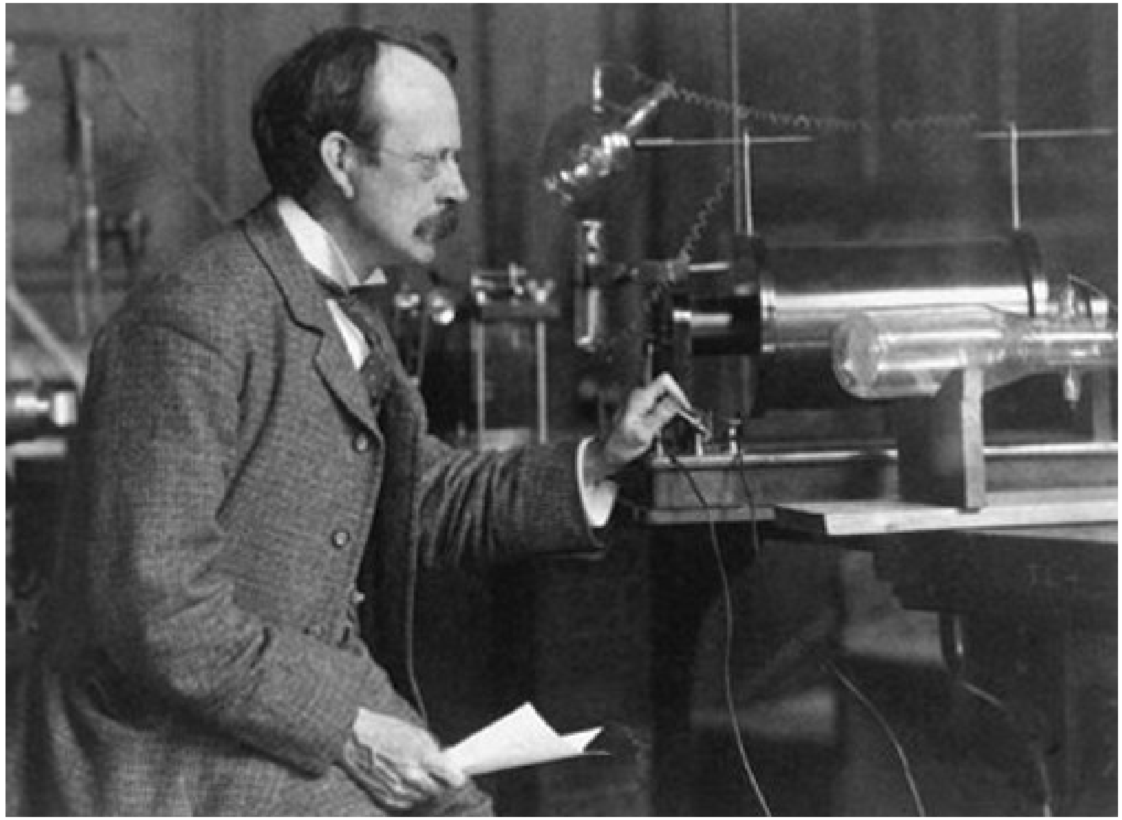
Transistors

"The single most important electrical invention of the 20th century."

-many scientists and engineers

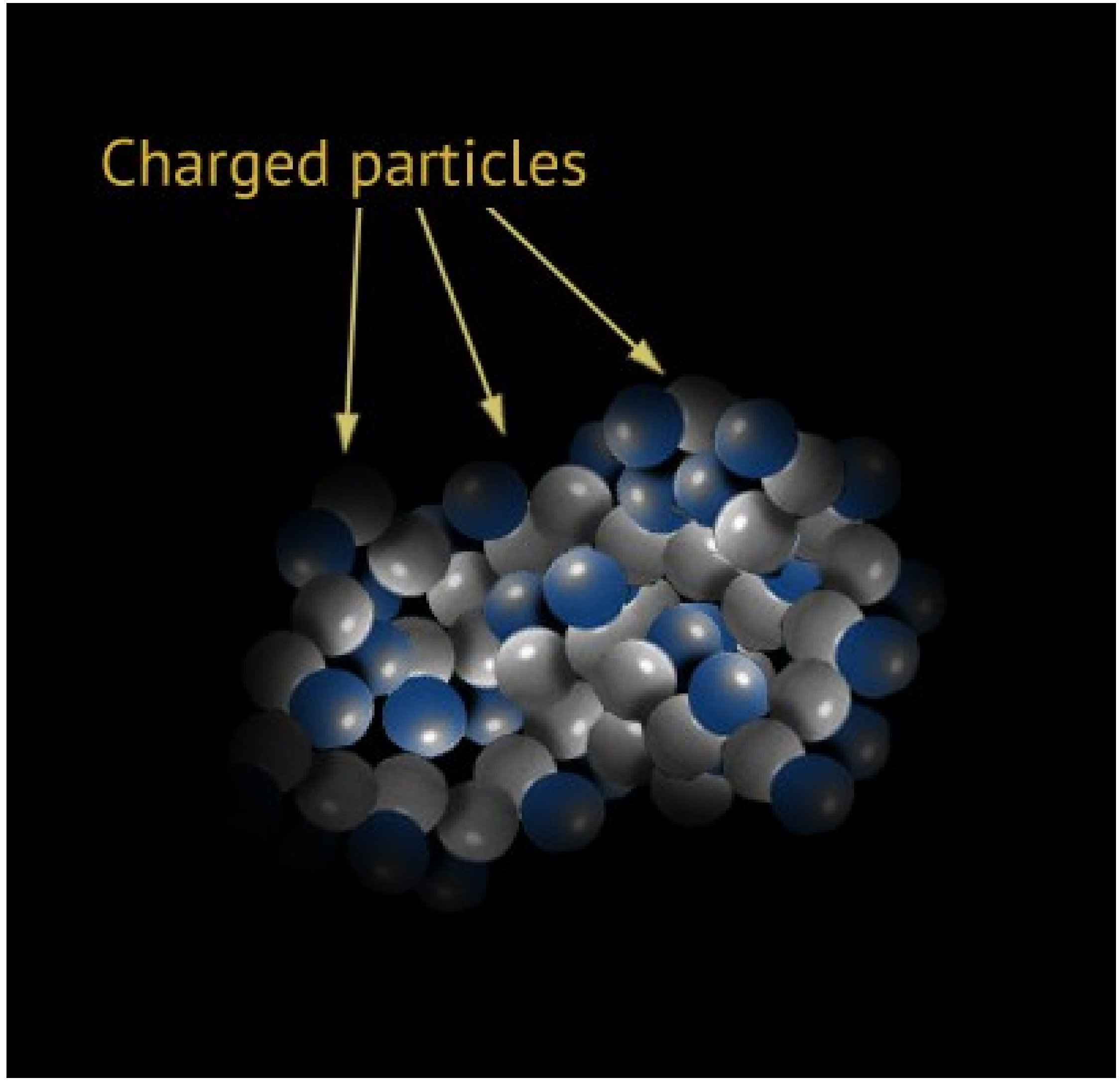
Theory Stuff

Quantum Mechanics. Super strange,
(but probably not directly applicable to
how we make electrical circuits.)

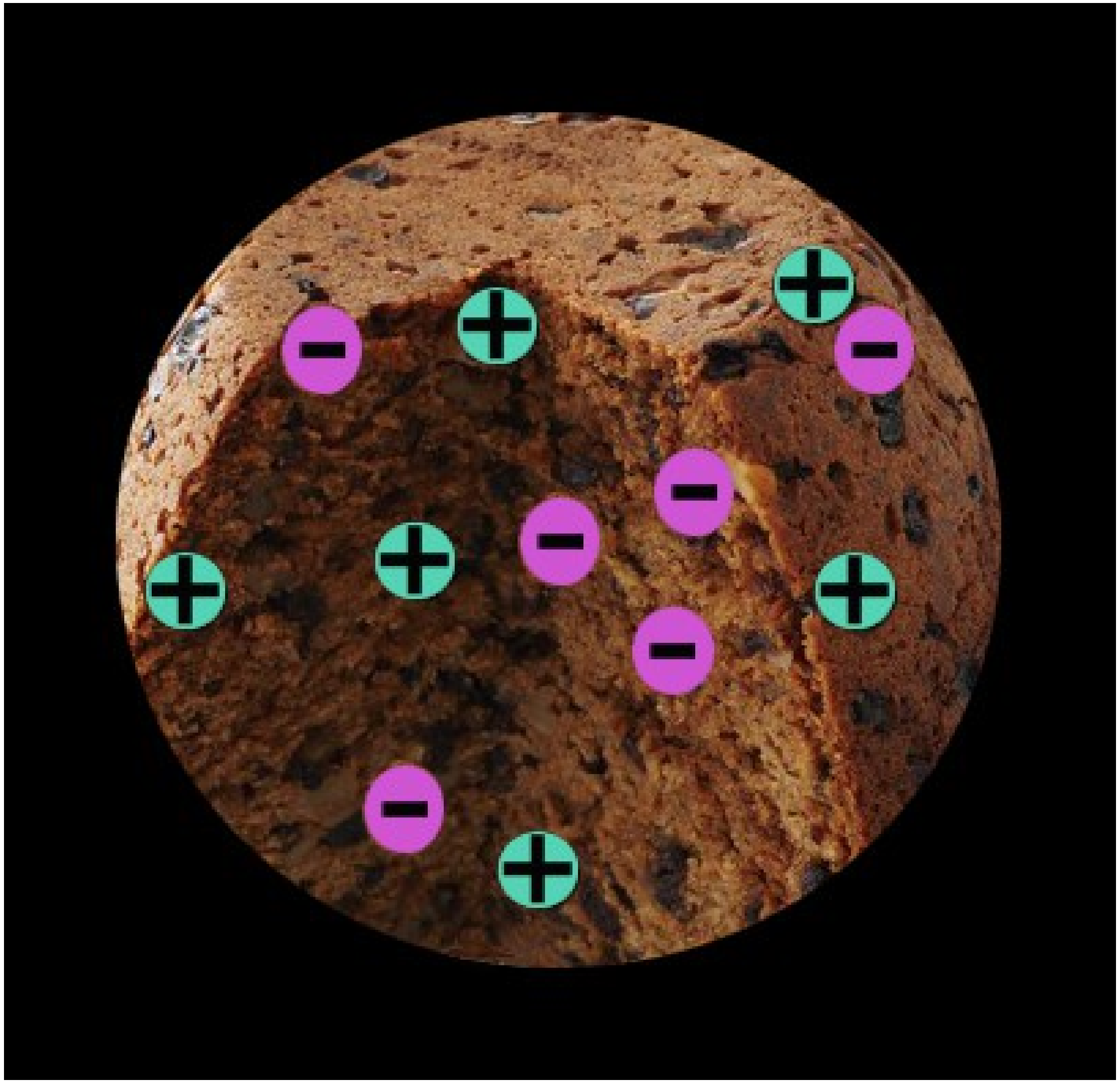


J.J. Thomson's discovered the electron in 1897. Thomson was studying "cathode rays", rays are emitted at the cathode, or negative terminal in a vacuum tube. The nature of cathode rays was controversial. It had been proposed that the cathode rays were negatively charged 'radiant matter'. Many Europeans thought they were an 'ethereal disturbance', like light.

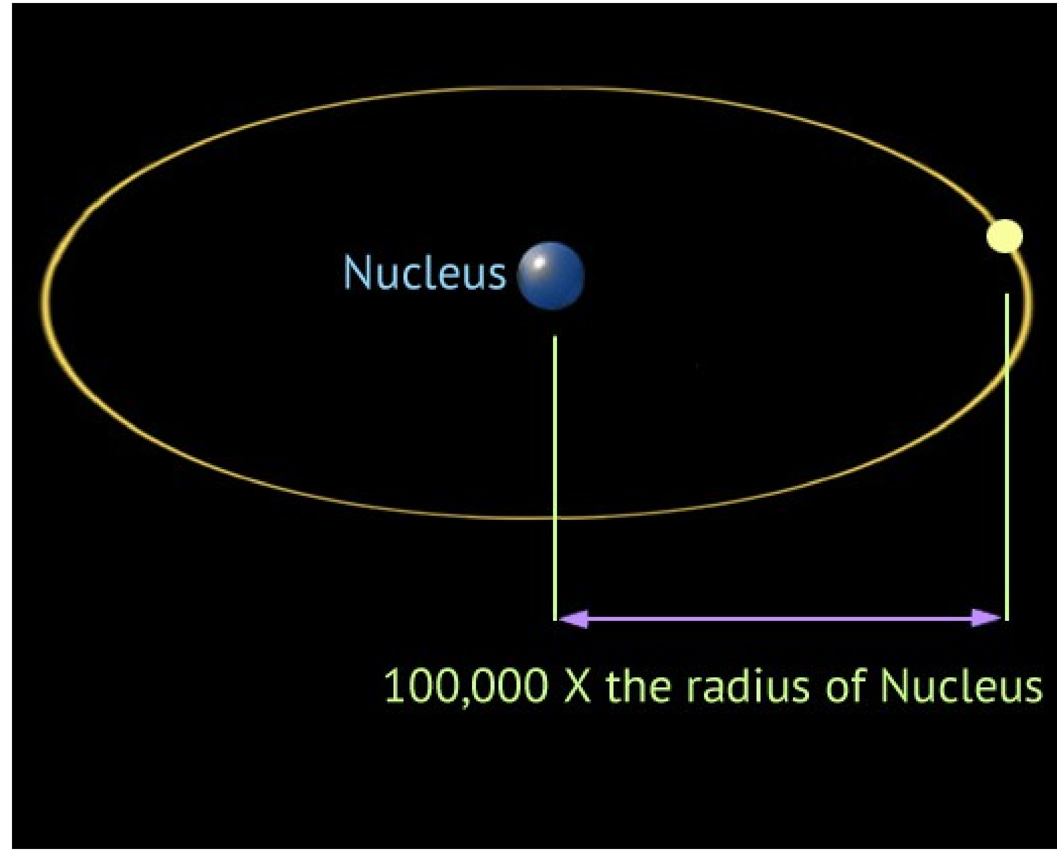
Thomson thought the rays must be particles, In Germany, Heinrich Hertz had observed the rays passing through thin sheets of gold. It seemed impossible that particles could pass through solid matter.



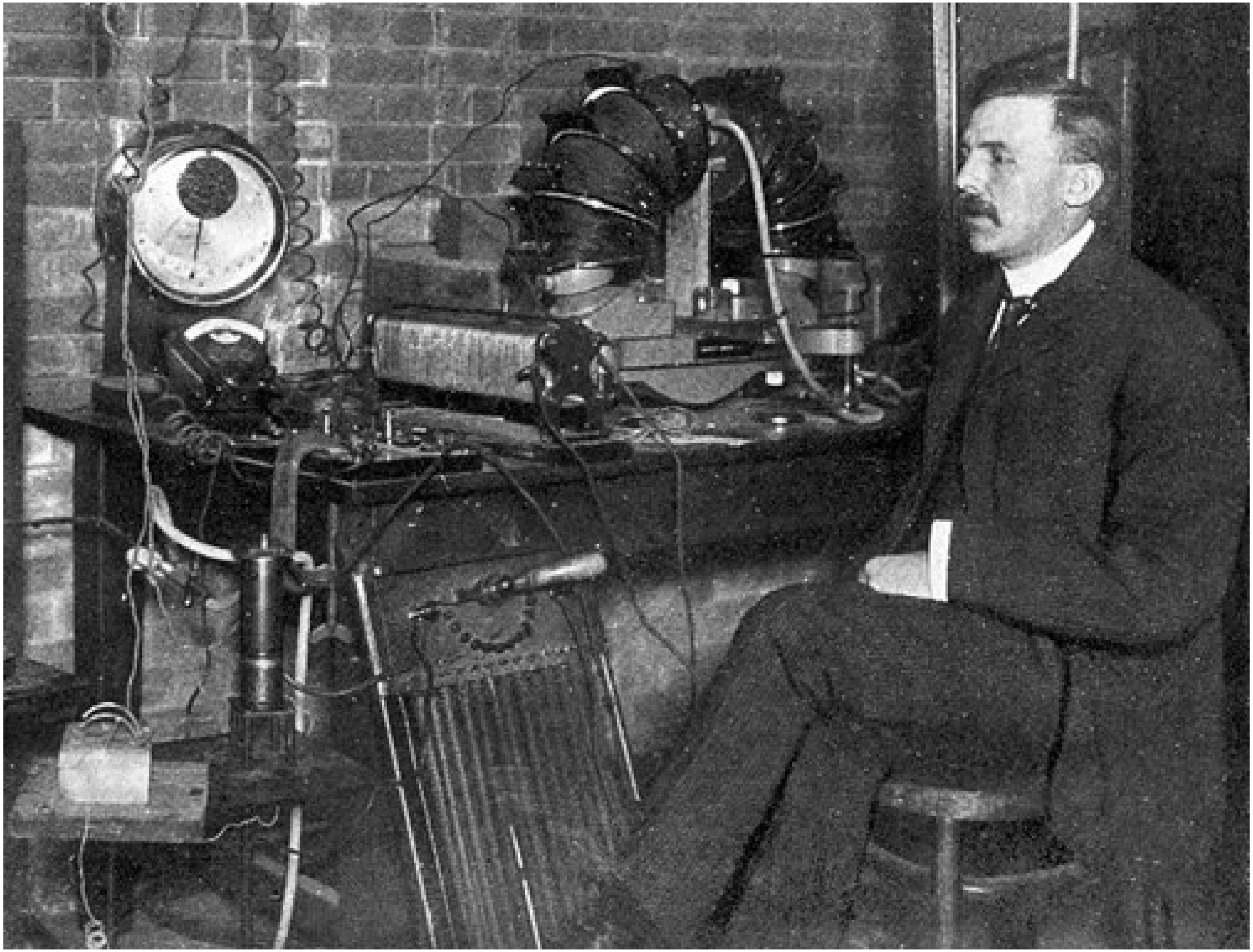
J.J. Thompson proposed a conception of matter as charged particles, evenly distributed.



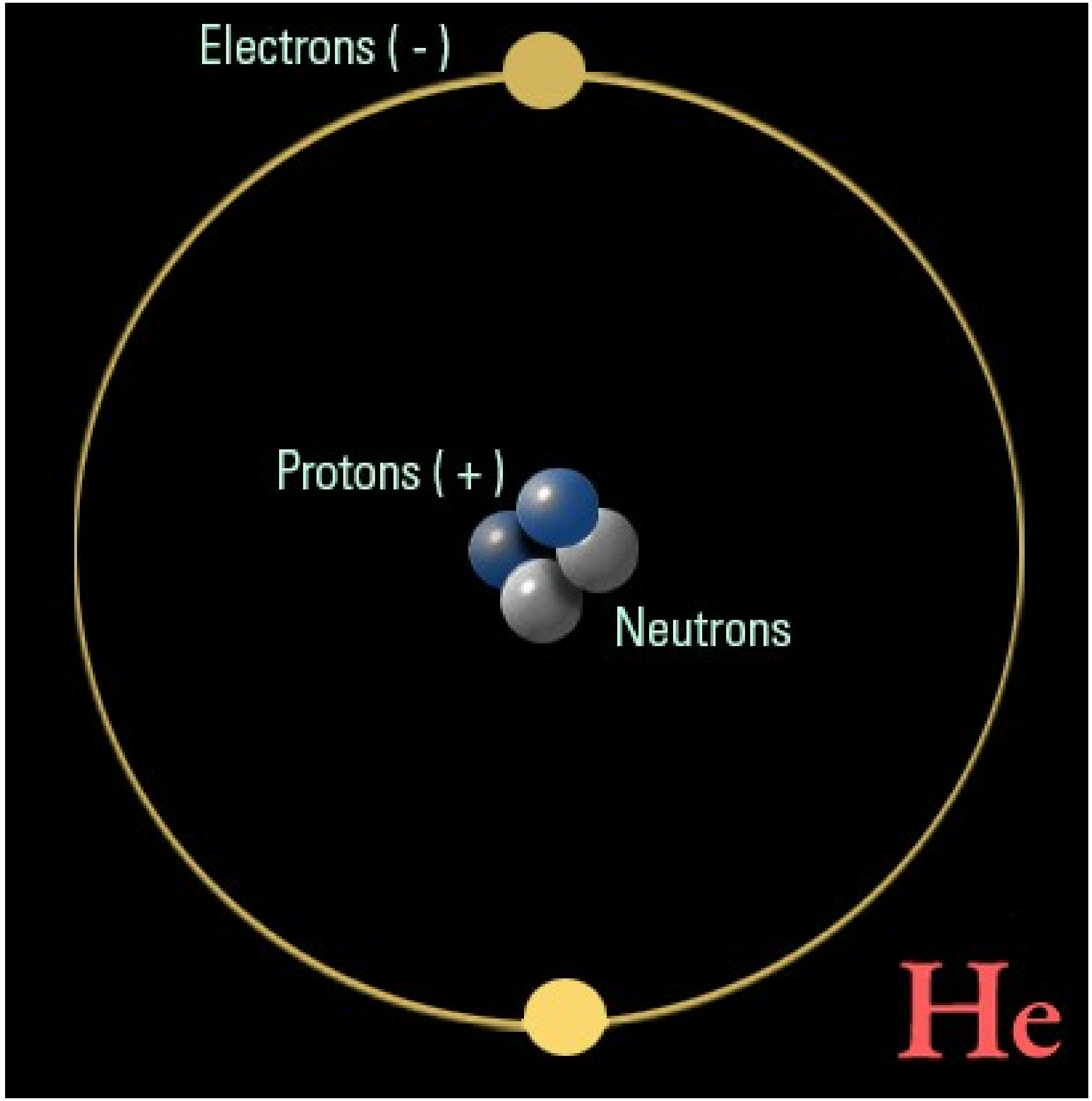
J.J. Thompson: “...like plums in plum pudding.”



In 1911 Ernest Rutherford discovered that (contrary to the "plum pudding" model) the atomic structure is mostly empty space, with electrons orbiting the nucleus at a distance of 100,000 times the nucleus' radius.

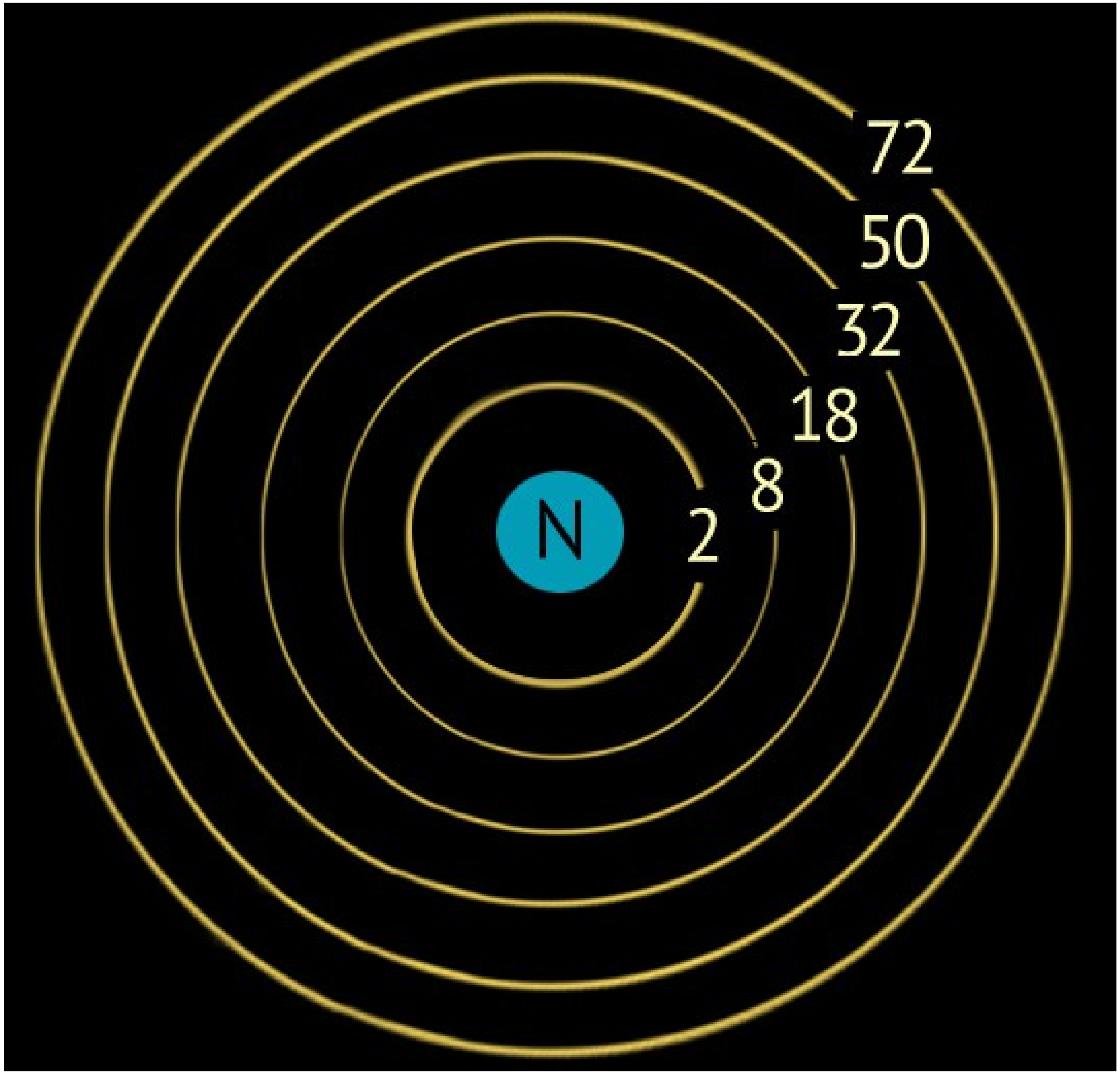


“It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you.”



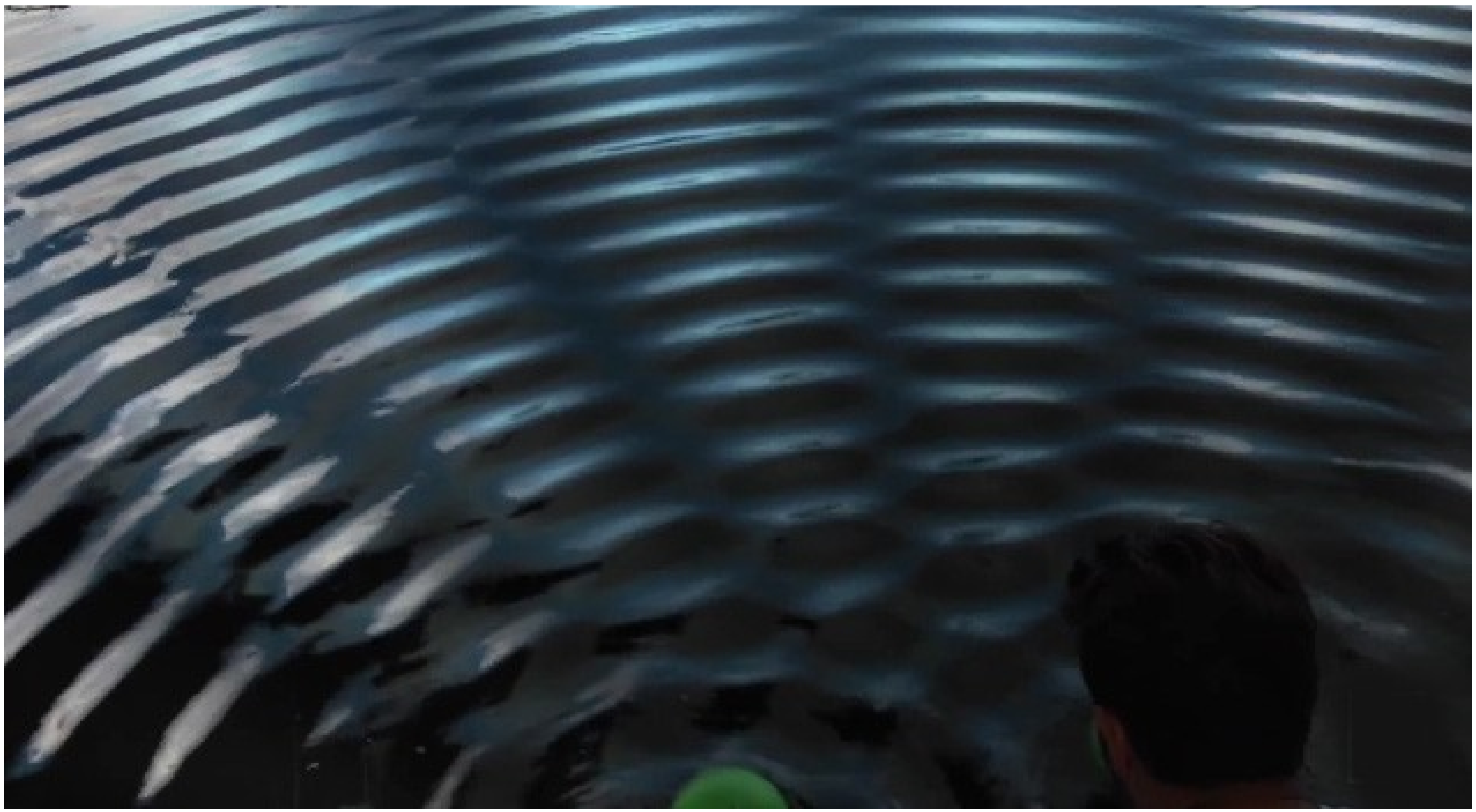
"Rutherford-Bohr model" of the atom

Niels Bohr developed it in 1913 after working with Rutherford. It has since had numerous amendments to account for discoveries in *quantum mechanics.*

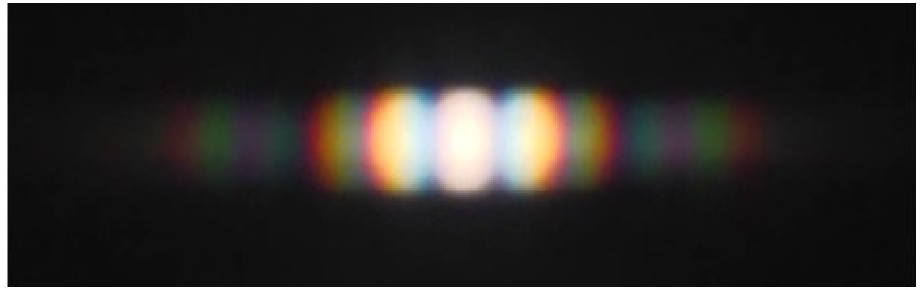


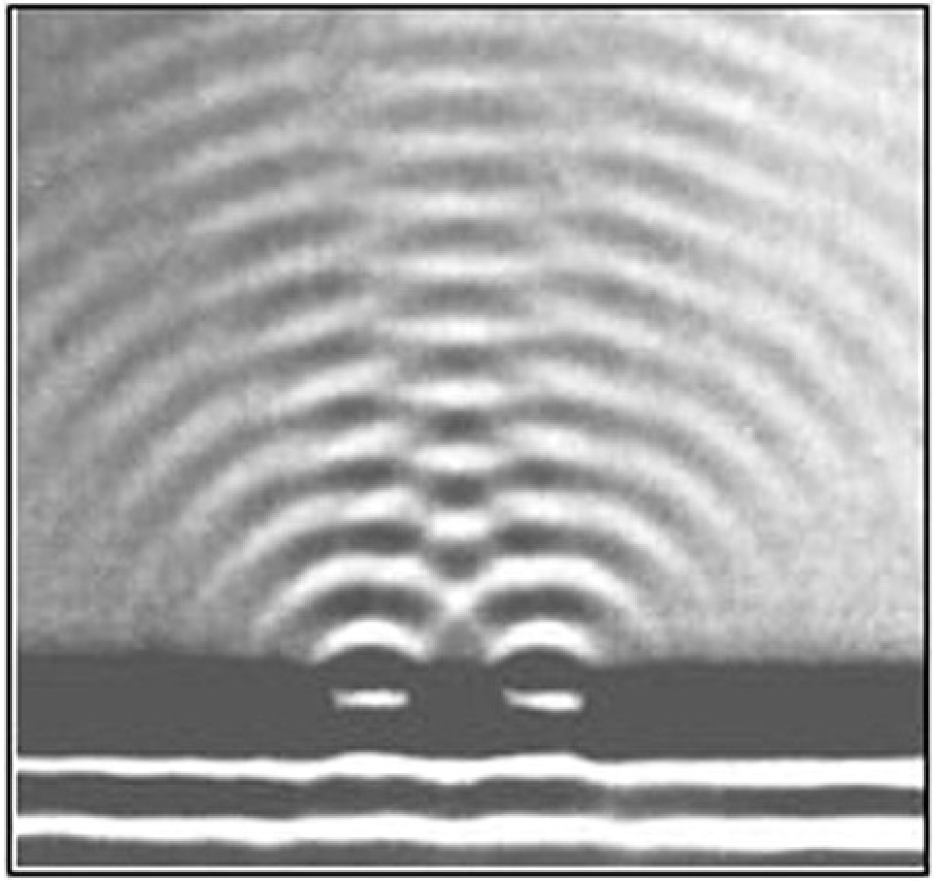
Bohr discovered that electrons could only exist in specific “quantized” orbits, with only a certain number of electrons allowed in each orbit or “shell”. The outer “valence” shell was key in how the atom interacted with other atoms.

Example of Quantum Phenomena: Photons in the “Double Slit Experiment”



This experiment, performed by Thomas Young in 1801, displays the fundamentally probabilistic nature of quantum phenomena.





Individual photons were observed to travel in “probability waves” that went through *both slits at the same time.* Electrons have been shown to exhibit the same behavior.

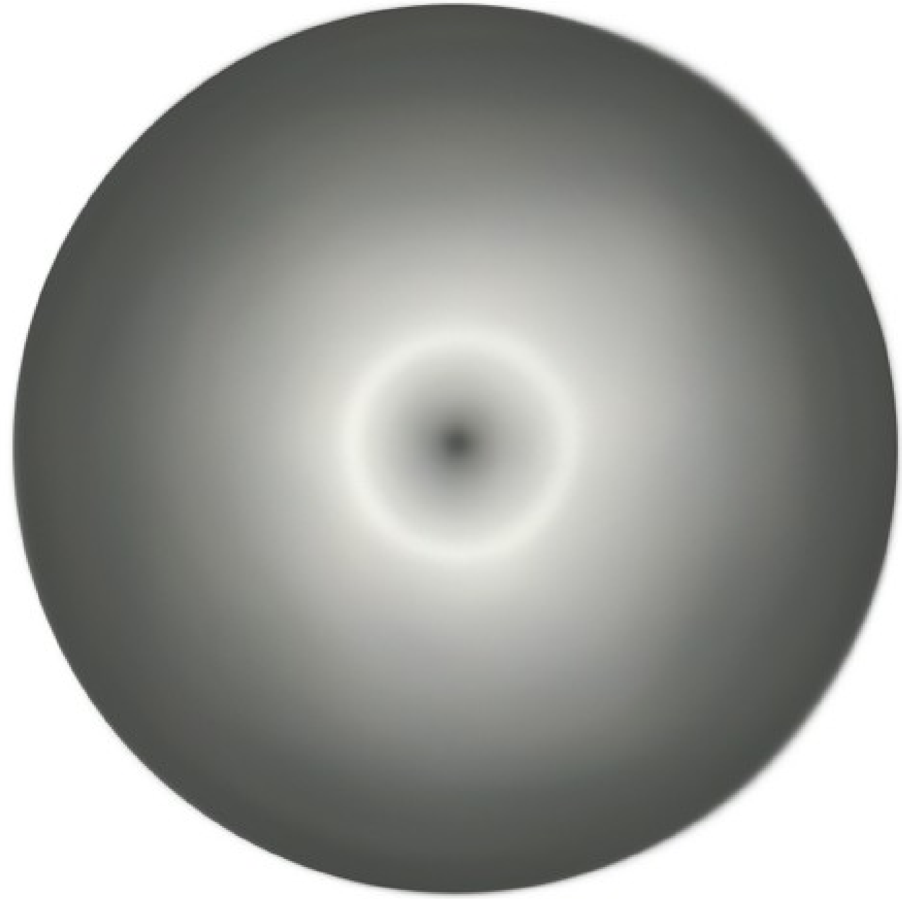
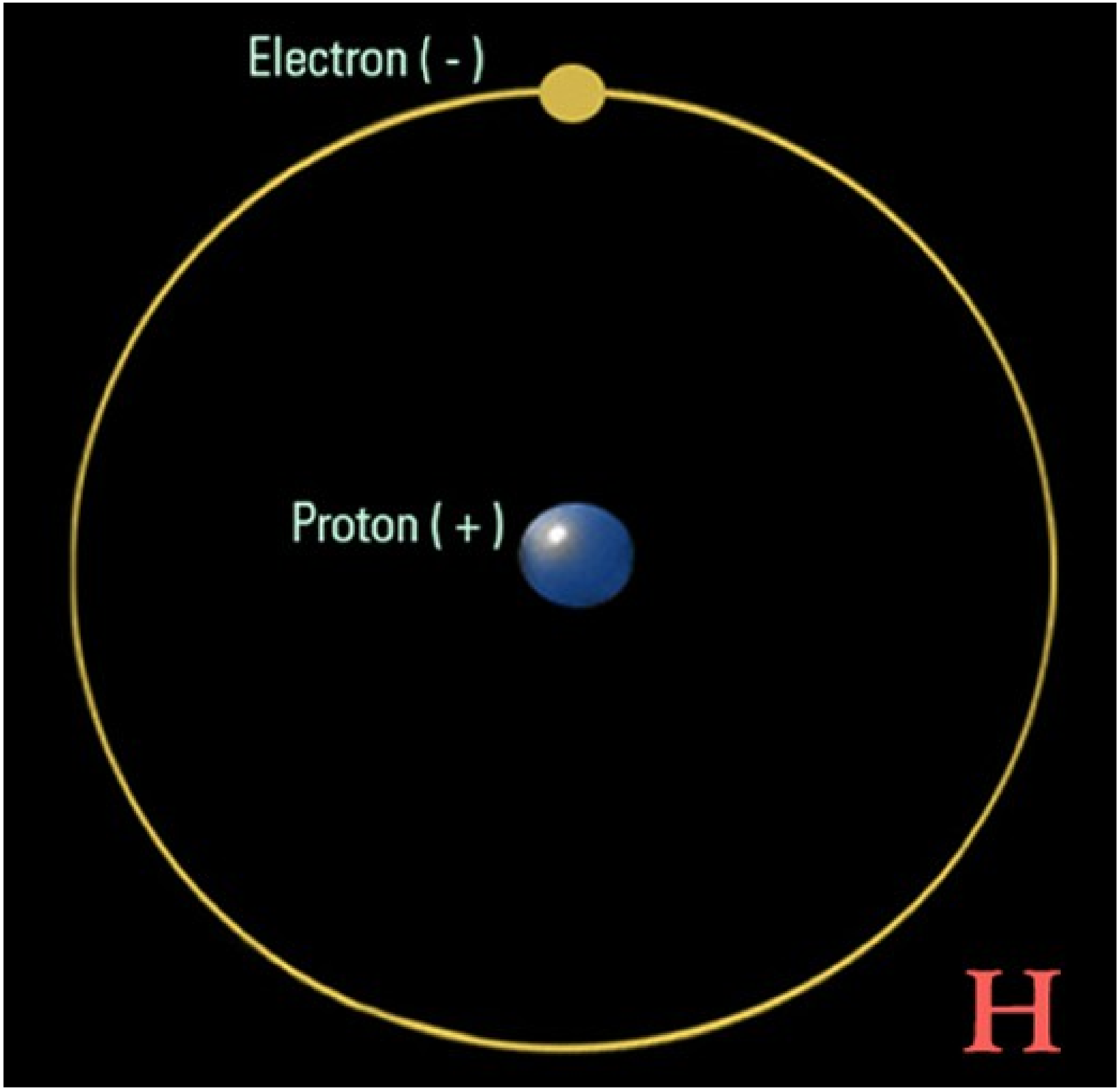


Illustration: Brian Cox "The Quantum Universe"

The current standard model in physics shows that electrons actually exists at multiple places at the same time (!) (...in something called a "probability wave" or "probability cloud".)

-Until it collides with something like a photon, "collapsing the probability wave" and causing it to exist in one specific location.



Hydrogen has the simplest atomic structure: One proton and one electron.
It's the most common element in the known universe.

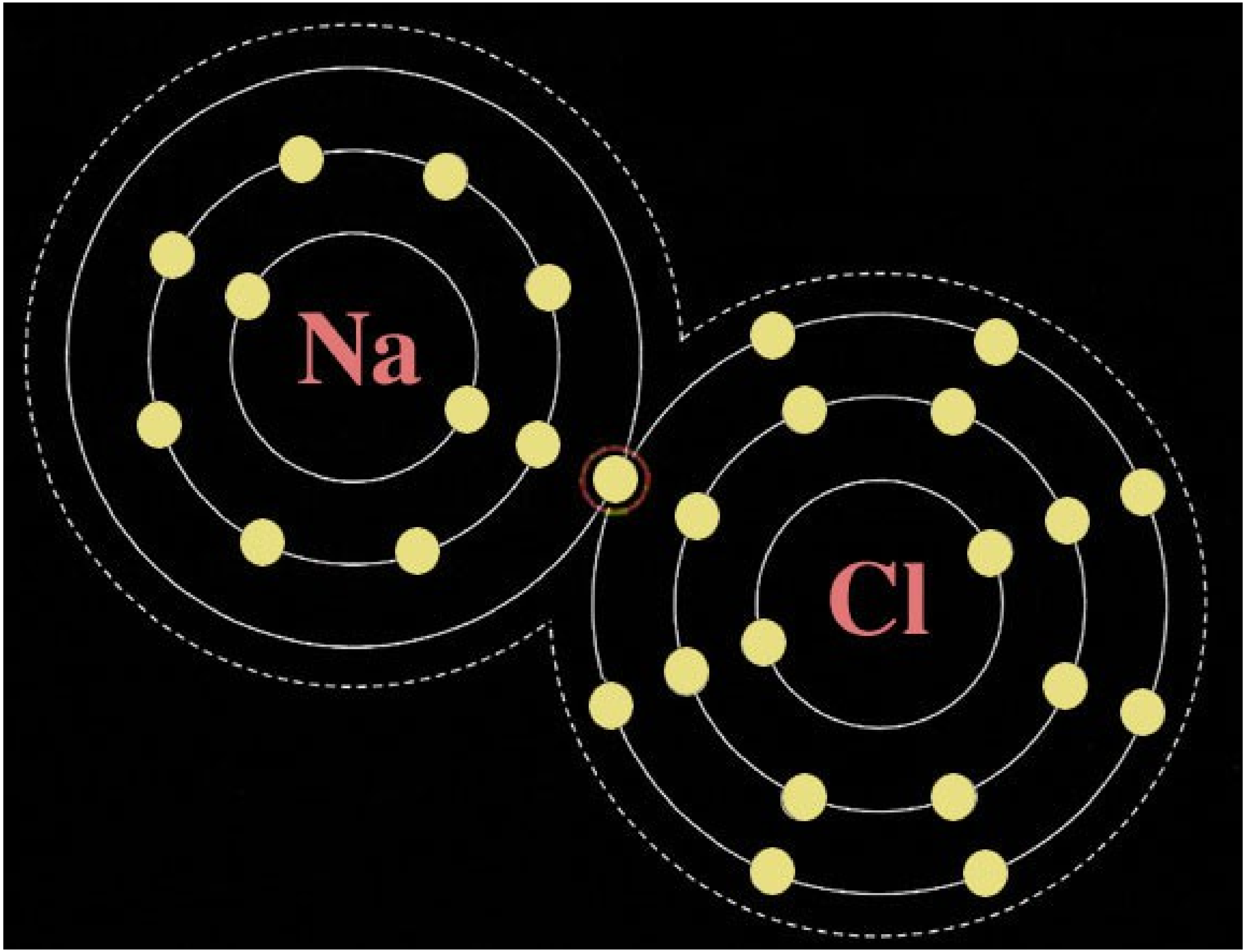
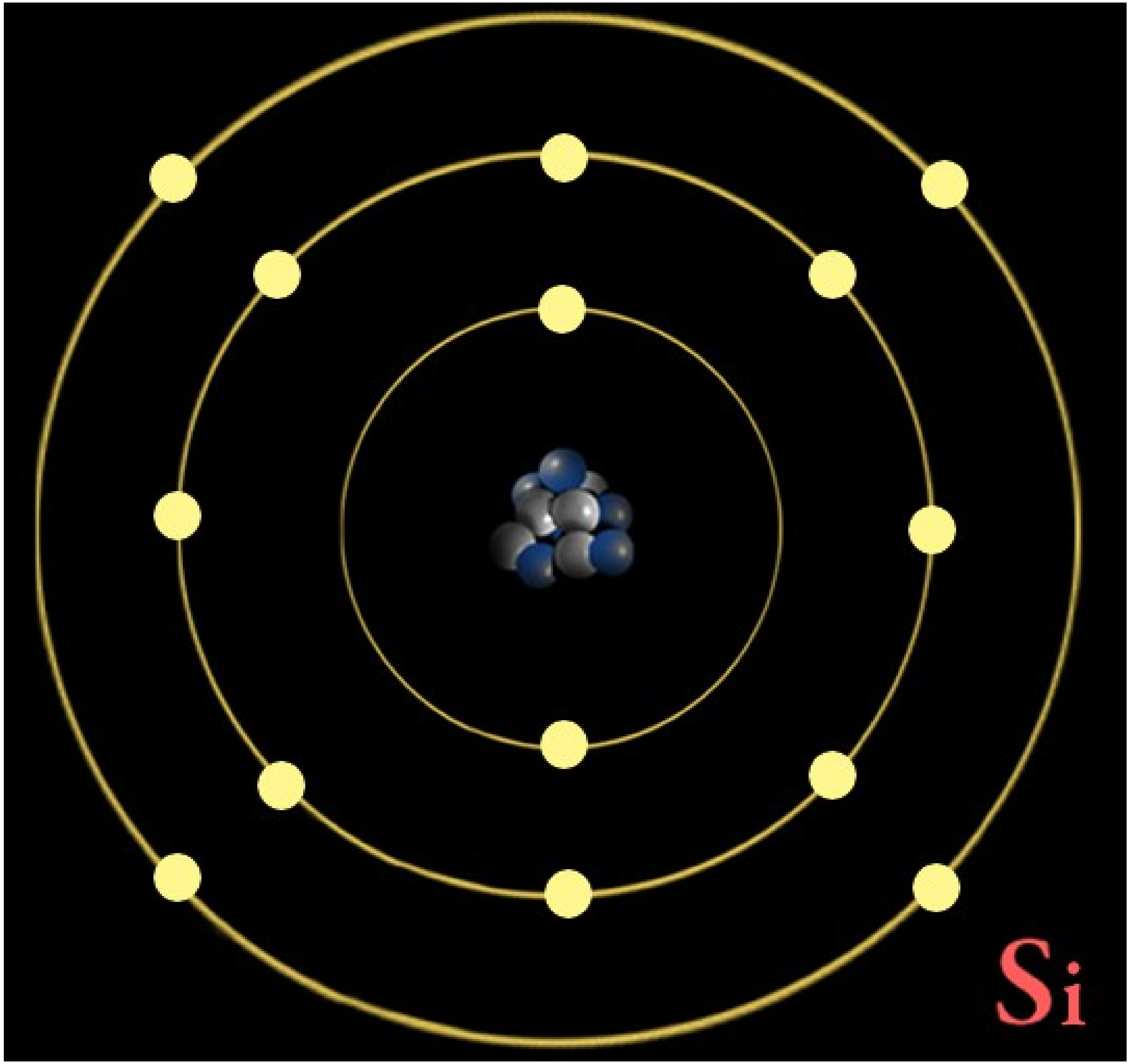
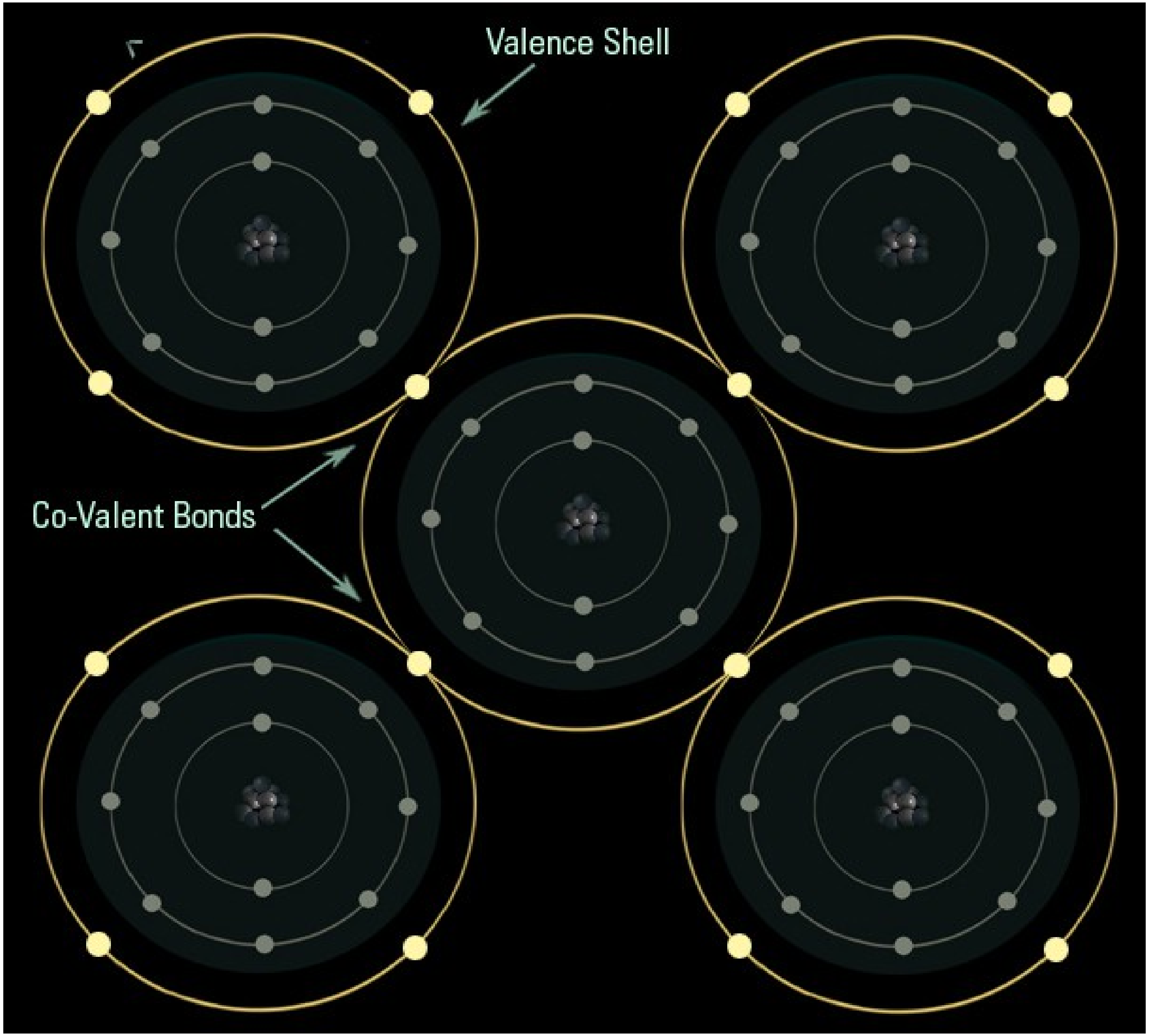


Table salt forms stable crystals because sodium (Na) has one lonely electron that travels easily, and chlorine's 7 valence electrons can happily accommodate an 8^{th}.
They form a molecule with “co-valent bonds” between it's atoms.

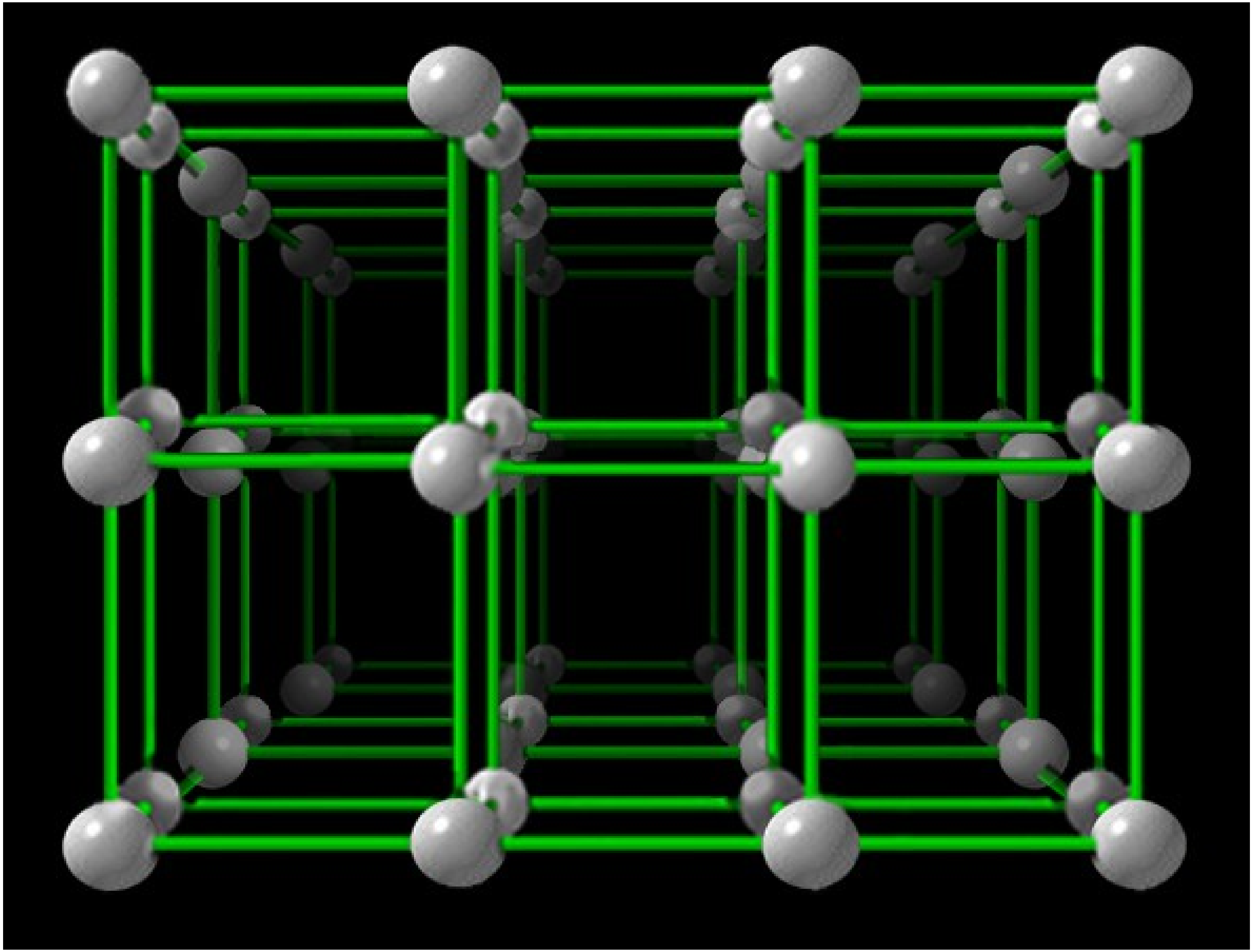


Silicon has 14 protons, 14 neutrons and 14 electrons
(4 electrons in the outer “valence” shell -which can hold 18.)



Silicon Crystal Lattice

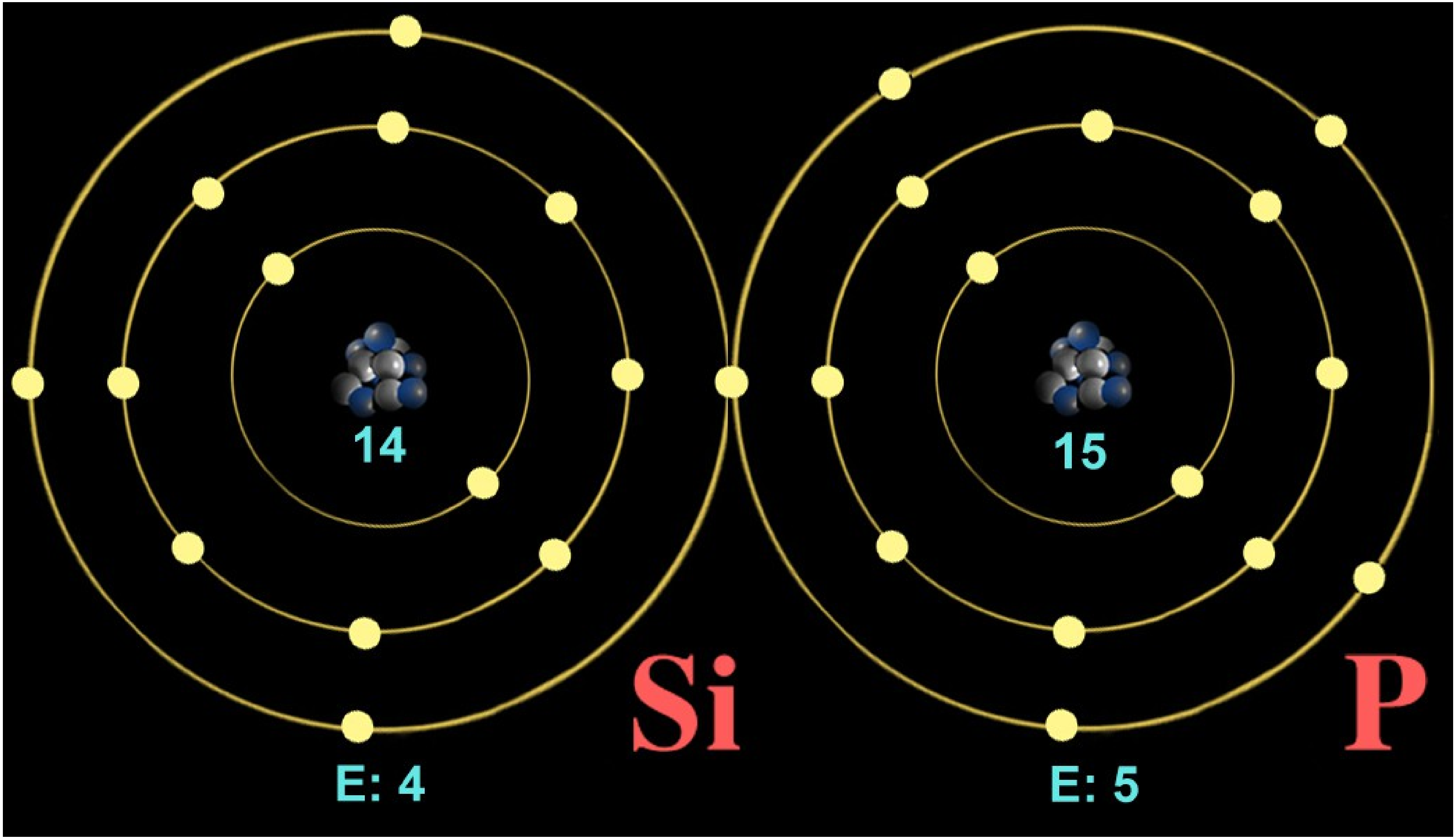
Like salt, **silicon can form crystals**. The 4 electrons in the outer shell form a structural connection with with adjacent atoms by sharing electrons in their valence shells. (co-valent bonds)



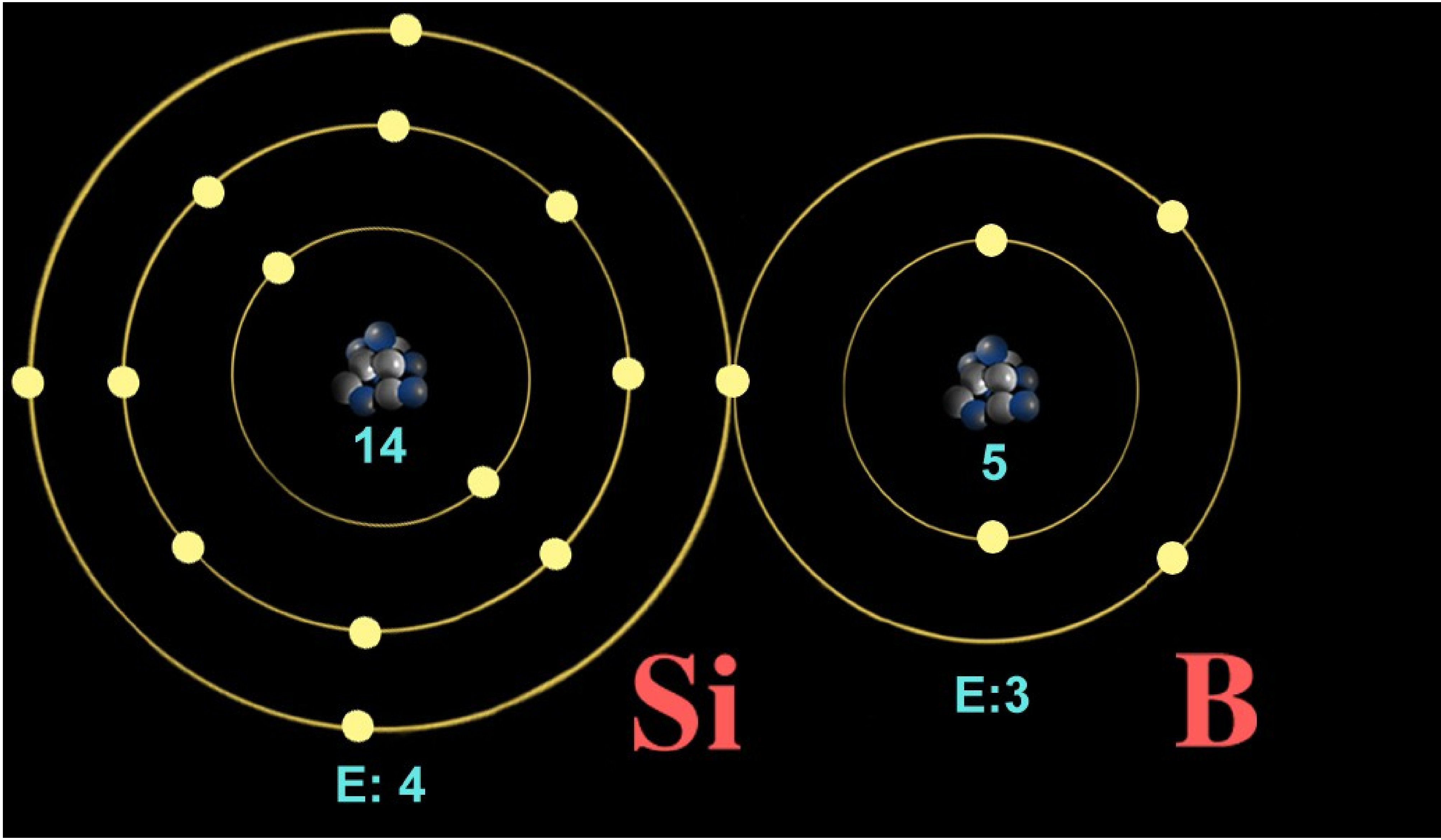
Another way to visualize the structure of silicon (focused on the electrons) is as a lattice or 3D matrix of silicon atoms bonded together with 4 co-valent bonds (to the electrons in the valence shell.)

The magic of semiconductors...

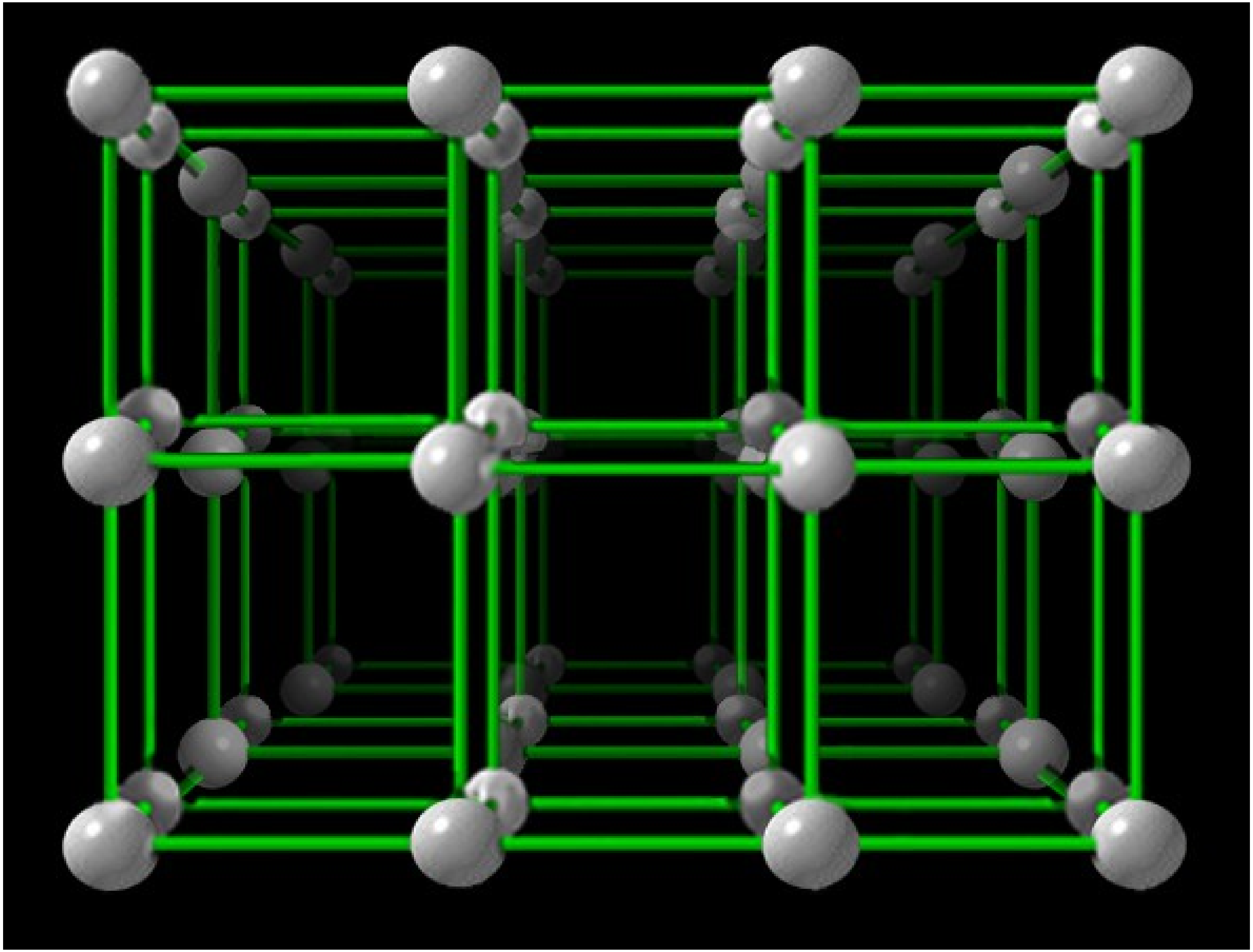
...comes from “doping” silicon crystals at the molecular level by introducing other elements to bond with, elements with different amounts of valence electrons.



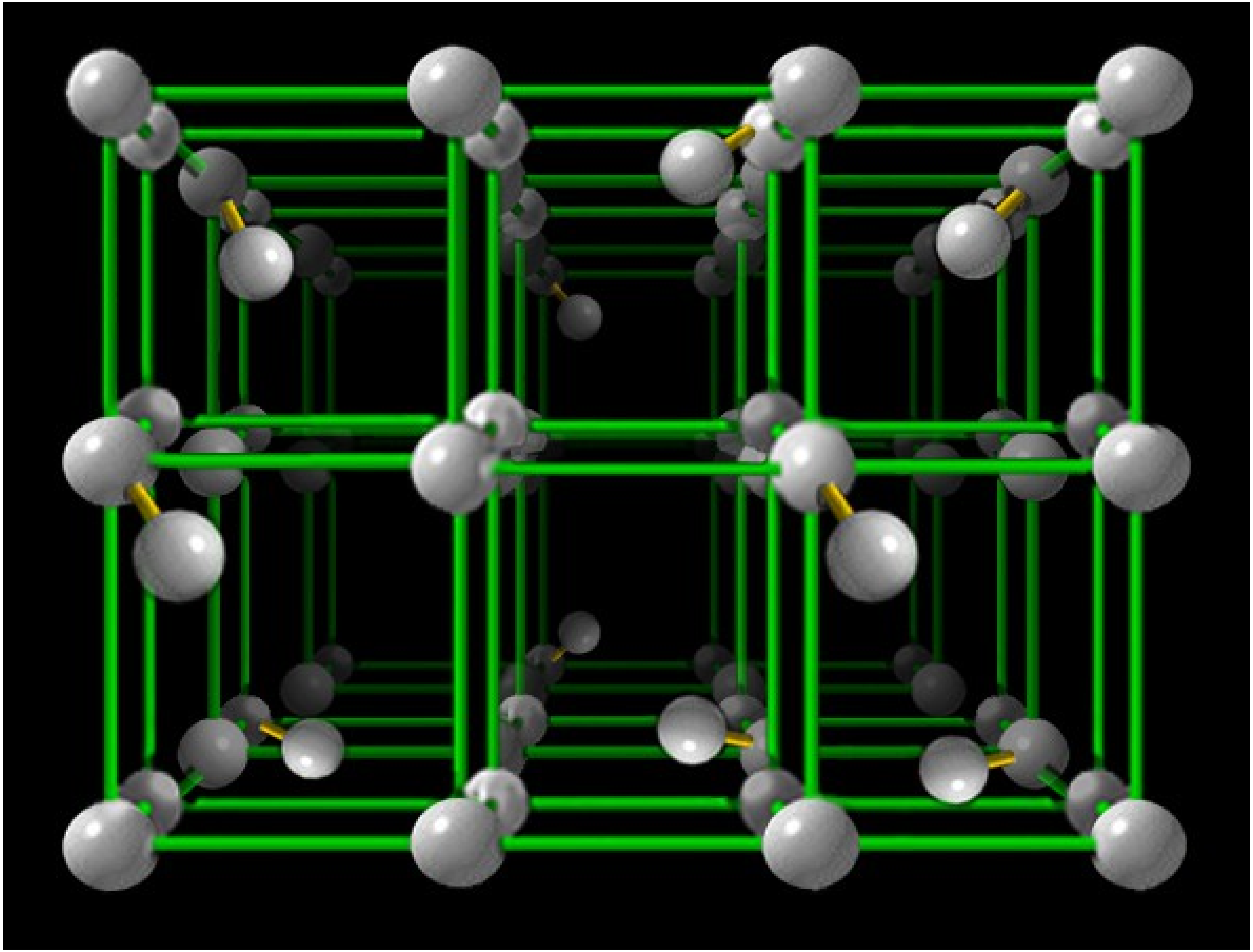
“Doping” with Phosphorus creates “N Type” Silicon.
It has extra (negatively charged) electrons in valence shells.



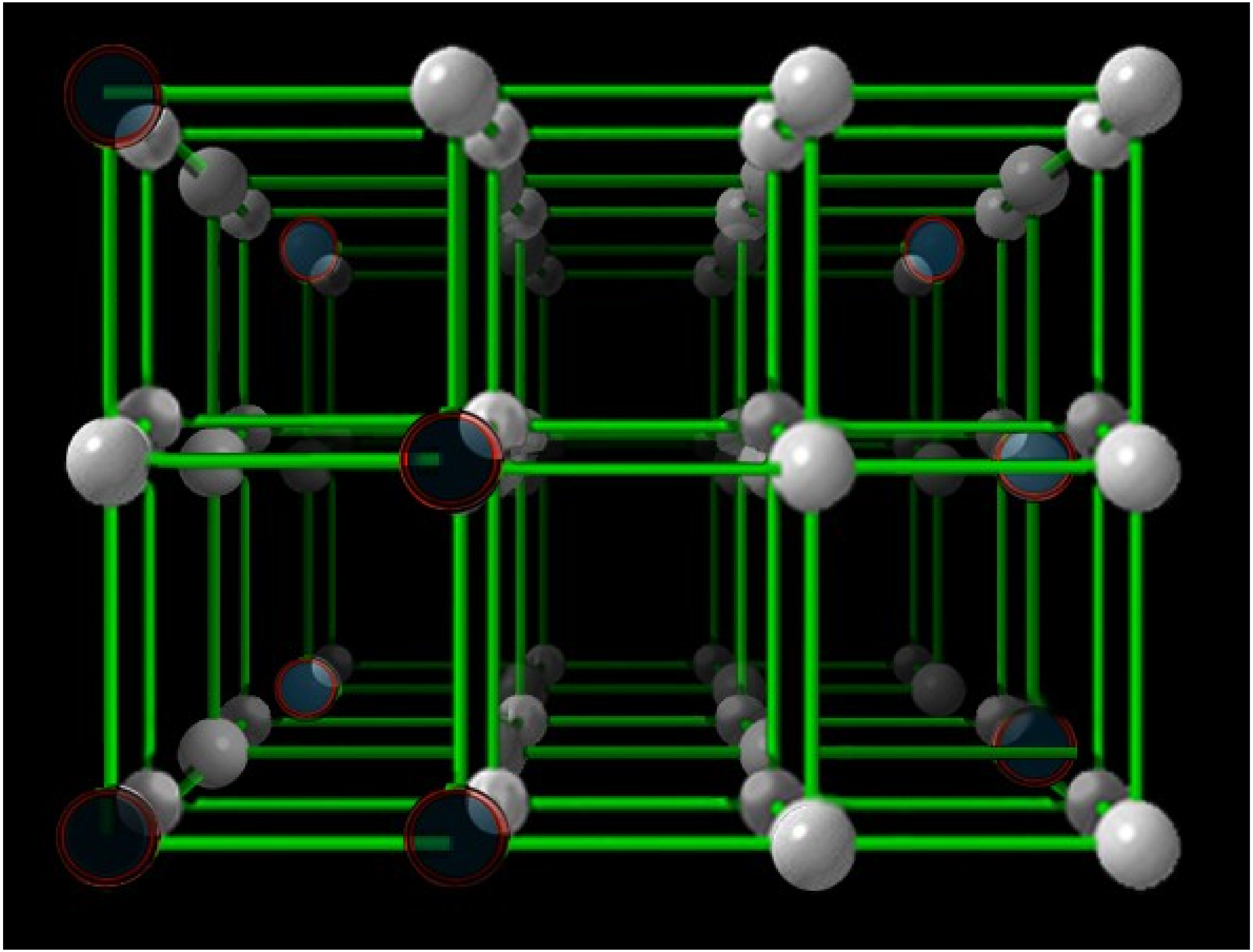
“Doping” with Boron creates “P Type” Silicon.
With fewer valence electrons, it introduce “holes” in the silicon crystals that can hold positive charge.



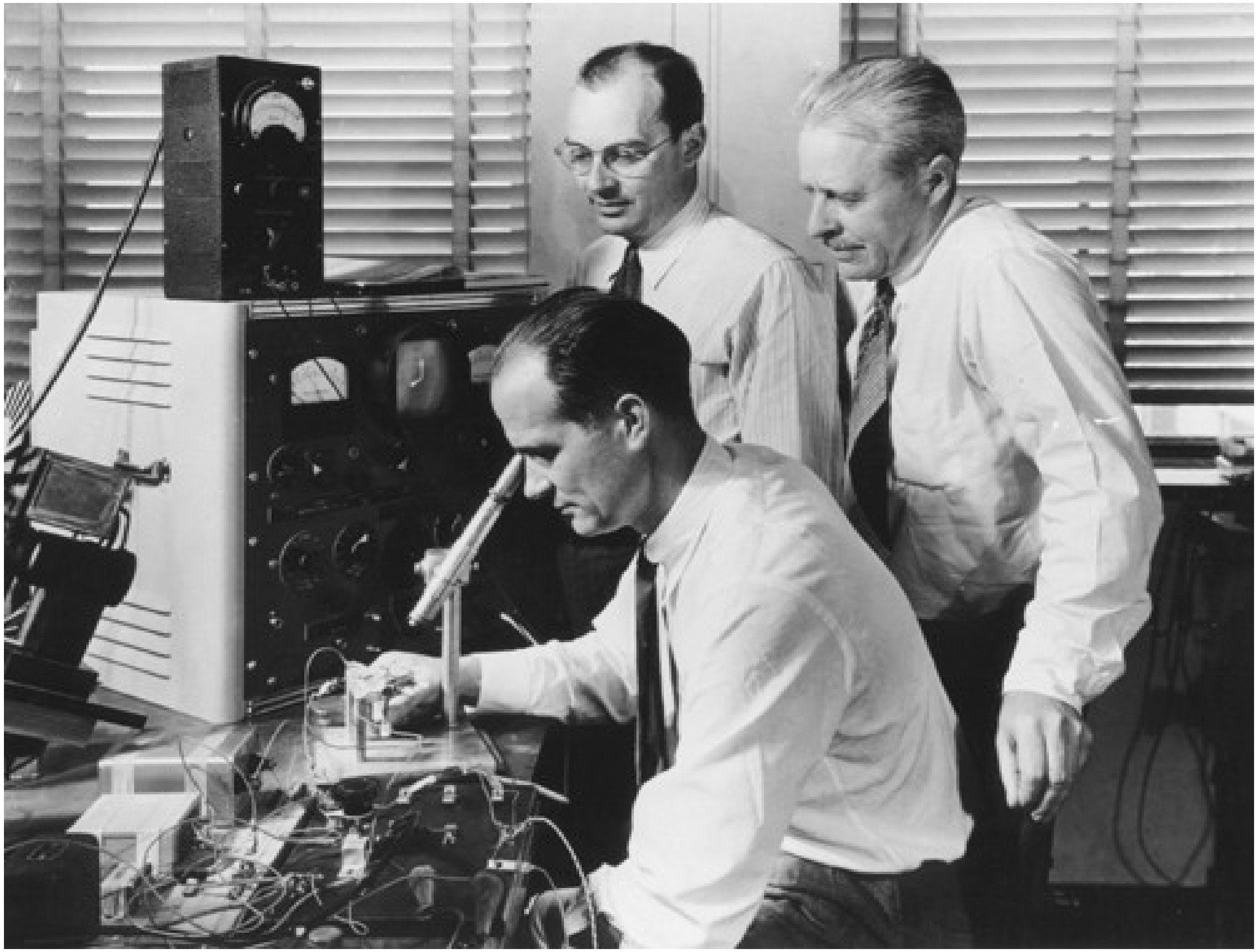
Another way to visualize the structure of silicon (focused on the electrons) is as a lattice or 3D matrix of silicon atoms bonded together with 4 co-valent bonds (to the electrons in the valence shell.)

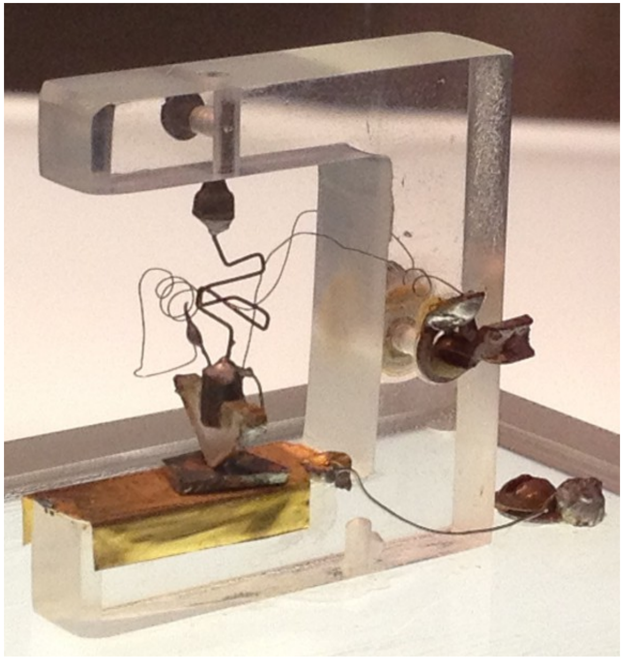


Silicon crystal **"doped" with Phosphorus** is full of extra (negatively-charged) electrons, and is called "**N-Type**" silicon

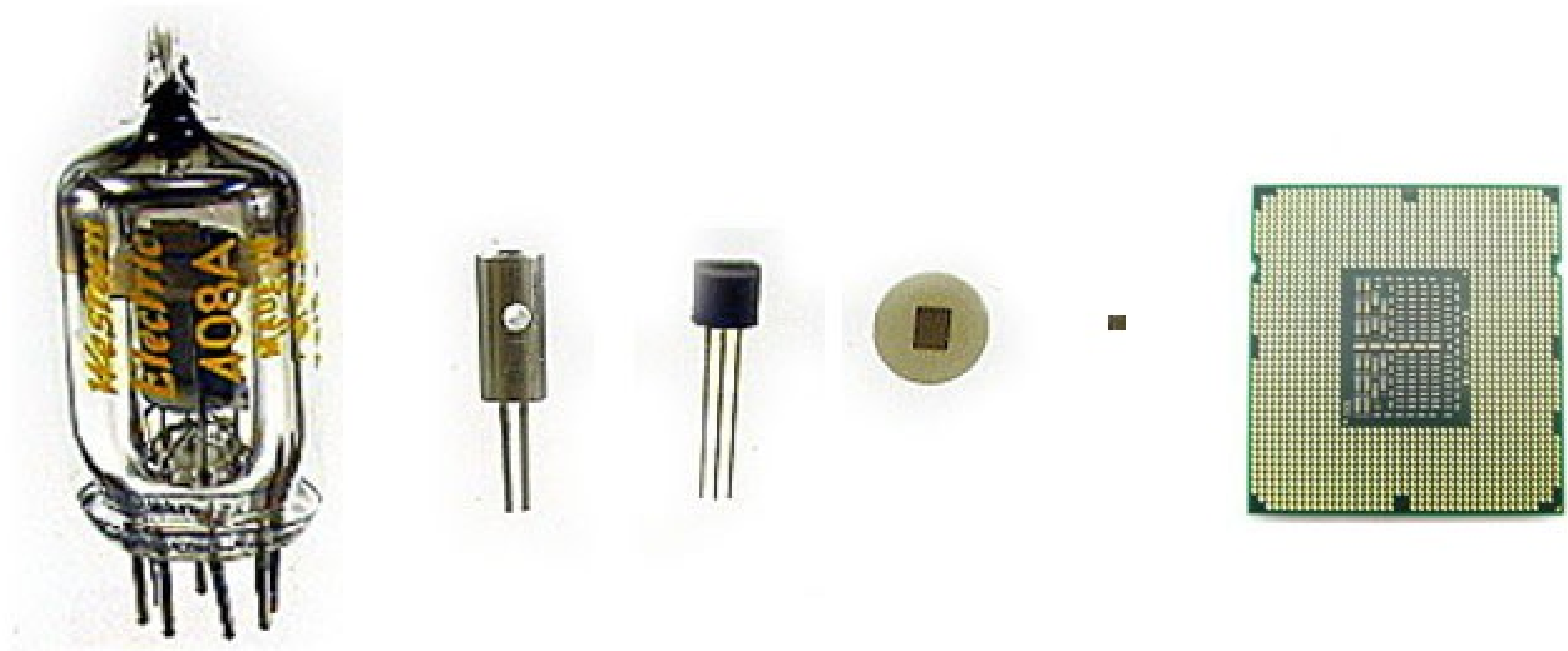


Silicon crystal **“doped” with Boron** is full of (positively-charged) “holes”, and is called “**P-Type**” silicon

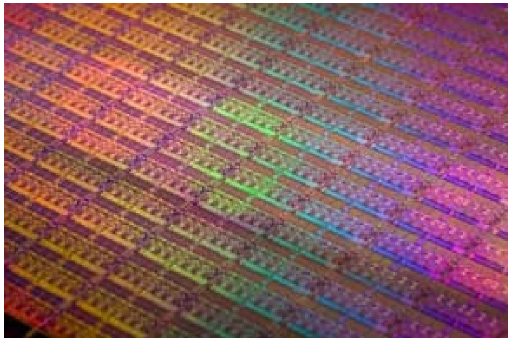


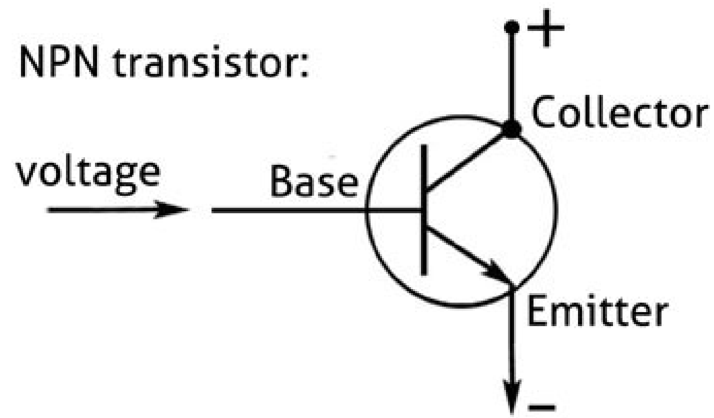


The inventors at Bell Labs, 1948:
John Bardeen, William Shockley and Walter Brattain
and their original device

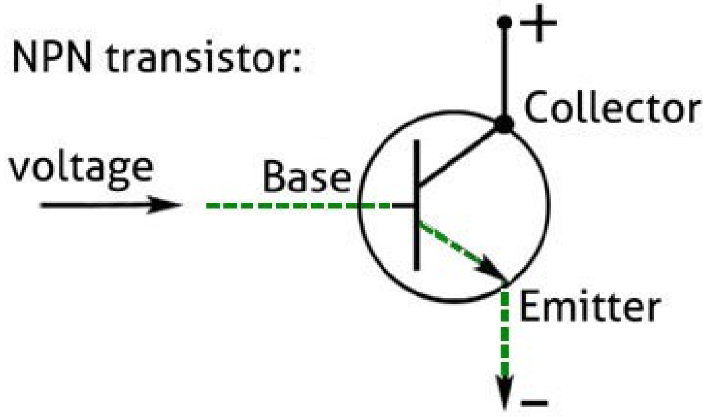


The evolution from vacuum tubes to chips.
-The current generation of Intel i7 ships have *1.16 billion* transistors on a single integrated chip.

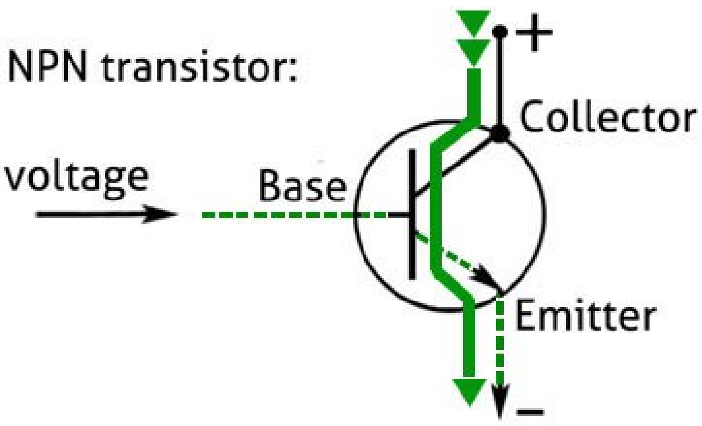




An electromotive potential (voltage) of about .7 volts applied to the base...

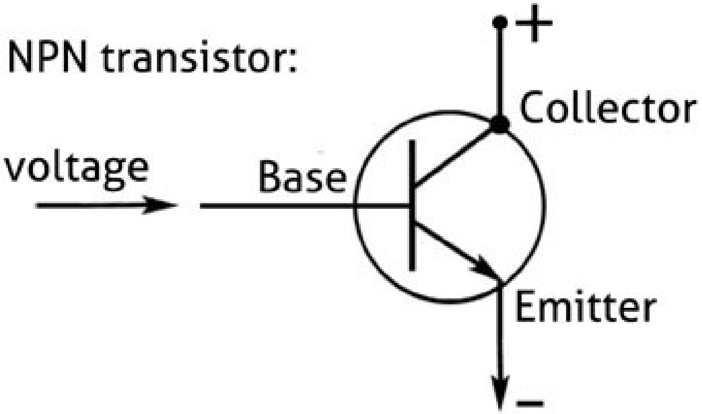


An electromotive potential (voltage) of about .7 volts applied to the base...

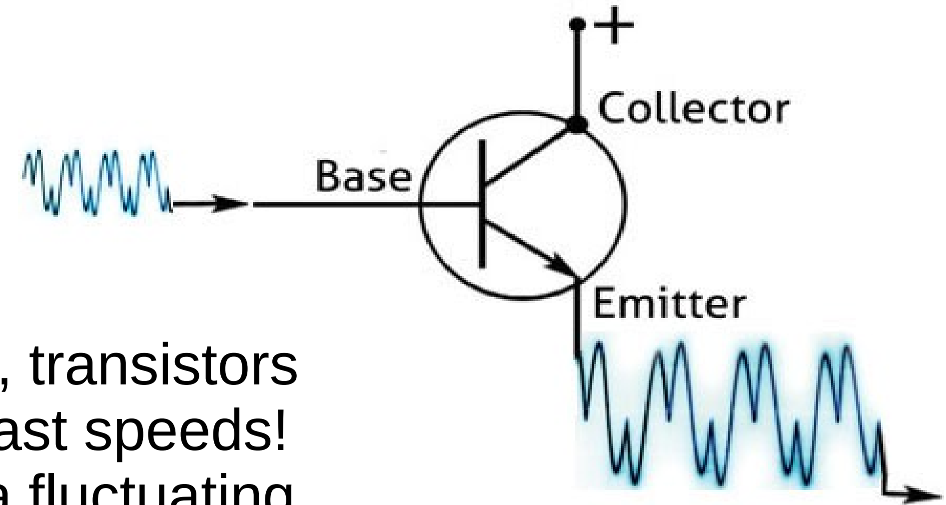


An electromotive potential (voltage) of about .7 volts applied to the base...

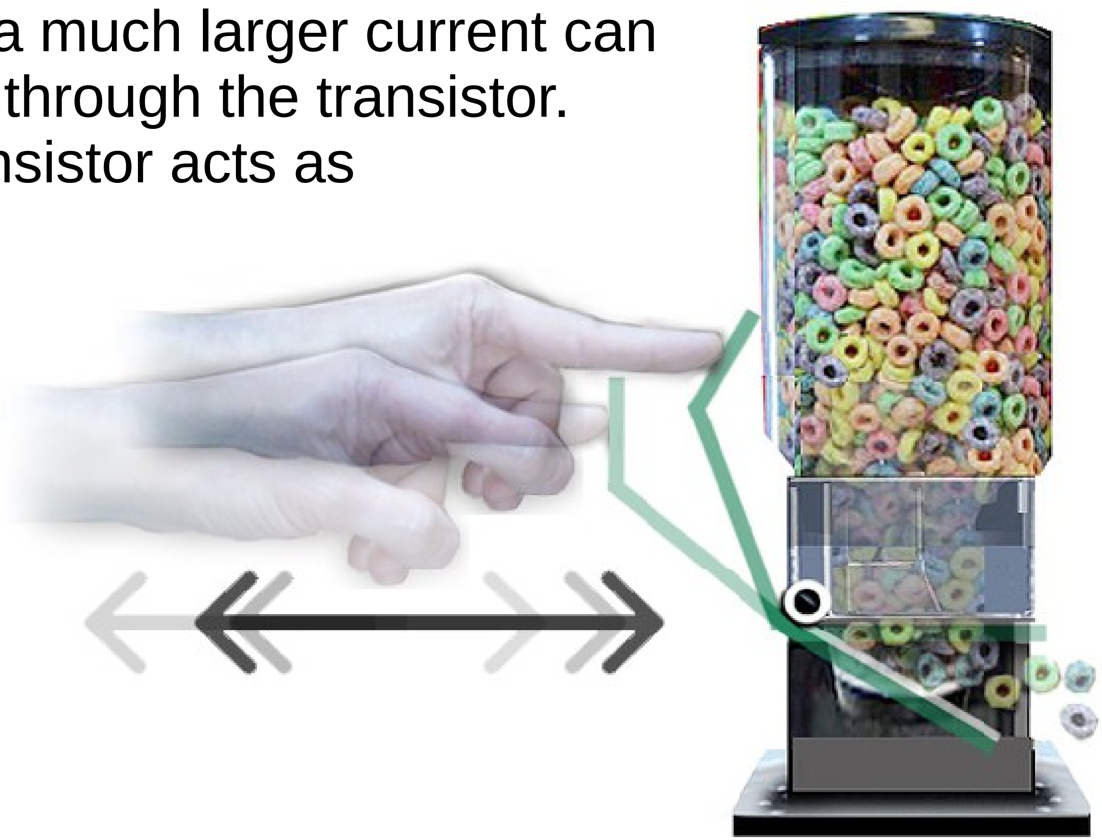
...allows current to flow from the collector and out the emitter.



So this example shows the transistor acting like **a switch**. It either allows current to pass through, or else the impedence is so high that no electricity flows.



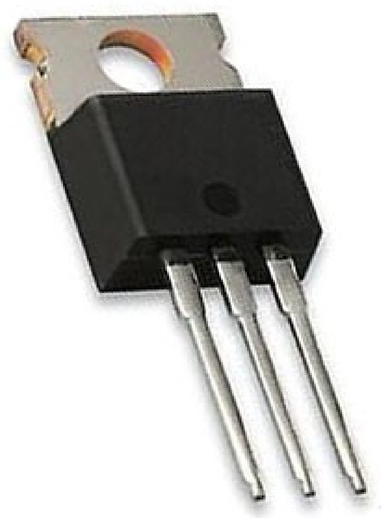
But unlike mechanical switches, transistors can switch current at lightning fast speeds! So if the current at the base is a fluctuating signal (like audio), a much larger current can be allowed to pass through the transistor.
In this case the transistor acts as an **amplifier.**



There are **many types** of transistors. In our first project, we will be using “NPN” transistors, essentially a three-layer sandwich of N-type and P-Type silicon.

Typical low-current transistors.
They look like this:

High amounts of current (like the amounts used by motors) can generate enough heat to burn-damage transistors.
So, in those cases we use “power transistors”.
They have a heat-sink on them and look like this:



Another common distinction regarding types of transistors is the difference between:

1) **metal–oxide–semiconductor field-effect transistors (MOSFET)**

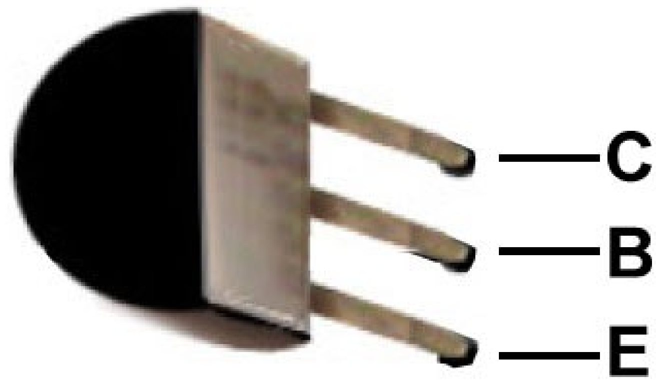
and

2) **bipolar-junction transistors**

MOSFET are by far the most common. Their terminals are usually referred to as “**source**”, “**gate**” and “**drain**”. They use the effect of an electromagnetic field to operate (instead of base-emitter current), so they are cooler and draw almost no current. They are the kind found miniaturized in computer chips. However they are more easily damaged, so artist-inventors often prefer bipolar transistors.

Bipolar-junction transistors are very robust and slightly cheaper than MOSFETs. Their three terminals are the “**collector**”, “**base**” and “**emitter**”.

The “2n2222 Bipolar Junction Transistor”



Viewed from above, with the flat face on the right, you can identify the pins as:

top: **Collector**
middle: **Base**
bottom: **Emitter**

Fun with transistors.

Enjoy living in the 21^{st} century!