= Atom =

An atom is the smallest constituent unit of ordinary matter that has the properties of a chemical element . Every solid , liquid , gas , and plasma is composed of neutral or ionized atoms . Atoms are very small ; typical sizes are around 100 pm (a ten @-@ billionth of a meter , in the short scale) . However , atoms do not have well @-@ defined boundaries , and there are different ways to define their size that give different but close values .

Atoms are small enough that attempting to predict their behavior using classical physics - as if they were billiard balls , for example - gives noticeably incorrect predictions due to quantum effects . Through the development of physics , atomic models have incorporated quantum principles to better explain and predict the behavior .

Every atom is composed of a nucleus and one or more electrons bound to the nucleus . The nucleus is made of one or more protons and typically a similar number of neutrons . Protons and neutrons are called nucleons . More than 99 @.@ 94 % of an atom 's mass is in the nucleus . The protons have a positive electric charge , the electrons have a negative electric charge , and the neutrons have no electric charge . If the number of protons and electrons are equal , that atom is electrically neutral . If an atom has more or fewer electrons than protons , then it has an overall negative or positive charge , respectively , and it is called an ion .

The electrons of an atom are attracted to the protons in an atomic nucleus by this electromagnetic force . The protons and neutrons in the nucleus are attracted to each other by a different force , the nuclear force , which is usually stronger than the electromagnetic force repelling the positively charged protons from one another . Under certain circumstances the repelling electromagnetic force becomes stronger than the nuclear force , and nucleons can be ejected from the nucleus , leaving behind a different element : nuclear decay resulting in nuclear transmutation .

The number of protons in the nucleus defines to what chemical element the atom belongs : for example , all copper atoms contain 29 protons . The number of neutrons defines the isotope of the element . The number of electrons influences the magnetic properties of an atom . Atoms can attach to one or more other atoms by chemical bonds to form chemical compounds such as molecules . The ability of atoms to associate and dissociate is responsible for most of the physical changes observed in nature , and is the subject of the discipline of chemistry .

= = History of atomic theory = =

= = = Atoms in philosophy = = =

The idea that matter is made up of discrete units is a very old idea , appearing in many ancient cultures such as Greece and India . The word " atom " was coined by ancient Greek philosophers . However , these ideas were founded in philosophical and theological reasoning rather than evidence and experimentation . As a result , their views on what atoms look like and how they behave were incorrect . They also could not convince everybody , so atomism was but one of a number of competing theories on the nature of matter . It was not until the 19th century that the idea was embraced and refined by scientists , when the blossoming science of chemistry produced discoveries that only the concept of atoms could explain .

= = = First evidence @-@ based theory = = =

In the early 1800s , John Dalton used the concept of atoms to explain why elements always react in ratios of small whole numbers (the law of multiple proportions) . For instance , there are two types of tin oxide : one is 88 @.@ 1 % tin and 11 @.@ 9 % oxygen and the other is 78 @.@ 7 % tin and 21 @.@ 3 % oxygen (tin (II) oxide and tin dioxide respectively) . This means that 100g of tin will combine either with 13.5g or 27g of oxygen . 13 @.@ 5 and 27 form a ratio of 1 : 2 , a ratio of small whole numbers . This common pattern in chemistry suggested to Dalton that elements react in

whole number multiples of discrete units ? in other words , atoms . In the case of tin oxides , one tin atom will combine with either one or two oxygen atoms .

Dalton also believed atomic theory could explain why water absorbs different gases in different proportions . For example , he found that water absorbs carbon dioxide far better than it absorbs nitrogen . Dalton hypothesized this was due to the differences between the masses and configurations of the gases ' respective particles , and carbon dioxide molecules (CO_2) are heavier and larger than nitrogen molecules (N_2) .

= = = Brownian motion = = =

In 1827 , botanist Robert Brown used a microscope to look at dust grains floating in water and discovered that they moved about erratically , a phenomenon that became known as " Brownian motion " . This was thought to be caused by water molecules knocking the grains about . In 1905 Albert Einstein proved the reality of these molecules and their motions by producing the first Statistical physics analysis of Brownian motion . French physicist Jean Perrin used Einstein 's work to experimentally determine the mass and dimensions of atoms , thereby conclusively verifying Dalton 's atomic theory .

= = = Discovery of the electron = = =

The physicist J. J. Thomson measured the mass of cathode rays , showing they were made of particles , but were around 1800 times lighter than the lightest atom , hydrogen . Therefore , they were not atoms , but a new particle , the first subatomic particle to be discovered , which he originally called " corpuscle " but was later named electron , after particles postulated by George Johnstone Stoney in 1874 . He also showed they were identical to particles given off by photoelectric and radioactive materials . It was quickly recognized that they are the particles that carry electric currents in metal wires , and carry the negative electric charge within atoms . Thomson was given the 1906 Nobel Prize in Physics for this work . Thus he overturned the belief that atoms are the indivisible , ultimate particles of matter . Thomson also incorrectly postulated that the low mass , negatively charged electrons were distributed throughout the atom in a uniform sea of positive charge . This became known as the plum pudding model .

= = = Discovery of the nucleus = = =

In 1909 , Hans Geiger and Ernest Marsden , under the direction of Ernest Rutherford , bombarded a metal foil with alpha particles to observe how they scattered . They expected all the alpha particles to pass straight through with little deflection , because Thomson 's model said that the charges in the atom are so diffuse that their electric fields could not affect the alpha particles much . However , Geiger and Marsden spotted alpha particles being deflected by angles greater than 90 ° , which was supposed to be impossible according to Thomson 's model . To explain this , Rutherford proposed that the positive charge of the atom is concentrated in a tiny nucleus at the center of the atom .

= = = Discovery of isotopes = = =

While experimenting with the products of radioactive decay , in 1913 radiochemist Frederick Soddy discovered that there appeared to be more than one type of atom at each position on the periodic table . The term isotope was coined by Margaret Todd as a suitable name for different atoms that belong to the same element . J.J. Thomson created a technique for separating atom types through his work on ionized gases , which subsequently led to the discovery of stable isotopes .

= = = Bohr model = = =

In 1913 the physicist Niels Bohr proposed a model in which the electrons of an atom were assumed

to orbit the nucleus but could only do so in a finite set of orbits , and could jump between these orbits only in discrete changes of energy corresponding to absorption or radiation of a photon . This quantization was used to explain why the electrons orbits are stable (given that normally , charges in acceleration , including circular motion , lose kinetic energy which is emitted as electromagnetic radiation , see synchrotron radiation) and why elements absorb and emit electromagnetic radiation in discrete spectra .

Later in the same year Henry Moseley provided additional experimental evidence in favor of Niels Bohr 's theory . These results refined Ernest Rutherford 's and Antonius Van den Broek 's model , which proposed that the atom contains in its nucleus a number of positive nuclear charges that is equal to its (atomic) number in the periodic table . Until these experiments , atomic number was not known to be a physical and experimental quantity . That it is equal to the atomic nuclear charge remains the accepted atomic model today .

= = = Chemical bonding explained = = =

Chemical bonds between atoms were now explained , by Gilbert Newton Lewis in 1916 , as the interactions between their constituent electrons . As the chemical properties of the elements were known to largely repeat themselves according to the periodic law , in 1919 the American chemist Irving Langmuir suggested that this could be explained if the electrons in an atom were connected or clustered in some manner . Groups of electrons were thought to occupy a set of electron shells about the nucleus .

= = = Further developments in quantum physics = = =

The Stern ? Gerlach experiment of 1922 provided further evidence of the quantum nature of the atom . When a beam of silver atoms was passed through a specially shaped magnetic field , the beam was split based on the direction of an atom 's angular momentum , or spin . As this direction is random , the beam could be expected to spread into a line . Instead , the beam was split into two parts , depending on whether the atomic spin was oriented up or down .

In 1924 , Louis de Broglie proposed that all particles behave to an extent like waves . In 1926 , Erwin Schrödinger used this idea to develop a mathematical model of the atom that described the electrons as three @-@ dimensional waveforms rather than point particles . A consequence of using waveforms to describe particles is that it is mathematically impossible to obtain precise values for both the position and momentum of a particle at a given point in time ; this became known as the uncertainty principle , formulated by Werner Heisenberg in 1926 . In this concept , for a given accuracy in measuring a position one could only obtain a range of probable values for momentum , and vice versa . This model was able to explain observations of atomic behavior that previous models could not , such as certain structural and spectral patterns of atoms larger than hydrogen . Thus , the planetary model of the atom was discarded in favor of one that described atomic orbital zones around the nucleus where a given electron is most likely to be observed .

= = = Discovery of the neutron = = =

The development of the mass spectrometer allowed the mass of atoms to be measured with increased accuracy . The device uses a magnet to bend the trajectory of a beam of ions , and the amount of deflection is determined by the ratio of an atom 's mass to its charge . The chemist Francis William Aston used this instrument to show that isotopes had different masses . The atomic mass of these isotopes varied by integer amounts , called the whole number rule . The explanation for these different isotopes awaited the discovery of the neutron , an uncharged particle with a mass similar to the proton , by the physicist James Chadwick in 1932 . Isotopes were then explained as elements with the same number of protons , but different numbers of neutrons within the nucleus .

= = = Fission , high @-@ energy physics and condensed matter = = =

In 1938 , the German chemist Otto Hahn , a student of Rutherford , directed neutrons onto uranium atoms expecting to get transuranium elements . Instead , his chemical experiments showed barium as a product . A year later , Lise Meitner and her nephew Otto Frisch verified that Hahn 's result were the first experimental nuclear fission . In 1944 , Hahn received the Nobel prize in chemistry . Despite Hahn 's efforts , the contributions of Meitner and Frisch were not recognized .

In the 1950s , the development of improved particle accelerators and particle detectors allowed scientists to study the impacts of atoms moving at high energies . Neutrons and protons were found to be hadrons , or composites of smaller particles called quarks . The standard model of particle physics was developed that so far has successfully explained the properties of the nucleus in terms of these sub @-@ atomic particles and the forces that govern their interactions .

= = Structure = =

= = = Subatomic particles = = =

Though the word atom originally denoted a particle that cannot be cut into smaller particles , in modern scientific usage the atom is composed of various subatomic particles . The constituent particles of an atom are the electron , the proton and the neutron ; all three are fermions . However , the hydrogen @-@ 1 atom has no neutrons and the hydron ion has no electrons .

The electron is by far the least massive of these particles at 9 @.@ 11 × 10 ? 31 kg , with a negative electrical charge and a size that is too small to be measured using available techniques . It is the lightest particle with a positive rest mass measured . Under ordinary conditions , electrons are bound to the positively charged nucleus by the attraction created from opposite electric charges . If an atom has more or fewer electrons than its atomic number , then it becomes respectively negatively or positively charged as a whole ; a charged atom is called an ion . Electrons have been known since the late 19th century , mostly thanks to J.J. Thomson ; see history of subatomic physics for details .

Protons have a positive charge and a mass 1 @,@ 836 times that of the electron , at 1 @.@ 6726 × 10 ? 27 kg . The number of protons in an atom is called its atomic number . Ernest Rutherford (1919) observed that nitrogen under alpha @-@ particle bombardment ejects what appeared to be hydrogen nuclei . By 1920 he had accepted that the hydrogen nucleus is a distinct particle within the atom and named it proton .

Neutrons have no electrical charge and have a free mass of 1 @,@ 839 times the mass of the electron , or 1 @.@ 6929 × 10 ? 27 kg , the heaviest of the three constituent particles , but it can be reduced by the nuclear binding energy . Neutrons and protons (collectively known as nucleons) have comparable dimensions ? on the order of 2 @.@ 5 × 10 ? 15 m ? although the ' surface ' of these particles is not sharply defined . The neutron was discovered in 1932 by the English physicist James Chadwick .

In the Standard Model of physics , electrons are truly elementary particles with no internal structure . However , both protons and neutrons are composite particles composed of elementary particles called quarks . There are two types of quarks in atoms , each having a fractional electric charge . Protons are composed of two up quarks (each with charge + 2 / 3) and one down quark (with a charge of ? 1 / 3) . Neutrons consist of one up quark and two down quarks . This distinction accounts for the difference in mass and charge between the two particles .

The quarks are held together by the strong interaction (or strong force) , which is mediated by gluons . The protons and neutrons , in turn , are held to each other in the nucleus by the nuclear force , which is a residuum of the strong force that has somewhat different range @-@ properties (see the article on the nuclear force for more) . The gluon is a member of the family of gauge bosons , which are elementary particles that mediate physical forces .

= = = Nucleus = = =

All the bound protons and neutrons in an atom make up a tiny atomic nucleus , and are collectively called nucleons . The radius of a nucleus is approximately equal to 1 @.@ 07 3 ? A fm , where A is the total number of nucleons . This is much smaller than the radius of the atom , which is on the order of 105 fm . The nucleons are bound together by a short @-@ ranged attractive potential called the residual strong force . At distances smaller than 2 @.@ 5 fm this force is much more powerful than the electrostatic force that causes positively charged protons to repel each other .

Atoms of the same element have the same number of protons , called the atomic number . Within a single element , the number of neutrons may vary , determining the isotope of that element . The total number of protons and neutrons determine the nuclide . The number of neutrons relative to the protons determines the stability of the nucleus , with certain isotopes undergoing radioactive decay .

The proton , the electron , and the neutron are classified as fermions . Fermions obey the Pauli exclusion principle which prohibits identical fermions , such as multiple protons , from occupying the same quantum state at the same time . Thus , every proton in the nucleus must occupy a quantum state different from all other protons , and the same applies to all neutrons of the nucleus and to all electrons of the electron cloud . However , a proton and a neutron are allowed to occupy the same quantum state .