An access to quantum physics via the states of a physical system

Following the example of Richard P. Feynman this is an attempt to give access to quantum physics not by using the wave functions and Schroedinger's equation, but via the basic states of a physical system.
1) This approach doesn't require much of mathematics and might therefore be accessible for students with little training in physics and mathematics. It doesn't require lessons about oscillations and waves.
2) By using few fundamental informations this approach allows an access to a wide field in nuclear physics, atomic physics, molecular physics, and chemistry. It might be part of an introduction to chemistry also.
3) This approach can lead to a treatment of certain aspects of wave mechanics and the philosophy of science.
4) Key information are given in normal print, *additional thoughts are given in italics.*

Energy levels

Many physical systems can have few values of energy only, the so called energy levels. Energy is received (absorbed) or sent out (emitted) by these systems as visible or invisible light (Infrared, ultraviolet, X-ray or gamma radiation).
The frequency of this light, that determines the color of the light, depends on the energy difference between the energy levels before and after the process. For the emitted or absorbed Energy E, the frequency ν of the light (for visible light the frequency determines its color) is determined by the formula $E = h \cdot \nu$
h is here a constant named in honor of the German physicist Max Planck, who discovered it. $h = 6.626 \cdot 10^{-34}$ *J·s*
Energy, therefore, is taken up or sent out as little packets, called quantum, plural quanta. Light consists of particles called photons.

States of an electron in an atom

Matter is made of atoms. Each atom consists of a heavy nucleus at its center and of electrons. The Hydrogen atom is the simplest atom, it has 1 electron only. This electron can be in *comparatively* few states (called orbitals) only. In other atoms, there are similar states for the electrons. An electron, that is not bound in an atom or molecule can have any energy whatsoever.
The possible states of a single electron in the Hydrogen Atom are designated by 4 numbers, its quantum numbers. The second of these numbers is written as a letter: s=1, p=2, d=3, f=4, …. For an elctron, the fourth quantum number can be ½ or - ½ we write simply + or -. An electron might therefore be in the state 4p3-, that means its quantum numbers are 4, 2, 3,-1/2. All atoms have the same possible states for a single atom.

Base states

Every state of an electron in an atom can be represented as a linear combination of its base states. A state of an electron, therefore, can be described by the numbers showing for each base state the probability, that the electron occupies this state. These numbers, therefore are called occupation numbers.

If we don't know the precise state of an electron, but know only, that with a probability of 50% it is in state 1s1+, with a probability of 0 % in state 1s1-, a probability of 30% in state 2s1+ , and with a probability of 20% in the state 2p2+. The occupation numbers of these states are therefore 0.50, 0.00, 0.30 , 0.20.

When we describe the place of a particle in space, we usually need 3 numbers, for example geographical longitude, geographical latitude and the height above sea level. Another possibility is: You choose one point in space and measure, how many meters your object is to the right of this point, behind this point and above this point. You can choose another point with other directions to measure the distances. For the new point of origin and the new directions ("a new coordinate system"), you have to measure or calculate the new distances (called coordinates) of your object. The same way, if you choose different base states of your system, you need to calculate the occupation numbers for these new states.

Pauli's principle

No electrons in the same system can be in the same state.

This means, that the electrons in an atom occupy the states with the lowest possible energy. A Hydrogen atom (Symbol H) has 1 electron only, therefore this electron is at the state 1s1+ or 1s1-. Helium (Symbol He) has 2 electrons, they therefore occupy 1s1+ and 1s1-. A Lithium atom (Symbol Li) has 3 electrons and they occupy the states 1s1+, 1s1-, and 2s1+ or 2s1-. The 6 electrons of a Carbon atom (Symbol C) occupy the states 1s1+, 1s1-, 2s1+, 2s1-, 2p1+, 2p2+. These states of the electrons determine the chemical properties of these atoms.
If you put energy into an atom, electrons will occupy states with a higher energy. and you have an excited atom. This surplus energy can be given away, for example by sending out a photon with the correspondent amount of energy.

Electrons have the property, that one of their quantum numbers, the spin, , can assume the values ½ or - ½. Particles with this property are called fermions. No 2 fermions can be in the same state.

Boltzmann's factor

If a system is warm, its particles move and hit each other and exchange energy by the

collision. Many particles gain only a small amount of energy by it, but few particles get a lot.
If the system consists of N particles and has the Kelvin Temperature T, then the number of those particles, who have an Energy of at least E is $N \cdot e^{-\frac{E}{k \cdot T}}$
Sufficient temperature is needed to break bonds between atoms, so that they don't have fixed places, as it is in a liquid, or that they even can leave a liquid to fly around as it is in a gas. High temperatures destroy molecules.

Bosons

Light particles (photons) like to be in the same state; the more photons are in a state, the higher the probability is for a new photon to be in the same state. *If Atoms can send out photons, and 100 photons are already in a certain state, then the probability that another atom will send out a photon into the same state is 101 times higher than the probability, that a single atom sends the same photon out without any other photons of this state present.*

When you have many excited atoms ready to send out a photon with a certain energy, one photon with this energy doubles the probability of more photons to be sent out. The more photons with the same energy pass these excited atoms, the higher the probability of others to follow. Therefore, you get an avalanche of photons with the same energy and the same direction. This effect is used with light in a LASER (light amplification by stimulated emission of radiation) and with microwaves in a MASER (microwave amplification ...)

In very cold metals electrons in certain metals can form electron pairs. These electron pairs have together the spin 1, 0 or -1. Particles with an integer spin as o, 1, 2, 3, 4, … are called Bosons. As the photons, they have a strong tendency to enter the same state and to stay there. If many electron pairs flow in the same direction with the same velocity, they cause any electron pair, that is kicked out of this flow by any collision, to return immediately t the main flow.. Therefore a loss of electron pairs in the flow and their energy doesn't take place, and the current flows forever. This effect is called superconductivity.

Helium atoms are also bosons. If the temperature is low enough, they also come into one common state and flow without losing energy. This effect is called superfluidity.

Energy at the exchange of electrons

If 2 atoms exchange an electron between states with the same energy E, this exchange can produce a bond between these atoms.
This exchange creates 2 new base states for the electron: The state 1) in atom 1 and state 2) in Atom 2, both with the energy E, are replaced by the combined states 1) +

2) and 1) - 2). These new states have the energies E+A and E-A. The energy E-A means, that you have to invest the additional Energy A in order to separate these particles, they are bound together.
This so called covalent bond is the mechanism responsible for the bond between atoms to form molecules like H_2O or CO_2. Usually this covalent bond between 2 atoms is caused by an electron pair, that means an electron at each atom, and these electrons swap their places. In schematic drawings of molecules each electron pair bon is symbolized by a short line between the atoms, as for example H-H. There are bonds consisting of 2 electron pairs, like in O=C=O.

If in a molecule electrons can be swapped between 2 different possible electron configurations of this molecule both with the energy E, this exchange creates again two new base states with the energies E+A and E-A and therefore an increased stability of the compound. In the benzene molecule C_6H_6 there are 2 possible ways for the bonds between the Carbon atoms. As the electrons can be exchanged between these 2 states, the hexagonal ring of these Carbon atoms is very stable.

In an atomic nucleus, that consists of protons and in most cases neutrons, these particles exchange other particles, the so called pions. This keeps the atomic nucleus together in spite of the very strong mutual repulsion of the positively charged protons.

Today even the electric force between 2 electric charges is seen as an exchange of photons between these charges.

In a metal electrons can jump between many, many atoms. That means, that in a metal one energy level splits up in a big number of energy levels close to each other, a so called band. Lower bands, called "valence bands" are totally filled with electrons. In bands, which are not filled or partially filled ("conduction bands"), electrons can easily enter another state. Therefore they can move in the metal nearly as easily as atoms in a gas.

If a single electron leaves a full band, there is a hole in the full band. An adjacent electron can move into this hole and opens thereby another hole at is former place. This hole acts like a particle with a positive electric charge.

Probabilities

When an atom receives energy, often this atom will send away this energy spontaneously. It is however, impossible to predict the exact moment, when this will happen, we can only state a probability.
Lets take, for example 100 radioactive atoms, of whom 50% decay within 5 minutes. After 5 minutes more we shall have only the half of 50 atoms, namely 25 atoms, and after additional 5 minutes the half of 25, which is about 12 atoms, and so on. This happens with the decay of radioactive atoms or at the emission of light.

The number N of particles existing at the time t is described by the exponential function. $N(t) = N(t=0) \cdot e^{-s \cdot t}$.

Also for the absorption of a stream of light or particles in matter, the intensity I decreases with the distance x covered in matter: $I(x) = I(x=0) \cdot e^{-k \cdot x}$
This effect can be easily seen in clouds: Thin clouds are bright, thick clouds are dark.

When light is sent out it is absorbed at precisely 1 point and at 1 moment only. But quantum physics can predict only the probability, that it happens at this place. This probability can be calculated as if light moves somehow like a wave. The same effect holds also for particles, like electrons. There are no objects in our everyday experience, that behave like waves and particles at the same time.

This has several consequences:
1) There are interference effects, which may cause places with high and low probability closely together.
2) Bound particles have comparatively few possible states.
3) For the Hydrogen atom these probabilities can be calculated for all base states. It can be seen for any of the states, where can find an electron in this state.
4) If an electron is bound to an atom, it is confined to a certain region around the atom. The wave properties allow it, however, to have a certain probability outside the confined space. If two confined spaces are close enough, that means, that the electron can move from one space to the other space. This effect is called tunnel effect, because a tunnel allows traffic without ascent and descent between 2 regions that are separated by a mountain ridge.
5) Common sense based on our everyday experience is not enough to understand everything.

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