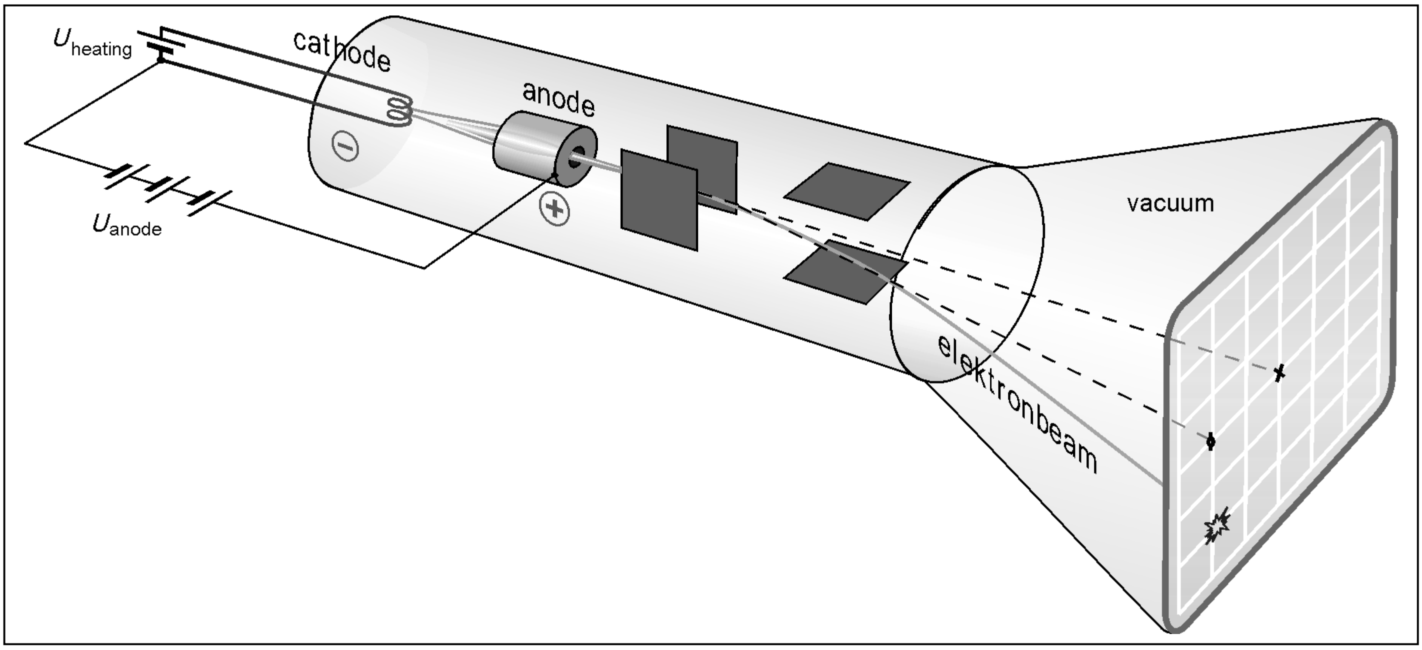
Atoms, electrons, nuclei

J.J. Thomson discovered the electron (1897)

cathode rays consisted of identical particles, independent of the element used for the cathode therefore this particle must be present in the atoms of every element



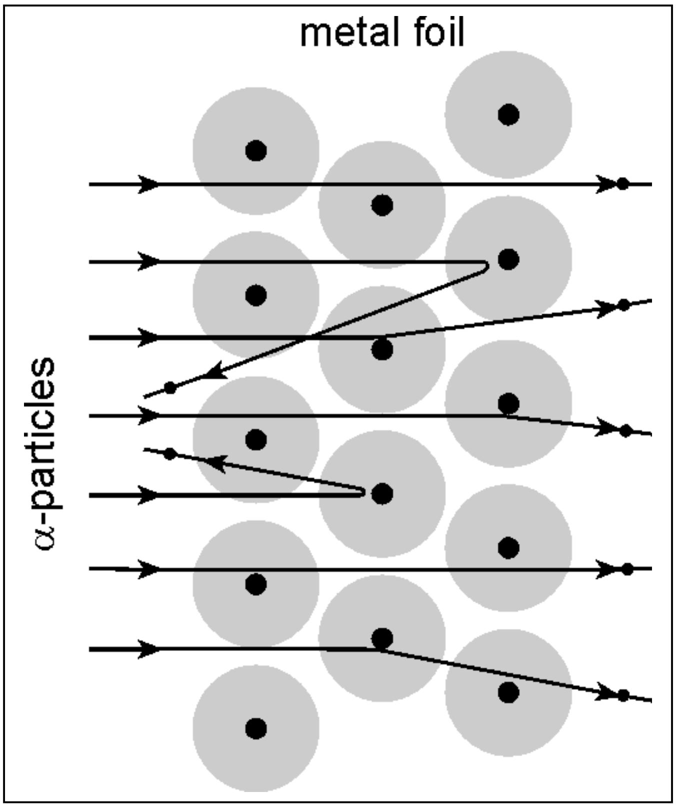
charge (q_e) and mass (m_e) of the electron was determined

'plum-pudding' model

Rutherford, discovered the nucleus (1911)

bombarded a piece of thin metal foil with α-particles:

mass is concentrated in a positively charged, very small nucleus

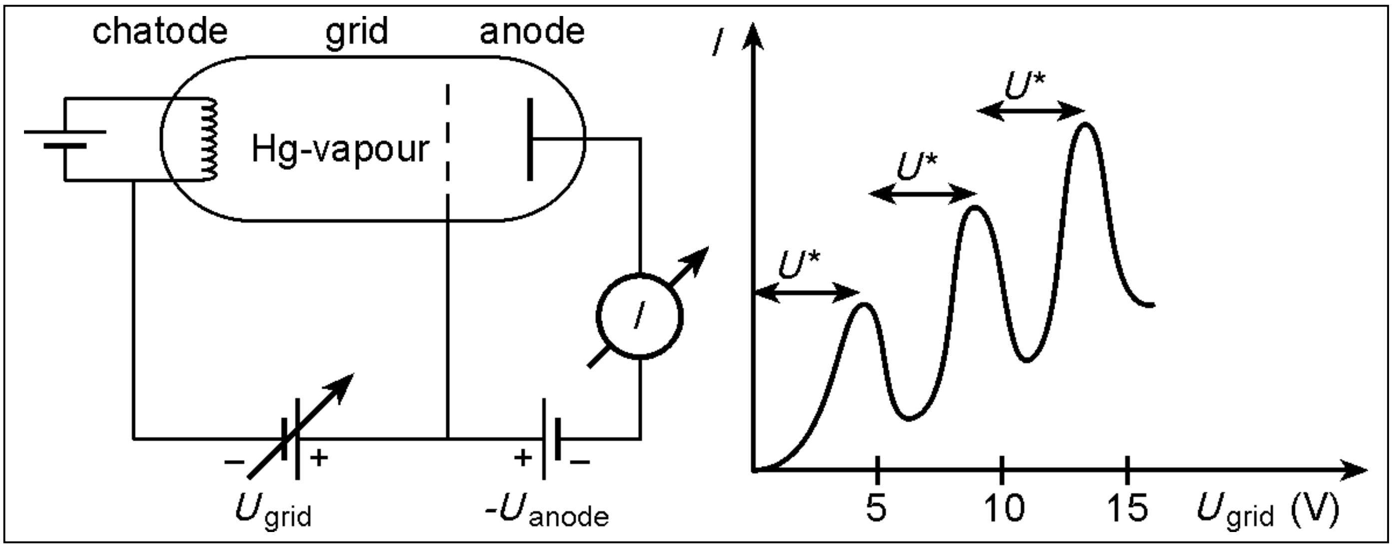


Rutherford's model:

electrons orbiting as 'planets' around the nucleus as the ‘sun’ in the center

such an atom cannot be stable

Franck-Hertz experiment: Direct evidence of energy quanta



anode is reached only by those electrons that have enough kinetic energy E_k to overcome the work eU_{anode}: $E_k \geq eU_{anode}$

electron collide with many Mercury atoms,

if $U_{grid} < U^*$, these collisions will always be elastic:

no energy loss and anode current (I) will increase;

if $U_{grid} = U^*$, collisions might become inelastic:

electrons may transfer their energy to a Mercury atom and anode current will decrease

Coclusion: energy of Mercury atom cannot change continuously, but only by certain discrete values, so-called quanta

Electron as a wave

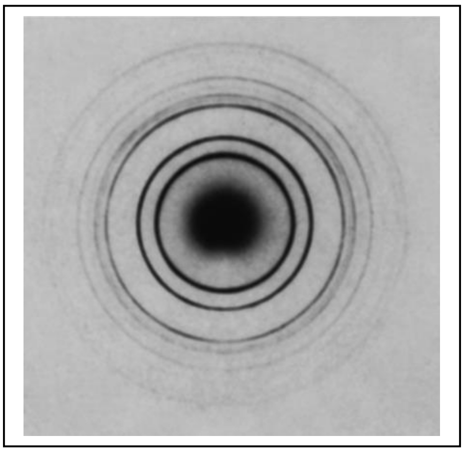
de Broglie (1923) described the discrete energy levels of electrons within an atom as results of a wave phenomenon

momentum of an electron $p = m_e v$

$$\lambda = h/p$$

where λ is the wavelength of the matter wave corresponding to the electron, and h is the Planck constant.

Davisson and Germer (1927) used electron beams to induce diffraction through a thin metal foil: interference



interference phenomena have been shown with various other particles: duality is a general characteristic of matter

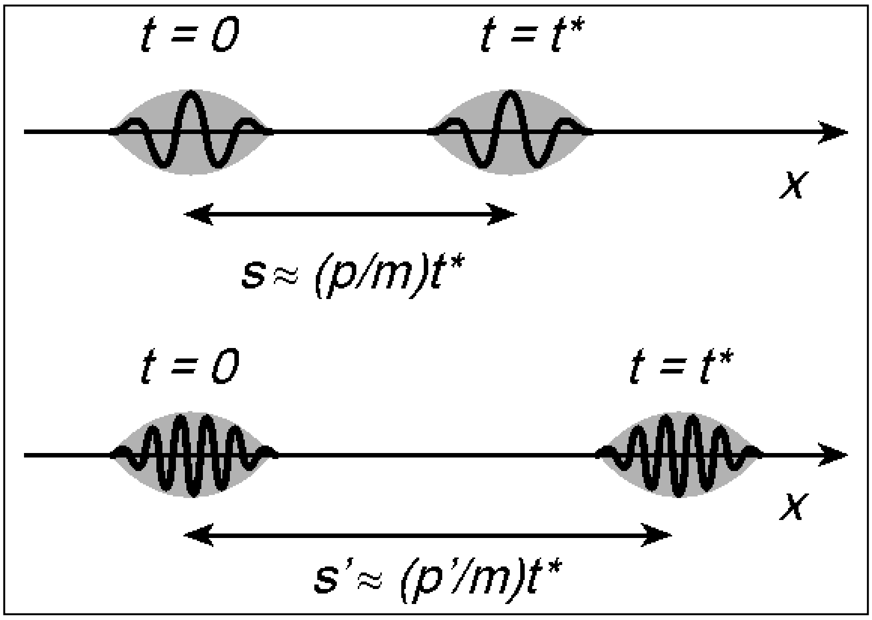
Propagation law of free electrons

state function $\psi(x,t)$; we can 'find' the electron where $\psi(x,t) \neq 0$,

its momentum $p = mv$ is given by the 'shape' of the function

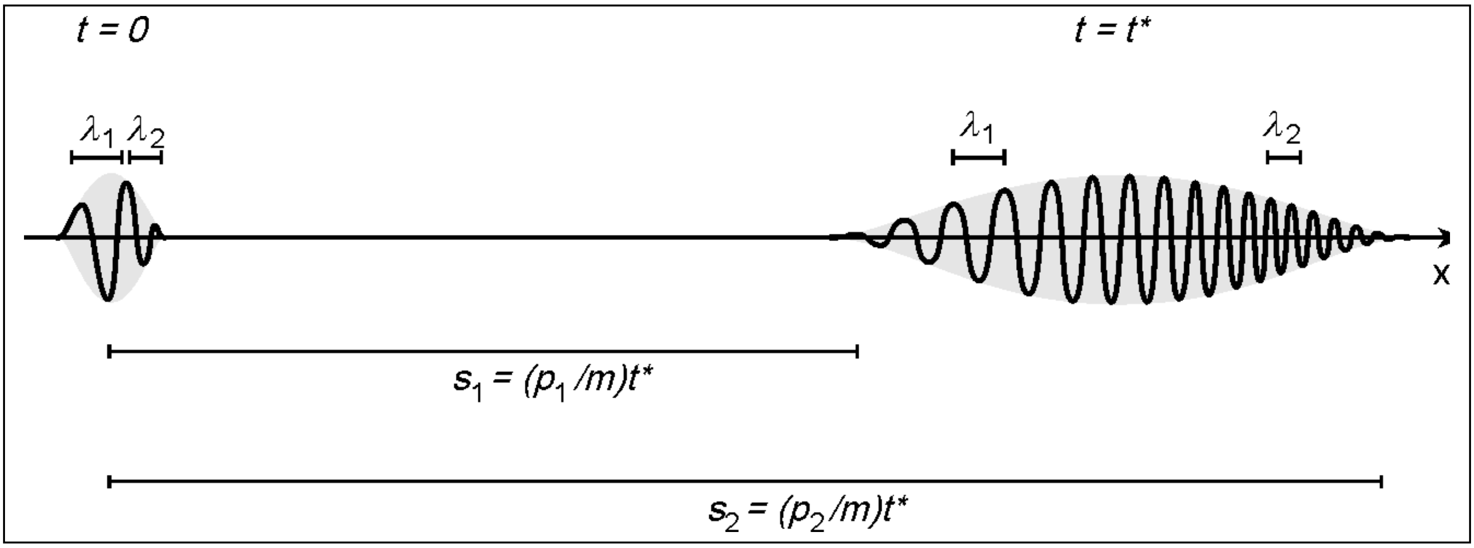
$$p = h/\lambda$$

incorrect hypothesis for slower and faster 'propagation' of an electron



in fact $\psi(x,t)$ is a non-periodic function, therefore it cannot be characterized with a single wavelength

$\psi(x,t)$ will disperse while propagating



Heisenberg uncertainty relation

$\psi(x,t)$ itself is a completely determined function but the position and momentum of the 'electron' – are uncertain

if uncertainty of position (Δx) and uncertainty of momentum (Δp)

$$\Delta x \cdot \Delta p \geq h$$

the more determined the position of the electron,

the less determined the momentum, and vice versa

based on dimension analysis an uncertainty relation can be given for the case of *energy* · *time*:

$$\Delta E \cdot \Delta t \geq h.$$

Bound state electron and atomic states

electric field will move the state function of the electron in its own direction

in case of atomic states, electrons do not have enough energy to leave the nucleus: electron is in a bound state

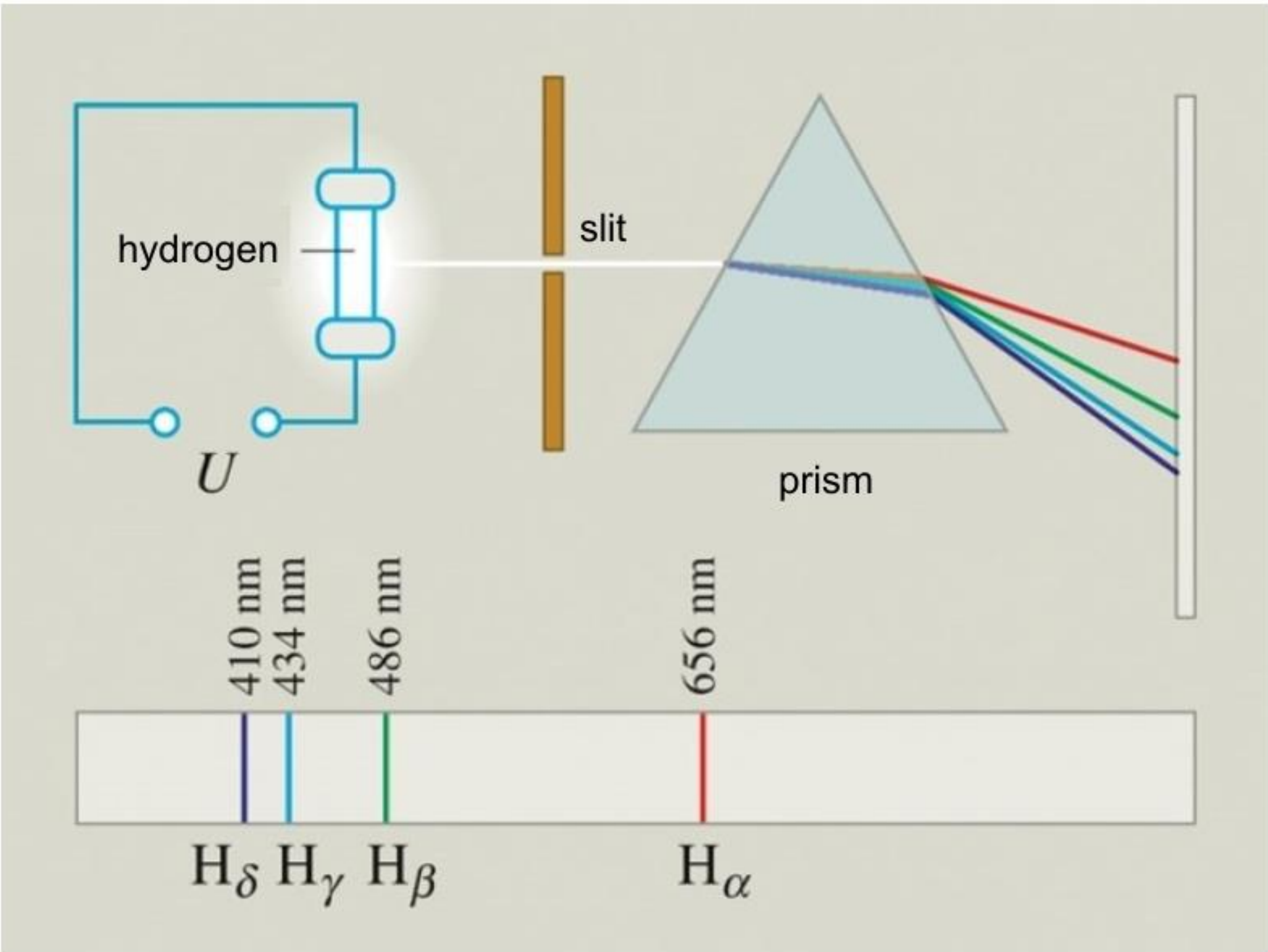
Bohr's model (incorrect, but useful)

electrons in an atom can only occupy certain distinct orbits around the nucleus: no radiation

atoms radiate if an electron 'jumps' from one such orbit to another ($E_m > E_k$)

$$hf = E_m - E_k$$

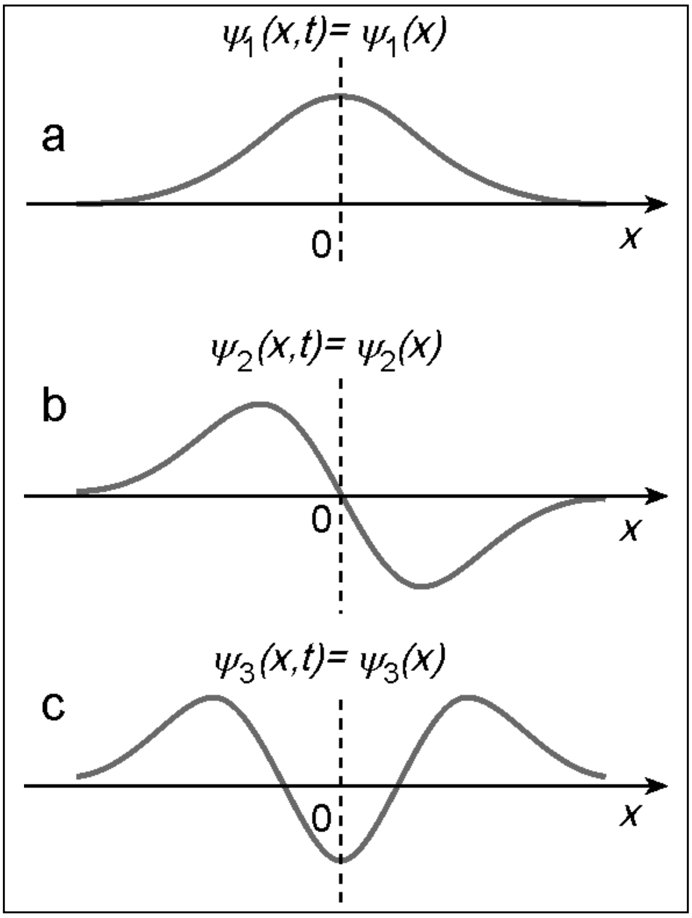
where E_m and E_k are the two energy levels for the given orbits, and h denotes the Planck constant



(simplified Hydrogen atom in one dimension)

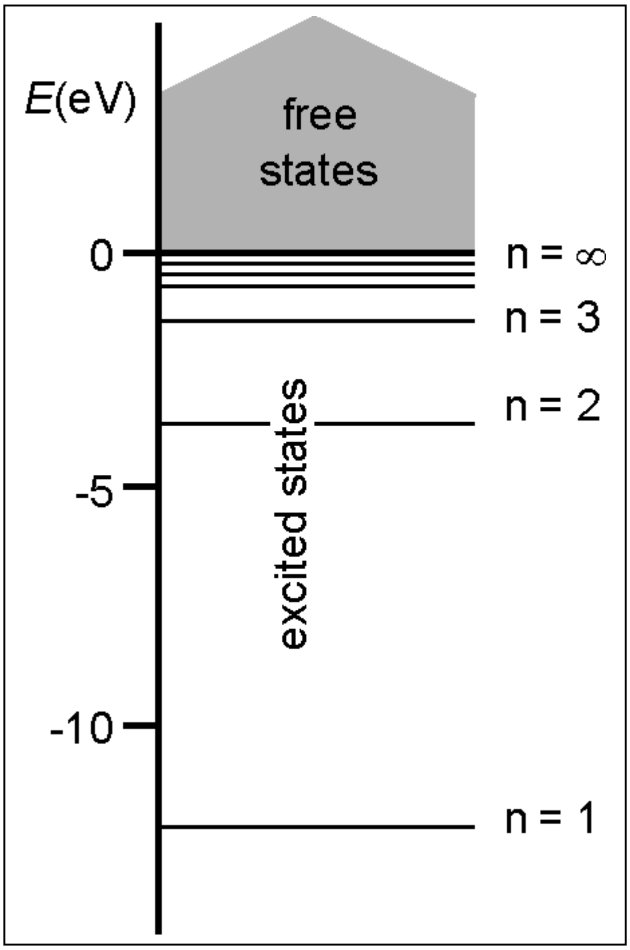
dynamical equilibrium between the effect of the nucleus to keep the state function close and together, and the natural dispersion of the state function itself

results: constant (with respect to time), stationary – i.e., time-independent – graphs $\psi(x)$ will form



Discrete atomic energy levels, principal quantum number
ground state energy
is needed to completely remove the electron (ionization energy)

energy difference of consecutive levels decreases with increasing n as $E_n = E_1/n^2$
n is the so-called **principal quantum number**, for $\boldsymbol{n}$ **= 1**, value represents the **ground state,** the $\boldsymbol{n}$ **= 2, 3,**... values represent the excited states



$$r_n = \frac{n^2 h^2}{4\pi^2 mkq^2} \qquad E_n = -\frac{2\pi^2 mk^2 q^4}{n^2 h^2}$$

Azimuthal and magnetic quantum numbers

As angular momentum is a vector, one quantum number is related to its length, the other to its direction, in bound states the angular momentum is quantized as well.

Spin and associated magnetic momentum of an electron
'The Stern-Gerlach Experiment'
atoms passing through an inhomogeneous magnetic field will be deflected

beam of Hydrogen atoms used in the experiment was split into two parts, proving the quantized nature of magnetic momentum, but based on the azimuthal and magnetic quantum numbers Hydrogen atom should have zero angular momentum in the ground state (we expect that the magnetic momentum will also be zero, i.e. such a beam is not deflected by an inhomogeneous magnetic field)

explanation: electrons have their **own** intrinsic magnetic momentum (associated with the angular momentum called **spin)**

this was proved experimentally: 'The Eistein-de Haas Experiment'
a tiny iron bar is fixed on a narrow torsion string inside a solenoid, after switching on the current the iron bar will turn