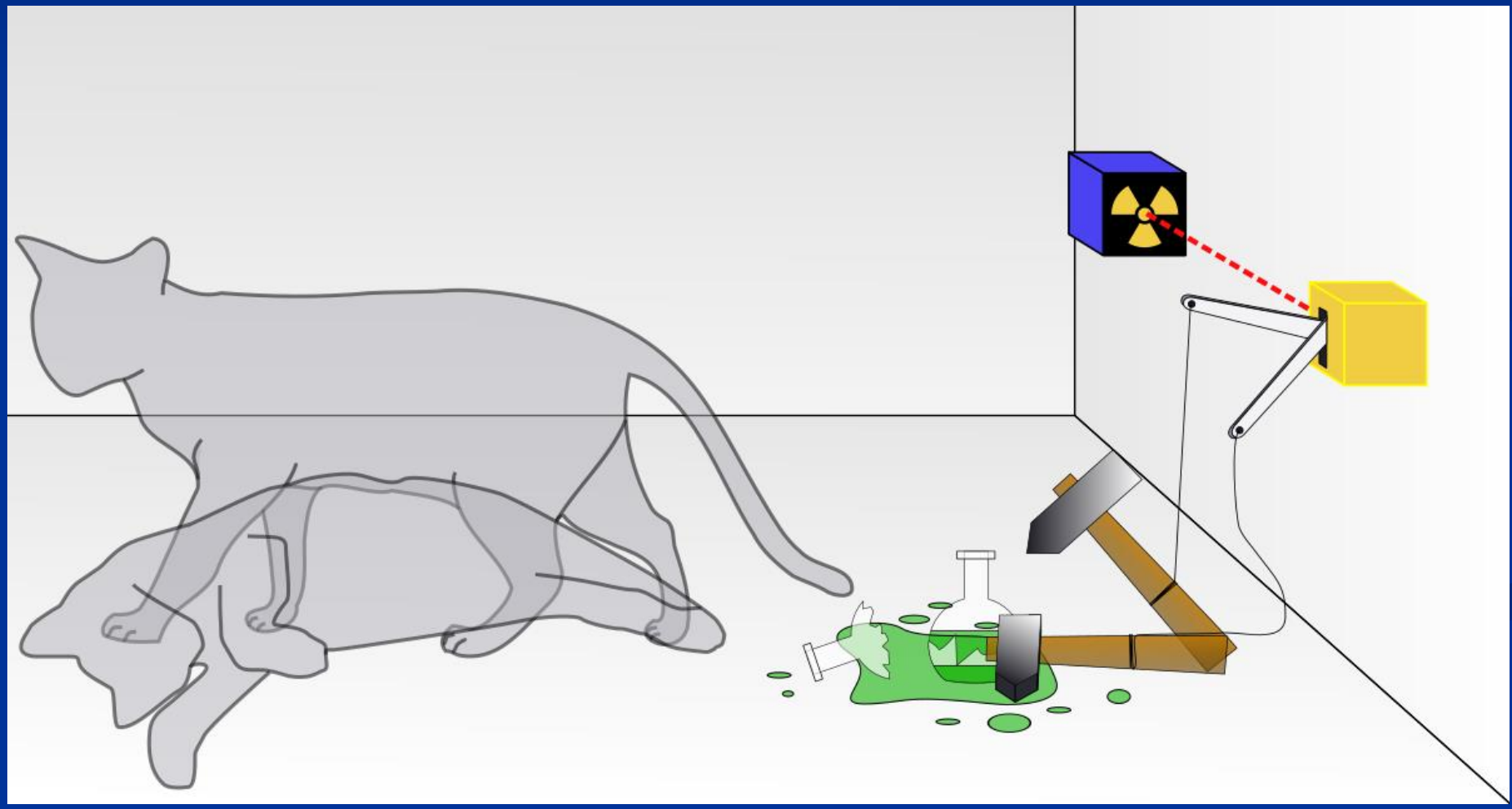
A statement or proposition seeming self-contradictory or absurd but in reality expressing a possible truth!

Zeno's Paradox





CAT Paradox in Quantum Physics



Carnivorous Island in Life of Pi

Twin Paradox

In Physics, the twin paradox is a thought experiment in special relativity, in which a twin makes a journey into space in a high speed rocket and returns home to find he has aged less than his identical twin who stayed on Earth.


Thank You !