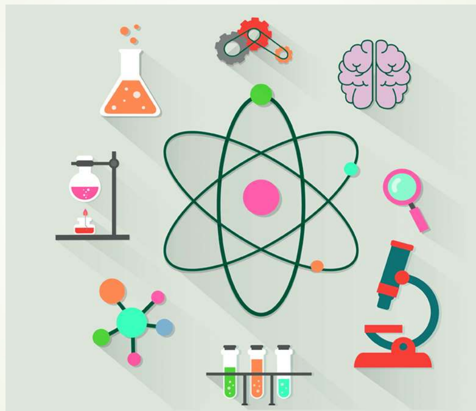
Small Things (are) Matter



John Michael Preston

Understanding energy, the behavior of particles and waves, and the willingness to imagine realities that seem absurd provided the tools for exploring the behavior of particles that are too small to see. This knowledge led to revolutions in chemistry, biology, computers, and creation of new materials. In this session, we consider the structure of atoms and how that knowledge created our modern world.

*In 400 B.C.E, Democritus proposed that matter is composed of building blocks separated by a void in which they could move. These building blocks were thought to be the smallest units of their kind and could not be further divided. The Greek word for *uncuttable* is *Atom.*
*The Egyptian word *khem* refers to the fertility of the flood plains around the Nile and their annual rebirth. The Egyptians were concerned with preserving bodies (mummies) using secret compounds that were later called chemicals.
*The study of inanimate materials was called *alchemy* in the West. Alchemists understood that some materials were combinations of others. They sought to identify the elemental substances that were pure and not mixtures.
*Two of the objectives of alchemy were to turn base metals like lead into gold and *to grant immortality. Alchemists did not achieve either objective, but they did identify and discover the properties of many elements.
*Alchemists thought a special stone, called the *philosopher's stone*, might have these abilities. This concept persists in today's culture.

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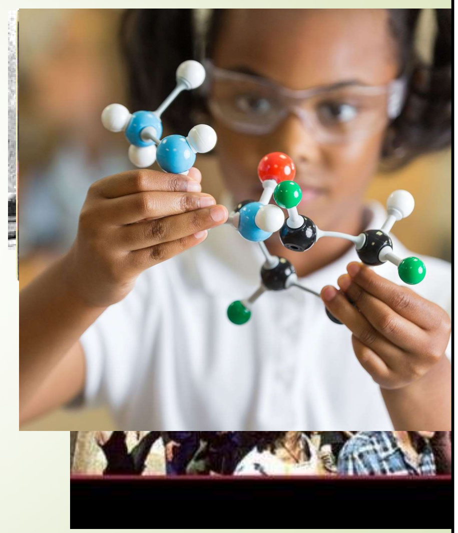
Physical World of the Small

- New Tools: Microscopes, mathematics, scientific method
- Motivating factors:
  - Steam
  - Electricity
  - Beer
  - Fame
- Science of Chemistry



* Following the revolution in scientific reasoning, scientists had new tools such as the microscope, mathematics, the scientific method, and laws of conservation to help them explore the physical world that was too small to observe directly.
*Several diverse factors motivated them such as:
*Getting more power from steam engines and turbines, *controlling and generating electricity, *brewing beer, and *fame
*The systematic exploration of the elements gave birth to the science of chemistry

Gas Laws

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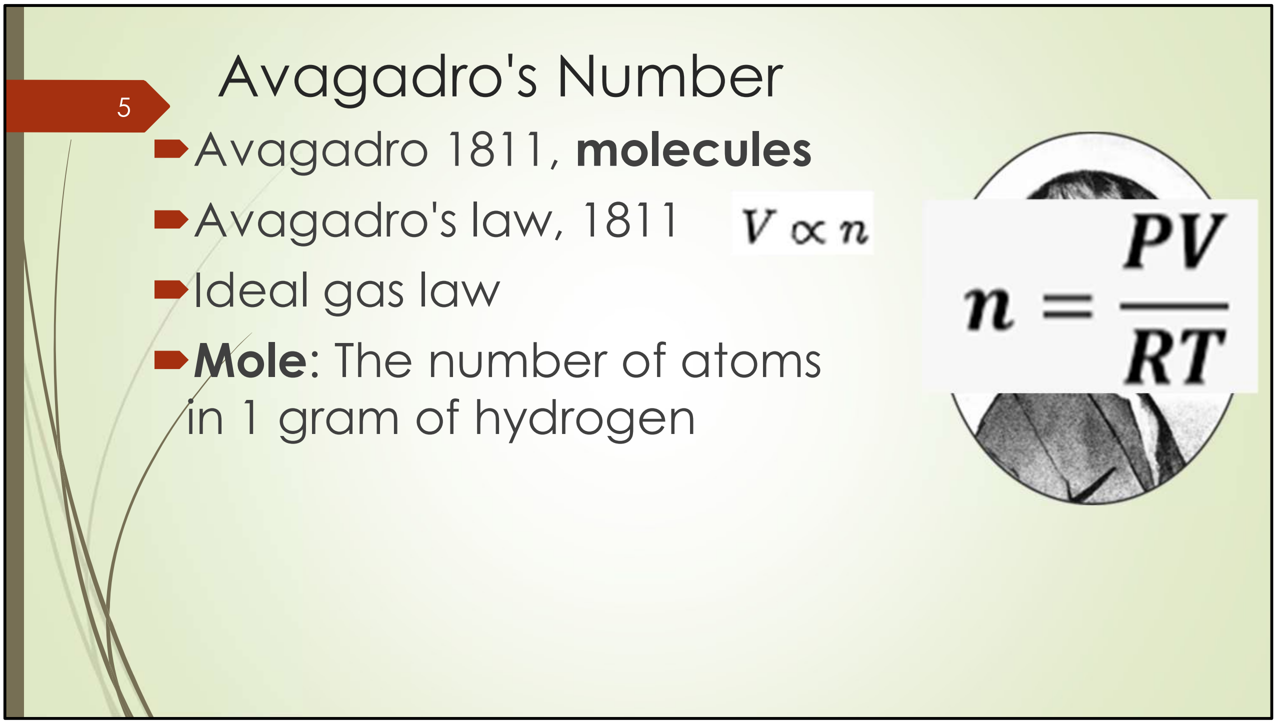
- Birth of chemistry
- Boyle's law, 1662, $V \propto \frac{1}{P}$
- Charles' law, 1787 $V \propto T$
- Gay-Lussac's law, 1808 $P \propto T$,

* Like the development of an understanding of the motion of the planets, chemistry began with gathering data about the behavior of elements, identifying natural laws regarding their behavior like Kepler's laws of planetary motion, and then proposing theories that explain those laws like Newton's theory of gravity. Like electricity, a natural law in chemistry is associated with the name of its discoverer, granting a form of immortality that escaped the alchemists. The behavior of gasses is a good example:

*In 1662, Robert Boyle discovered that volume is inversely proportional to absolute pressure at a constant temperature. (Absolute pressure is relative to a vacuum rather than to atmospheric pressure)

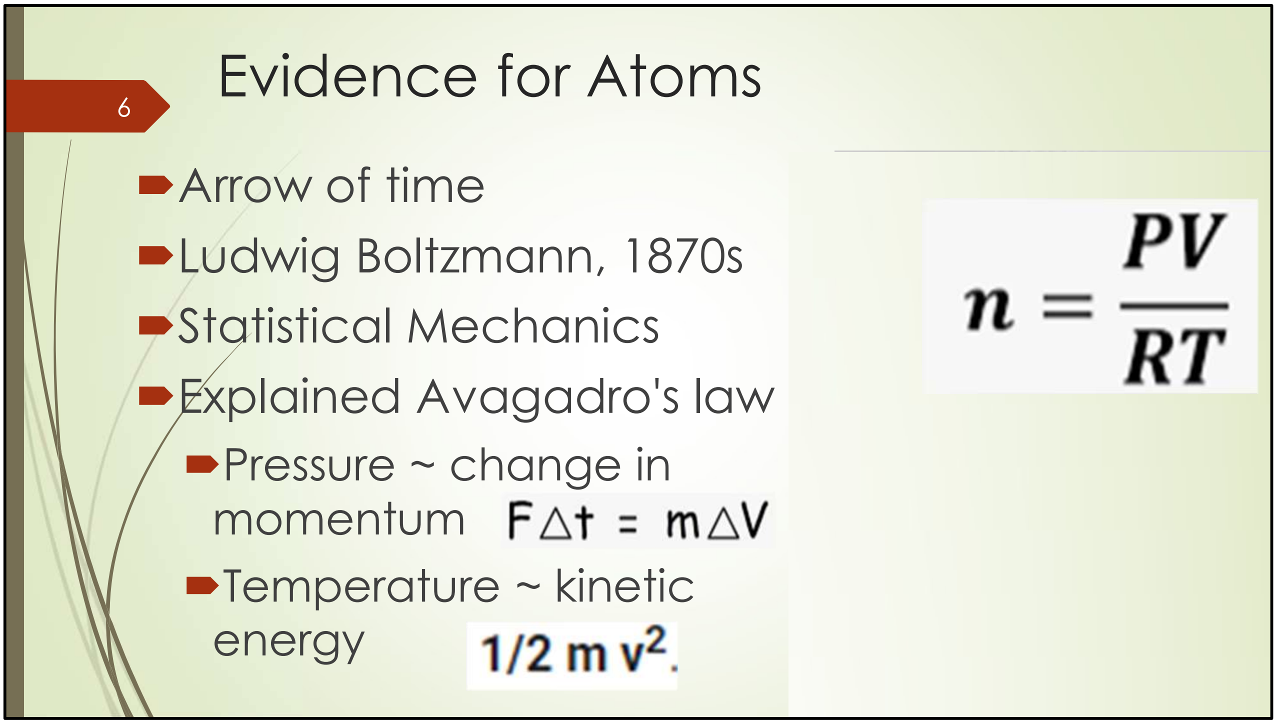
*In 1787, Jacque Charles discovered that volume of a gas is proportional to the absolute temperature (relative to absolute zero, e.g. degrees Kelvin)

*In 1808, Joseph-Louise Gay-Lussac discovered that pressure is proportional to Temperature if both are absolute measures and the amount of gas and volume is the same



*In 1811, Amedeo Avagadro proposed that elements are one kind of atom and that compounds are groups of atoms he called *molecules*
*In 1811, Avagadro discovered that the volume of a gas is proportional to the number of molecules or atoms if the temperature and pressure are the same. Another way to think of this is if you had containers of two different gasses with the same volume, temperature and pressure, they would contain the same number of atoms or molecules. The remarkable thing about this gas law is that it implies that gasses whose atoms or molecules might have very different mass will have the same volume if the pressure and temperature are the same. Like Galileo, he did not have an explanation for this law.
*All of these laws can be combined into a single law called the *Ideal Gas* Law that shows the relationship between pressure (P), Volume (V), Temperature (T) and the number of gas atoms or molecules. The R is a constant that reconciles the different units of measure for the other factors in the formula. It is relatively easy to measure the pressure, volume, and temperature of a gas but Avagadro didn't know how many atoms or molecules were in a given sample and he didn't know the value of R. It's called the *Ideal* gas law because it ignores the attraction the molecules have for each other.
*Until the actual number could be determined, they made up a number called a **mole** (short for molecule). For our purposes at this point in the course, we can say that a mole is the number of hydrogen atoms needed to have a mass of 1 gram. It is the name of a number, just like dozen, but the actual value of that number wasn't known until after his

death.



*One of the roadblocks to accepting the theory of atoms was the apparent contradiction between Newton's description of collisions that was reversable in time and the second law of thermodynamics (entropy increases) that held that processes became more random with time.
*In the 1870s, Ludwig Boltzmann, proposed that when many objects, like atoms, were involved, a reversable combination of collisions was possible but it was just one of many and that most of them led to a more random distribution.
*Boltzmann invented *statistical mechanics* which is the explanation of things like gas laws as the statistical average of the collisions of many particles that obey Newtonian laws of motion.
*Boltzman explained Avagadro's law by observing that *pressure depends on the impulse when the particles changed momentum (direction) when colliding with the container's walls and that *temperature is a measure of the average kinetic energy of the particles which depended on their mass and velocity. *Both had mass in their formulas and when substituted into the gas law, the mass divides out. Which explains why atoms and molecules of different mass have the same ratios of pressure, volume, and temperature. (Lighter atoms exert the same pressure at the same temperature by moving faster.)

Merging Newton and Statistics

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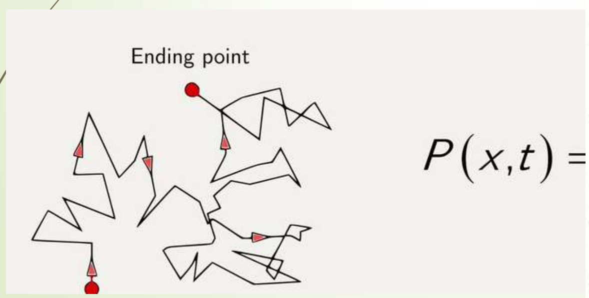
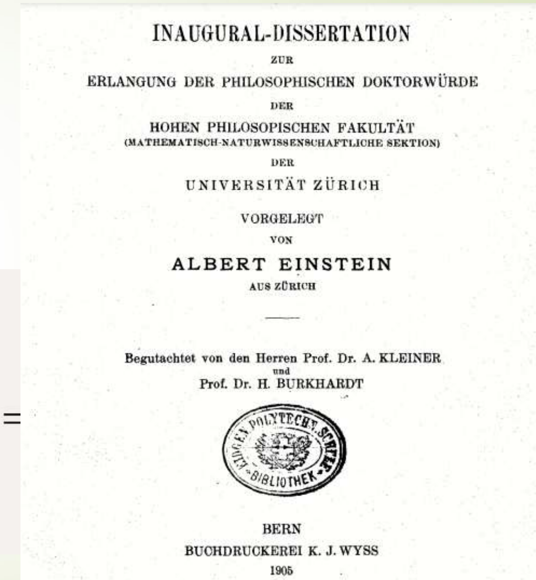
- Microscopes
- Brownian motion, 1828
- Albert Einstein, 1905

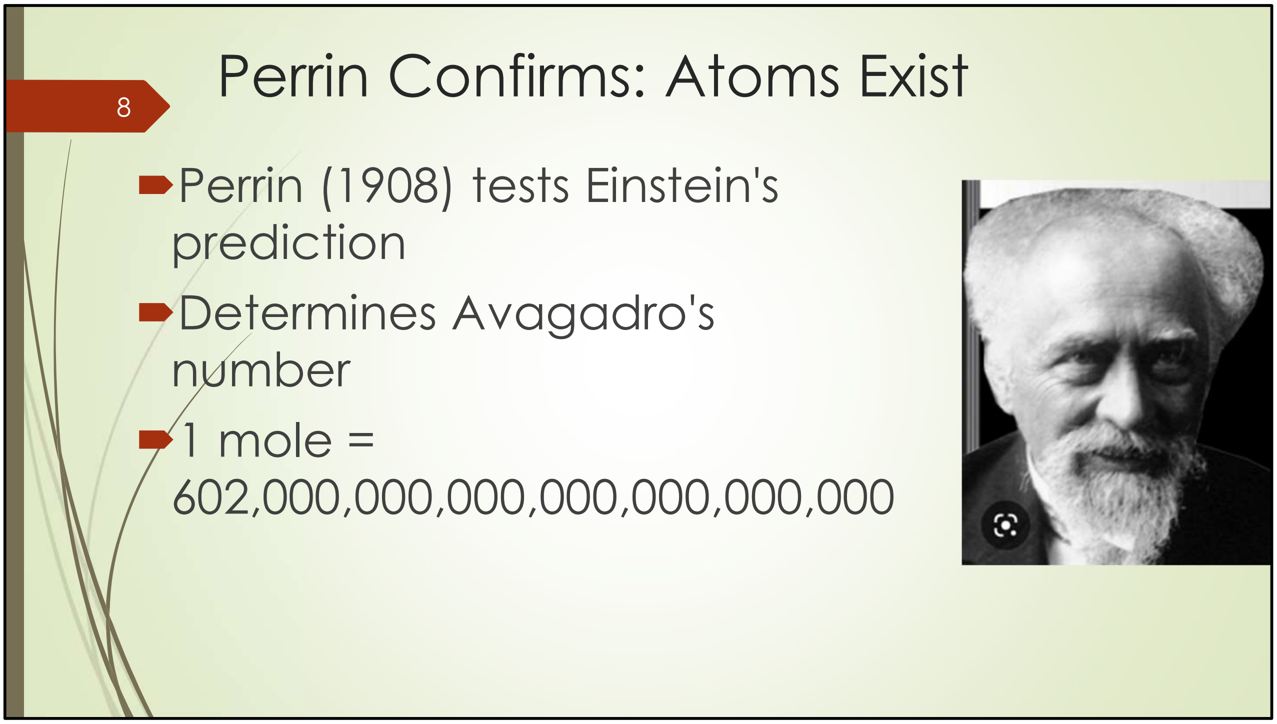



INAUGURAL-DISSERTATION
ZUR
ERLANGUNG DER PHILOSOPHISCHEN DOKTORWÜRDE
DER
HOHEN PHILOSOPISCHEN FAKULTÄT
(MATHEMATISCH-NATURWISSENSCHAFTLICHE SEKTION)
DER
UNIVERSITÄT ZÜRICH
VORGELEGT
VON
ALBERT EINSTEIN
AUS ZÜRICH

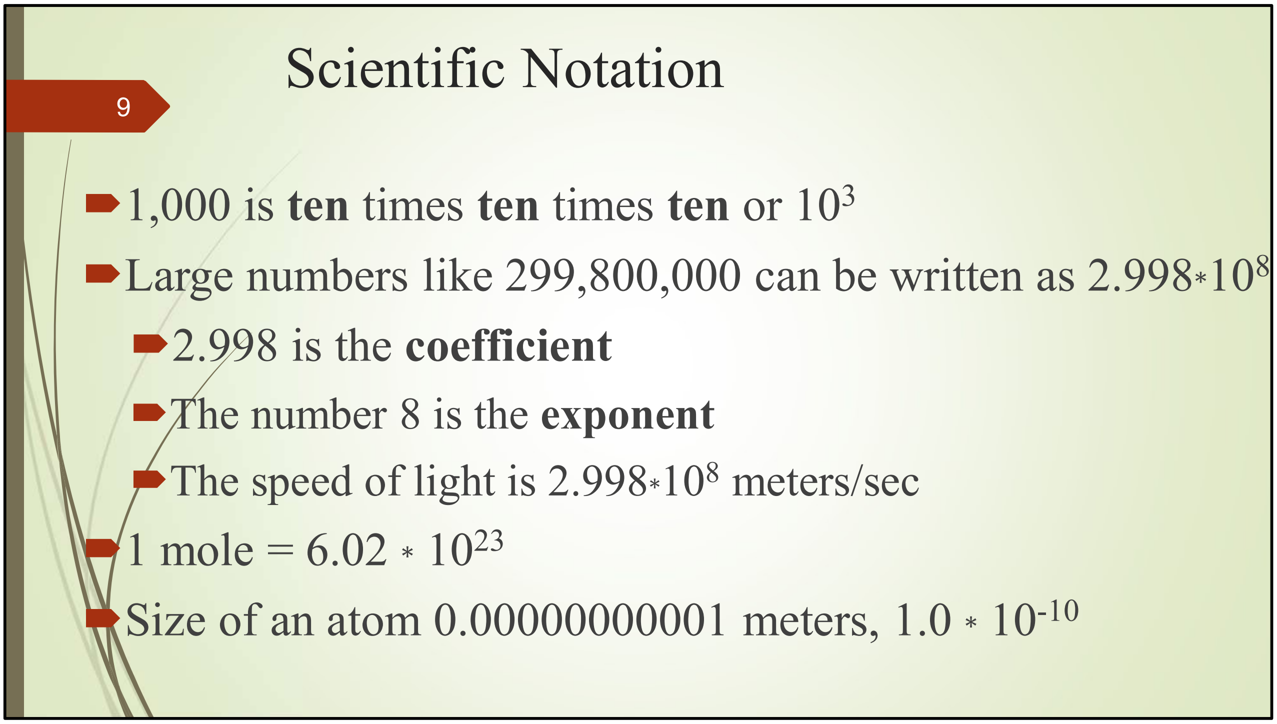
Begutachtet von den Herren Prof. Dr. A. KLEINER
und
Prof. Dr. H. BURKHARDT

BERN
BUCHDRUCKEREI K. J. WYSS
1905

*Improvements in microscopes allowed scientists to see very small objects like plant cells, large bacteria, and spores.
*In 1828, a botanist, Robert Brown, noticed that very small objects like plant spores suspended in water appeared to vibrate and move about in a random manner. He didn't have an explanation, but the phenomena bears his name. This effect is known as *Brownian motion*.*
*In 1905, a young PhD candidate at the University of Zurich named Albert Einstein wrote his *dissertation on how to *predict the average distance a particle would travel if its motion was the result of random collisions with much smaller particles.



*Einstein's formula predicted the average behavior of many particles. To test Einstein's formula, Jean Babtiste Perrin put together a team to measure Brownian motion enough times to see if the average matched Einstein's formula which it did, thus confirming the existence of atoms.
*Perrin was able to estimate the number of atoms in a mole and named it Avagadro's number.
* Perrin found that a mole is a little more than 600 billion trillion.



*To discuss really large numbers, we use multiples of ten. This method is called Scientific notation.
*For example, the speed of light is about 299,800,000 meters/sec. It can be written as 2.998×10^8, where *2.998 is the coefficient, and 8 is the exponent or multiple of ten. *It is also the number of places you would have to move the decimal place to the right to reconstruct the original number. We say that the speed of light is 2.998×10^8 meters per second
*Using scientific notation, 1 mole is a bit more than 6, followed by 23 zeros
*Scientific notation works for very small numbers. A negative power of ten describes the number of places you would have to move the decimal place to the left to reconstruct the original number.

Looking for Patterns

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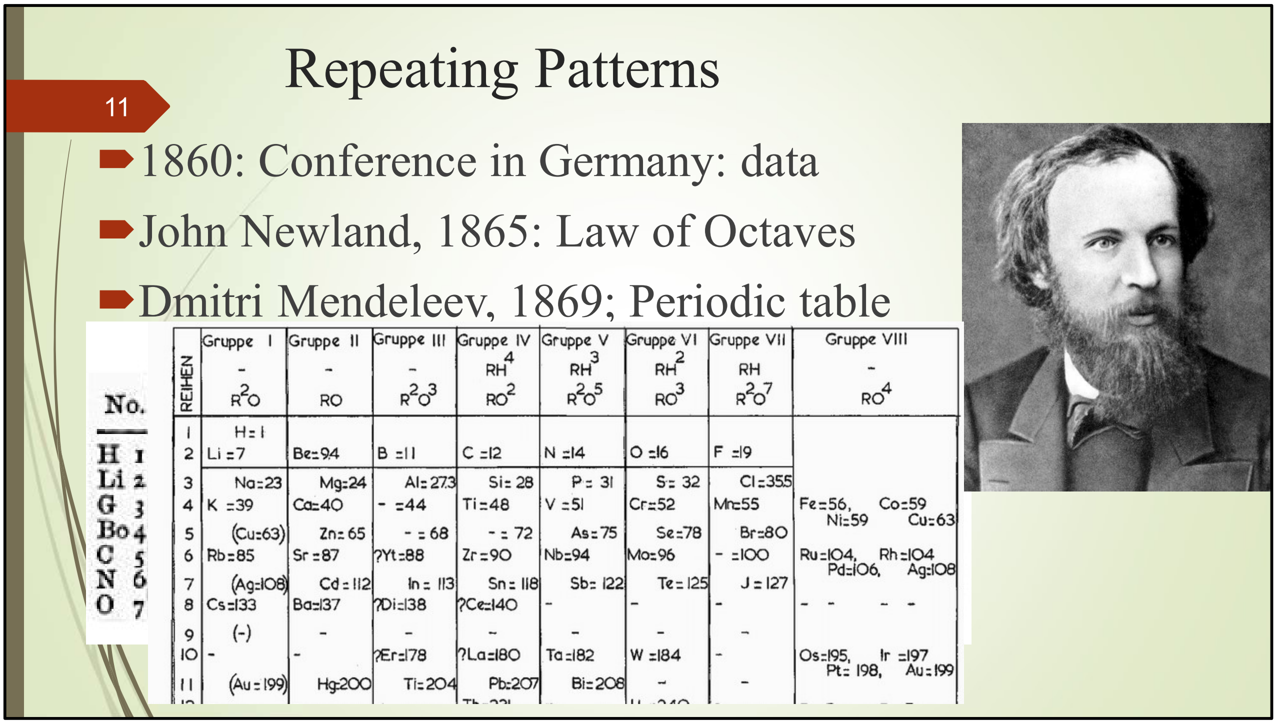
- Atomic number: sequence starting with hydrogen
- Atomic mass of one mole (based on Hydrogen):
  - 1 Hydrogen: 1 gram (by definition)
  - 2 Helium, about 4.003 grams
  - 3 Lithium: 6.94 grams
  - 4 Beryllium: 9.01 grams
  - 5 Boron: 10.81 grams

*Once scientists knew the value of Avagadro's number, they could compare the masses of two different elements if they had the same pressure, volume, and temperature. Each type of atom in the sequence is assigned a whole number called the **atomic number**, where Hydrogen is 1, Helium is 2, Lithium is 3 and so on.
*They could also measure the mass of a mole of each element. Most of the masses they measured were close to whole number multiples of the mass of hydrogen like the next four atomic numbers but not exactly. (Read the bullet points)



REIHEN	Gruppe I – R^2O	Gruppe II – RO	Gruppe III – R^2O^3	Gruppe IV RH^4 RO^2	Gruppe V RH^3 R^2O^5	Gruppe VI RH^2 RO^3	Gruppe VII RH R^2O^7	Gruppe VIII – RO^4
1	H=1							
2	Li=7	Be=9.4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5	
4	K=39	Ca=40	–=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63
5	(Cu=63)	Zn=65	–=68	–=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	–=100	Ru=104, Rh=104, Pd=106, Ag=108
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	–	–	–	– – – –
9	(–)	–	–	–	–	–	–	
10	–	–	?Er=178	?La=180	Ta=182	W=184	–	Os=195, Ir=197, Pt=198, Au=199
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	–	–	

Scientists worked feverishly to identify new elements and record their properties including their density, boiling and melting points and how they reacted to other elements. *In 1860, at a conference of chemists in Germany, a detailed list of the properties of each element was published.

*By 1865, a British chemist, John Newlands, recognized that the characteristics of the elements appeared to repeat every eight elements which he proposed as the *law of octaves*, suggesting a possible connection to the physics of music. *In his table, the atomic number increased vertically and elements in the same row had similar properties. He assumed that these 50 elements were a complete list.

In 1869, a Russian chemist, Dmitri Mendeleev, proposed another table . In his table, the atomic number increased horizontally and elements in the same column were similar. By this time, they knew of at least 70 elements. He recognized that his table was probably incomplete, so he left gaps as predictions where more elements might be found. His table also had eight columns. This periodic repetition of properties as the atomic number increased, was evidence that atoms had an internal structure, and it has something to do with the number 8.

Electricity and Chemistry

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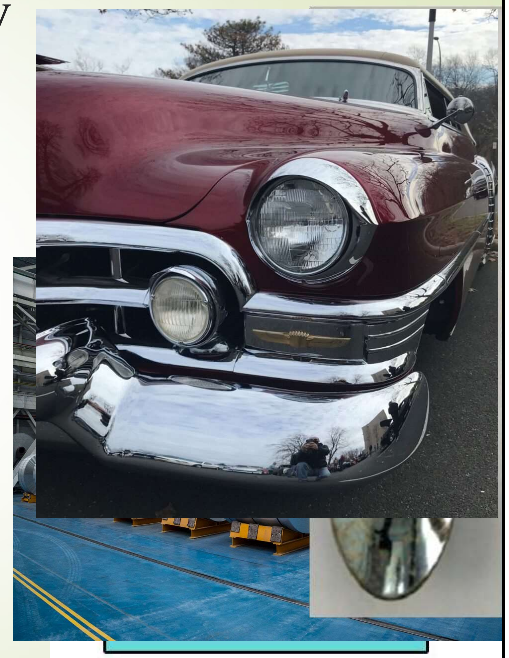
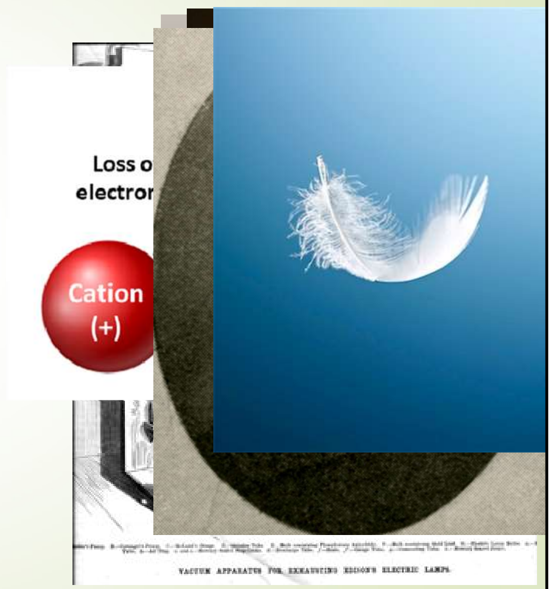
- Electroplating
- Electrolysis of water: Nicholson and Carlisle; 1800
- Negative post is the cathode
- Refining metals like aluminum, copper, nickel and lead



*Electric current is an important tool in chemistry. It can be used for depositing thin layers of metals like *silver, *gold, and *chromium on stronger metals like steel. This process is called **electroplating**
Electric current can also separate compounds into separate elements in a process called **electrolysis**. *In 1800, *William Nicholson and *Anthony Carlisle discovered that if you *connect a battery to two conductors immersed in water, that the water molecules will separate into molecules of oxygen at the positive conductor and hydrogen gas at the negative conductor.
*The negative conductor is called the **cathode** and the positive conductor is called the **anode**.
*Electrolysis can be used to extract elements like aluminum, copper, nickel, and lead from rocks found in the earth.

Vacuum Tubes and Electrons

- Vacuum pump
- William Crookes, 1879, cathode rays
- J.J. Thomson, 1897, beam deflected by static electricity
- Mass of an electron; 1/1840 mass of an atom
- Ions



Just as air friction obscures the behavior of falling objects, the presence of air obscures the behavior of electricity.
*In 1865, Hermann Sprengel improved the air pump so that it could remove almost all of the air from a glass container. His air pump became known as a vacuum pump, and it was used by *Edison to make incandescent lamps where the absence of air *allowed a white-hot wire to glow without burning up.
*In 1879, William Crookes embedded metal wires and plates in a glass tube and pumped out almost all of the air. *He observed that the remaining gas and part of the glass tube glowed green when the tube was connected to a source of electricity and that a beam appeared to travel from the negative plate towards the positive.
*In 1897, J.J. Thomson demonstrated that the beams emanated from several different materials and they could be deflected with electricity or magnetism. *He measured the deflections and calculated the mass to prove the beam consisted of negatively charged particles *whose mass was about 1/1840 the mass of the smallest atom. He is credited with the discovery of the first subatomic particle, later called an electron.
*Most atoms have neutral electric charge. Those with an extra electron are negative ions and those with less are positive ions.

Cathode Rays and Vacuum Tubes

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- Cathode ray tubes (CRT)
- Vacuum tube
  - Diodes; one direction
  - Switches; on/off
  - Amplifiers
- Vacuum tube electronics

*The glow caused by the beam of electrons could be enhanced by coating the inside of the tube with phosphorescent elements and the direction of the beam could be controlled by magnetic coils
*Cathode ray tubes (CRT) were used in radars and televisions to create images from electric signals. *Notice the coil of wire around the narrow part of the tube.
*If one of the plates was heated, it transmitted the current much better than a cold plate.
*If an alternating current was applied to a Crookes tube and only one end was heated, the tube functioned as a **diode** that only conducted in one direction.
*If a metal grid is placed between the cathode and anode, an electric charge on the grid can control the flow between the cathode and anode. A strong negative charge on the grid can repel the electron beam and shut off the flow, creating an on/off switch.
*If a weak electric signal is applied to the grid, the flow of a strong current though the tube can be modulated, creating an amplifier.
*Radios and televisions built prior to 1954 used vacuum tubes as diodes, switches, and amplifiers.

Photoelectric Effect

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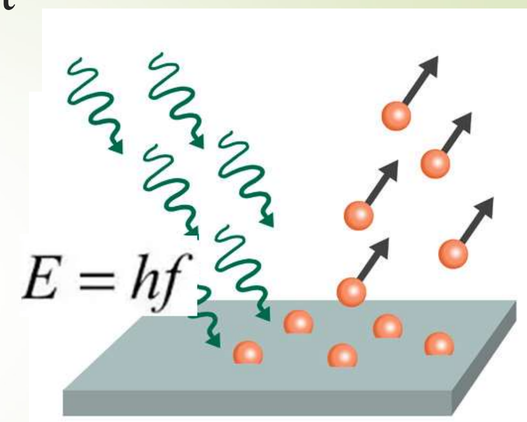
- Threshold
- This is called the **photoelectric effect**
- Color matters
- Einstein 1905, light is quantized, **photons**
- Photons have momentum



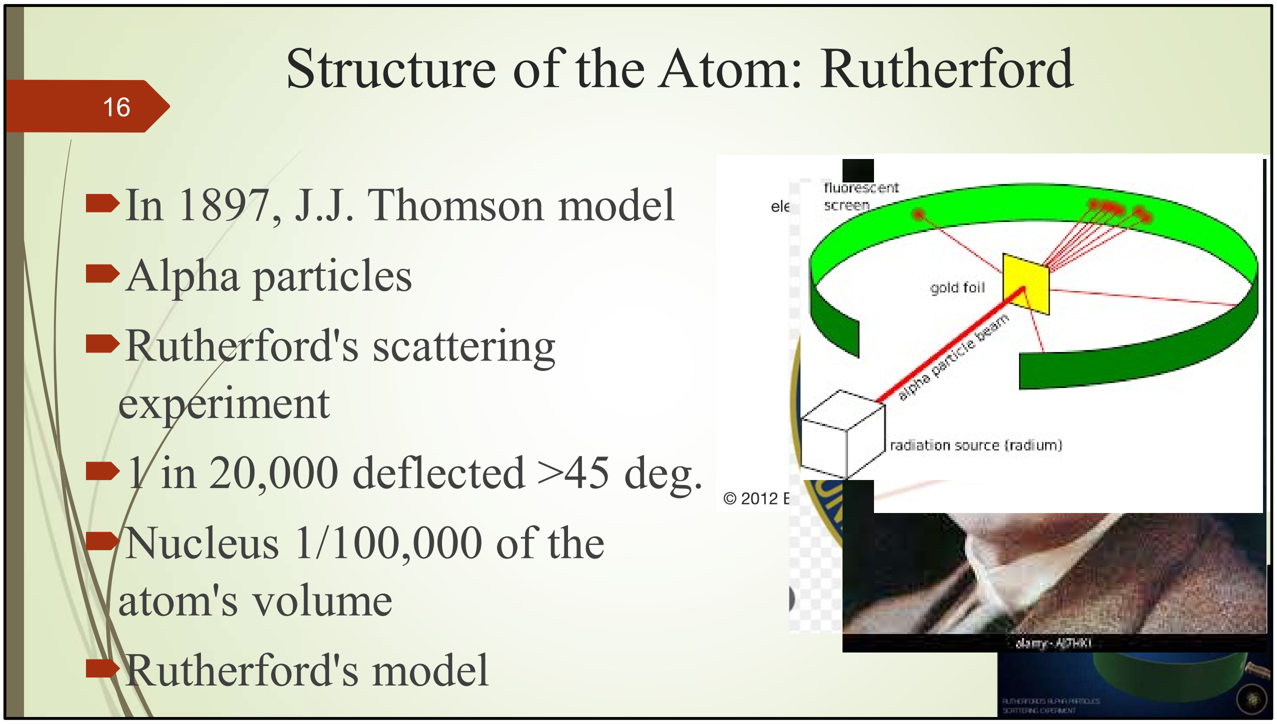
$$p = \frac{E}{c} = \frac{hf}{c}$$

*The electrons need some extra energy to escape the surface of the cathode which is called the threshold energy. In most cathode ray tubes this energy is provided by a small heater. *Another method is to illuminate the cathode with light. This is called the **photoelectric effect**

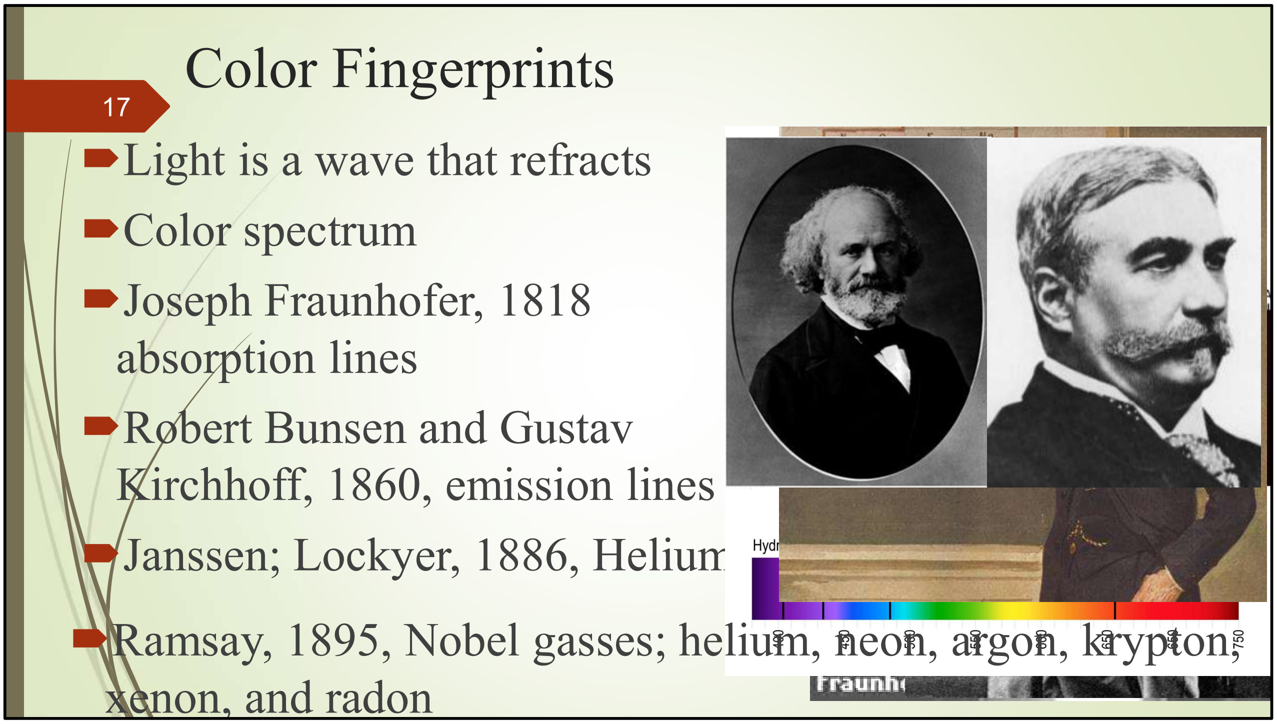
*What puzzled scientists at the time was that the color of the light made a big difference. For example, no matter how bright a red light might be, current wouldn't flow. But even a small amount of blue or ultraviolet light would work.

*In 1905, Albert Einstein proposed an explanation. He said that one must think of light as tiny bundles of quantized energy, later called photons, where the *energy is proportional to the frequency (h is a constant) and the *photons of light interact with electrons one-on-one. Either a single photon had enough energy to knock one electron free of the surface or it didn't.

*The photons also had momentum even though they had no mass. P is momentum, f is frequency, and c is the speed of light.



*In 1897, J.J. Thomson proposed a model of the atom in which the electrons were evenly distributed in a cloud of positive charge. They knew that similar charges repel each other so it made sense that the same charges were as far apart as possible.
*In 1911, Ernest Rutherford was experimenting with a type of particle beam that emanated spontaneously from a newly discovered element called radium. *He called them **alpha** particles and later identified them as having two positive charges and an atomic mass of 4. When these particles hit a screen coated with a phosphor, they gave off a flash of visible light
*Rutherford directed two assistants to run an experiment where a beam of alpha particles traveled through an extremely thin gold foil. If Thomson's model was correct, the evenly distributed mass and charge of the atom would have little effect on the direction of the alpha particles. *
*Surprisingly, about 1 in 20,000 alpha particles was deflected through an angle of more than 45 degrees.
*Rutherford concluded that all of the positive charge and almost all of the atom's mass was concentrated in a tiny bundle called a nucleus that was one-hundred thousandth the volume of the whole atom.
*Rutherford suggested a model that showed the electrons orbiting the tiny nucleus. *His model is still used as a logo for government agencies.



*Recall that waves refract and change direction when they traverse a boundary between two mediums in which they travel at different speeds and that light is a wave.
*Newton discovered that different colors of light refract by different amounts and that a beam of white light consists of many different wavelengths that can be separated into a spectrum of visible colors from red to violet.
*In 1818, Joseph Fraunhofer noticed that *when light from the sun was spread out into a spectrum of colors, certain wavelengths of light were missing and showed up as black lines in the spectra.
*In 1860 Robert Bunsen and Gustav Kirchhoff observed that *light from heated or excited gas like hydrogen could be separated into distinct colors called an emission spectrum that *matched some of the lines in Fraunhofer's absorption spectrum
*In 1868, two astronomers, Pierre Janssen and Joseph Lockyer, observed that the spectra of light coming from the sun's corona *had a bright yellow emission line that did not correspond to any known element. Lockyer named the new element **Helium** after the sun.
*In 1895, William Ramsey proposed another column be added to the periodic table for a group of gasses that did not react chemically but could be detected by their spectra. They are helium, neon, argon, krypton, xenon, and radon. Each element had a unique emission spectrum which gave researchers a new tool for discovering new elements

Bohr Model of the Atom

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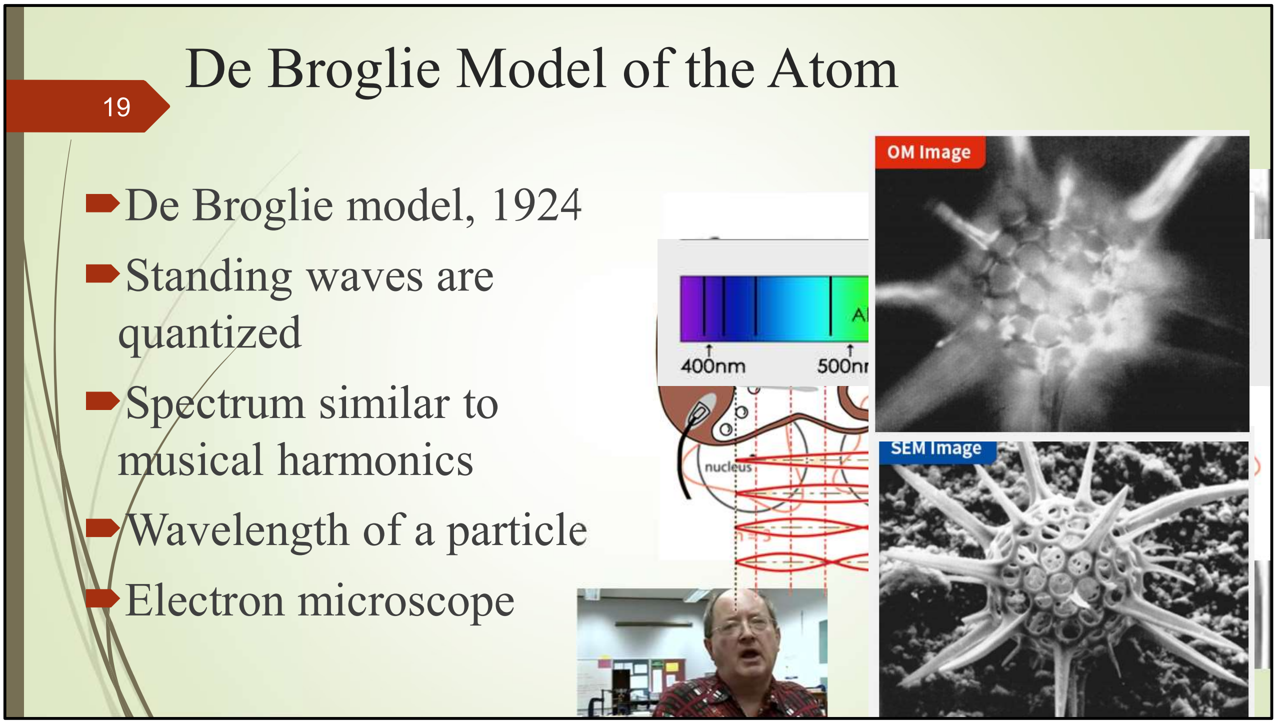
- Niels Bohr, 1913,
- orbits and energy levels are quantized
- Photons could bump electrons to higher levels
- Electrons falling downward give off photons with the same energy
- Phosphors

*In 1913, Niels Bohr proposed a model of the atom to explain the *emission and *absorption spectra of hydrogen; the simplest atom.
*He suggested that the single electron could orbit the nucleus at fixed distances that corresponded with increasing amounts of stored energy. The orbits and corresponding energy levels were quantized.
*The absorption spectrum was due to photons of just the right energy transferring energy to bump orbital electrons into higher orbits, removing the photons from the spectrum
* The emission spectrum is created when the orbital electrons drop to lower levels and give off energy as photons with frequencies that match the energy levels of the available orbits
*Phosphors absorb energy from invisible sources like ultraviolet light or electron beams and then emit photons in the visible range like these elements of a TV screen (see UV demo). Bohr's model did not explain why the energy levels were quantized.



*In 1924, Louis de Broglie proposed an explanation of the quantized energy levels of Bohr's model that was based on the concept of standing waves.
*Recall that the standing waves on a guitar string are quantized where only integer multiples of the fundamental wave would fit on the length of the string. *Similarly, de Broglie argued, the electron vibrates as it orbits the nucleus and only the orbits whose lengths are integer multiples of the fundamental will be stable as standing waves.
*One can think of the colors emitted or absorbed by the electron of a hydrogen atom as a harmonic scale!
*de Broglie's equation shows the wavelength of a particle's motion is inversely proportional to its momentum. For particles on a human scale, the wavelength is too small to notice.
*The wavelength of an electron is much smaller than the wavelength of light. This characteristic inspired the invention of the electron microscope which has magnification power thousands of times greater than microscopes that use visible light.

Electron Orbits for Larger Atoms

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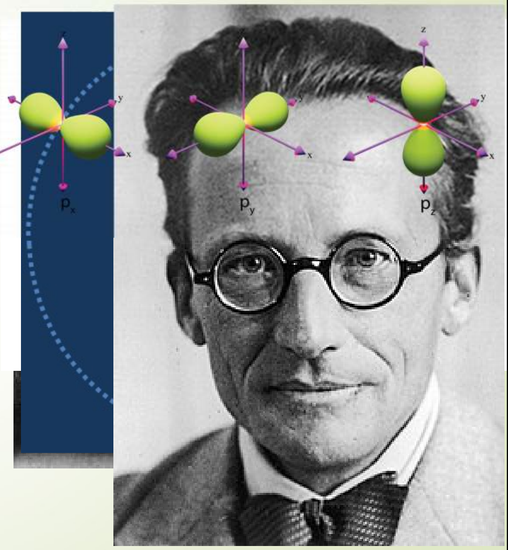
- Electron interaction
- Spin creates magnetism
- Pauli, 1940, Exclusion principle
- Lithium, 3 electrons
- Erwin Schrödinger, 1926
- Orbital shapes



*The Bohr model with de Broglie waves does a decent job of explaining the behavior of the hydrogen atom which has only one electron. Atoms with more than one positive charge in the nucleus attract an equal number of electrons and these electrons interact with each other as they try to fit into the available energy levels near the nucleus.
*Recall that moving electric charges create magnetism and that two magnets will attract each other in pairs, NS to SN. A spinning electron is like a tiny magnet.
*In 1940, Wolfgang Pauli identified four factors that are important for these interactions; Energy level, angular momentum, charge, and direction of spin. Pauli proposed that no two electrons orbiting the same atom could have the same four characteristics.
*For example, an atom with two electrons (Helium) might have both of them in the lowest energy orbit but they would have to have opposite spin. An element with three electrons (Lithium) or four electrons (Boron) would have to put the third and fourth electrons in a new, higher energy level. Larger elements with more than four electrons had more complex energy levels and orbital shapes.
*In 1926, Erwin Schrödinger developed a mathematical equation that would predict the shapes of additional orbitals. *The next shape orbital at the second and third energy levels has two lobes, as if the electron was orbiting in a figure-eight path. There are three of these, at right-angles to each other where each has a different angular momentum, and each can hold two electrons.

Uncertainty and Observation

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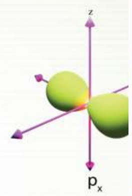
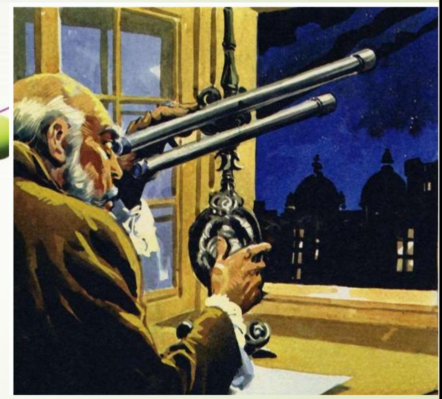
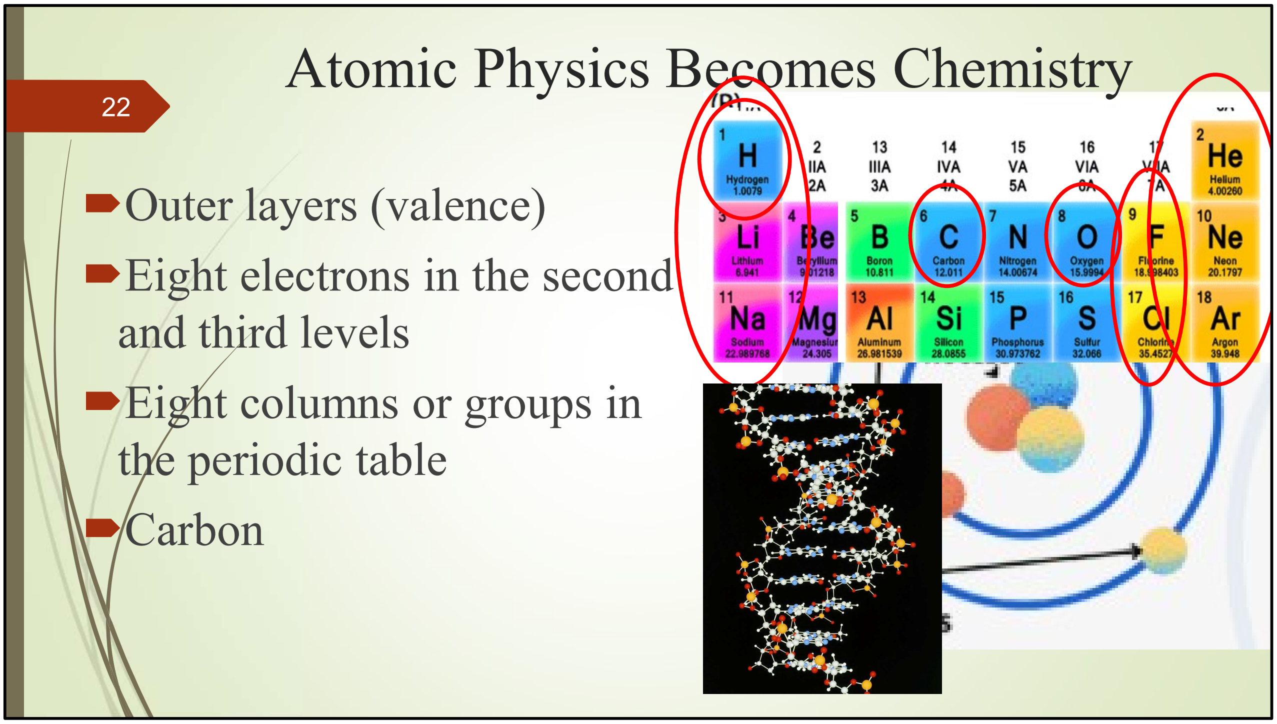
- Scientist as observer
- How we observe
- Werner Heisenberg, 1927, uncertainty
- Uncertainty of position or momentum greater than a minimum
- Orbitals are probabilities, not paths





*Early scientists saw themselves as independent observers of the natural world who recorded data and sought underlying laws of nature that fit the data.
*Studying the structure of the atom brought this view of a scientist's role into question. We observe the behavior of objects by interacting with them. To "see" and object, we bounce light off of it and then form images from the light. This works well for relatively large objects that are not affected noticeably by the photons of light but this doesn't work for extremely small particles, like electrons. Recall that Einstein explained the photoelectric effect by stating that photons behaved like particles that had momentum which could knock electrons out of a metal electrode.
*An important shift in thinking occurred in 1927 when Heisenberg explained that the act of detecting and measuring small particles like electrons with photons of light would change their position and/or velocity. This made it impossible to plot the path of an electron using photons of light by observing a sequence of positions and directions.
*He said there would always be some uncertainty in the measurement of either the position or the momentum. This uncertainty is negligible for objects of human size, but it means that we cannot know the paths electrons take near the nucleus
*Schrodinger's orbitals are probabilities, not actual paths



*If an atom has electrons in more than one energy level, the arrangement of electrons in the outermost layer are the ones that will interact with other atoms. They are called **valence electrons**. The number of valence electrons in the outer energy level determines how that element will combine with valence electrons in other atoms to create molecules.
*The second and third energy levels have eight possible positions. Recall that Newland and Mendeleev recognized that the properties of elements repeated periodically based on the number 8.
*The periodic table of the first 18 elements is arranged by the number of valence electrons that are available to form connections with valence electrons from other atoms. This table can be used to predict how elements will combine. *For example, elements in the first column have one electron in the outer energy level while those in seventh column are one short of a full layer and will react readily to form molecules, e.g. NaCl or table salt. *Oxygen is two short of a full layer so it will combine with two hydrogen atoms to form H2O (water).
*The elements in the far-right column have electrons in all the available orbitals so they have none to share with other atoms nor do they need electrons to complete their shells. They do not form molecules with other atoms.
*Carbon has either four extra electrons or is four short of a full layer. It can combine with many other atoms to form complex molecules including the basic molecules of life. Its properties are the basis for an entire branch of chemistry called **organic chemistry**.

Photosynthesis and TNT

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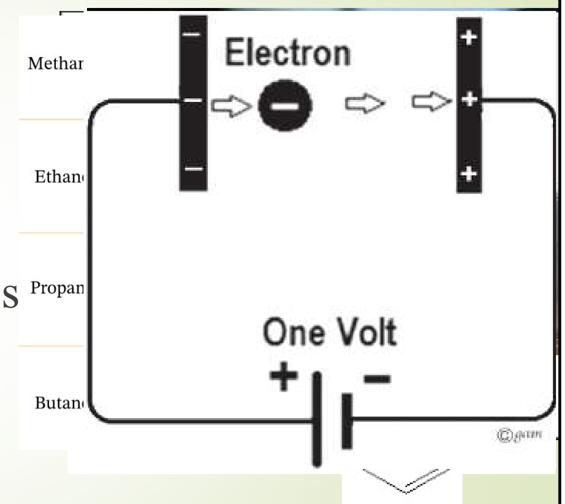
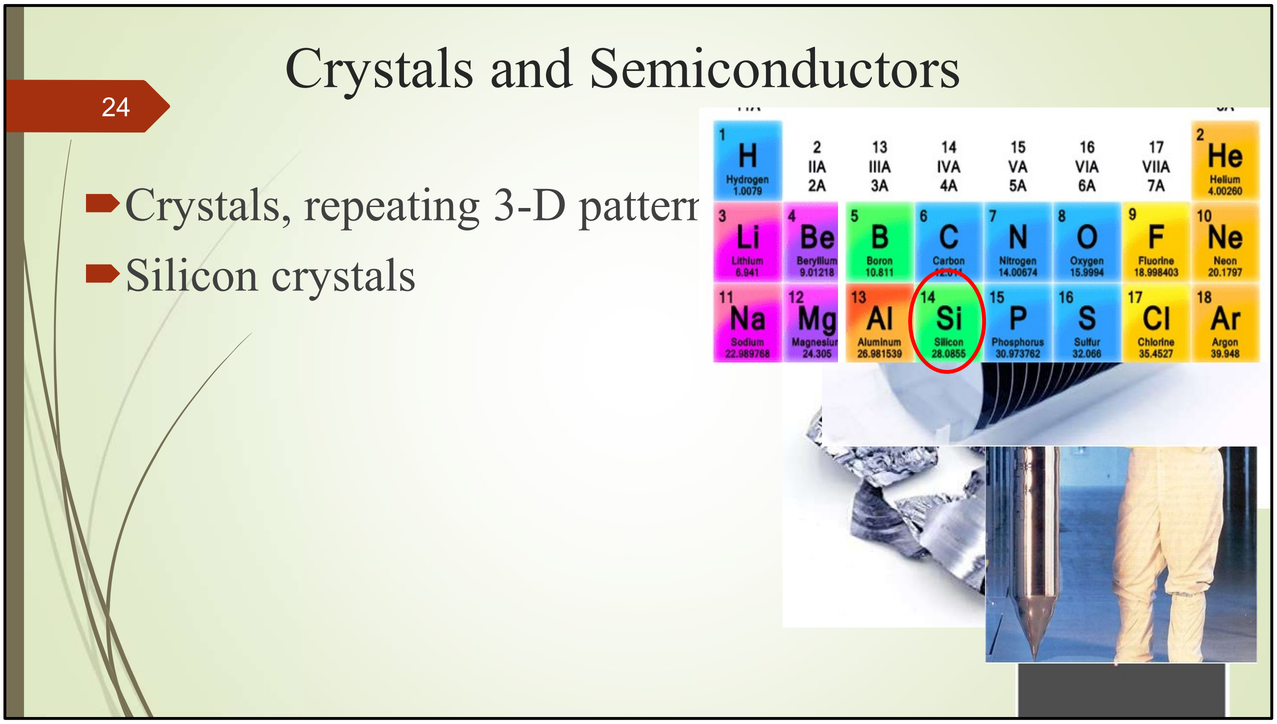
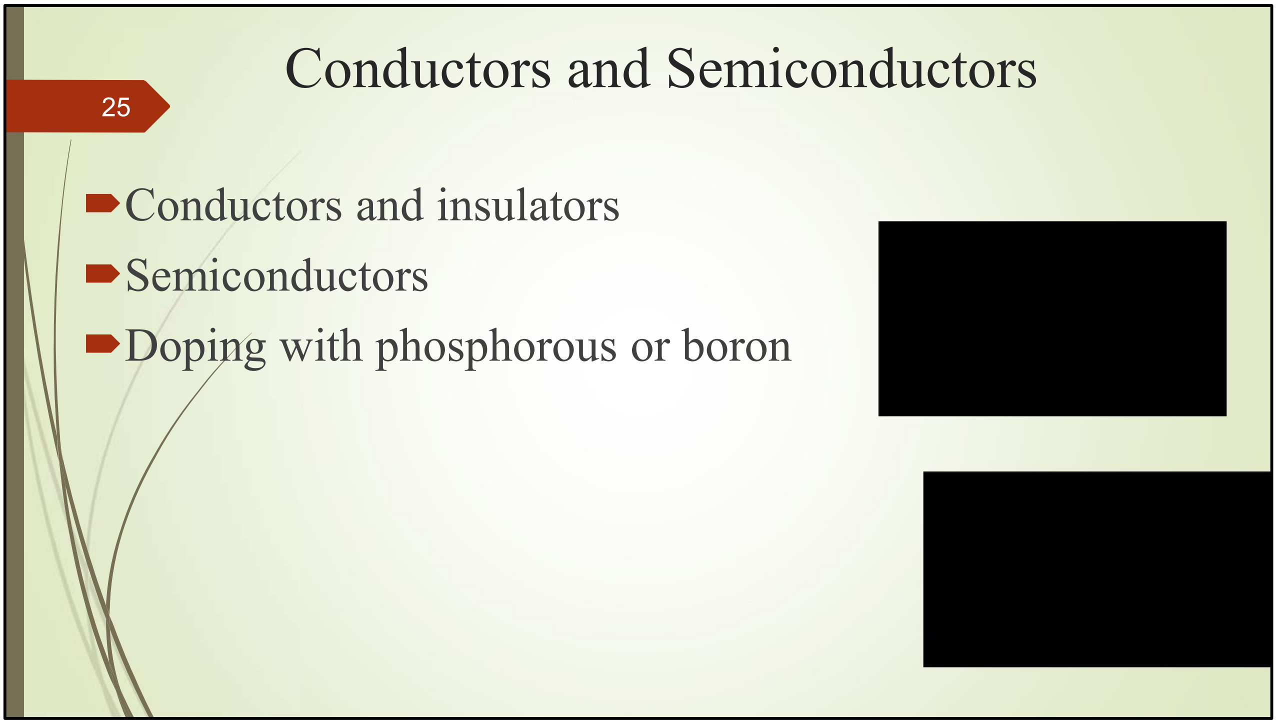
- Organic molecules
  - Methane; hydrocarbons
  - Benzene
- Chlorophyll and Photosynthesis
- Electron volt (unit of energy)
- Energy per molecule, 10ev
- Trinitrotoluene (TNT), 39ev



*Molecules based on carbon are called **organic** molecules
*One carbon atom can combine with four hydrogen atoms to create a molecule named **methane**. Combinations of hydrogen and carbon are called **hydrocarbons**. *The carbon atoms form chains with hydrogen atoms attached to form more complex molecules that store energy.
*Carbon atoms can form rings like benzene molecules. *To simplify the diagrams, just the bonds between carbon atoms are represented by lines and hydrogen atoms are assumed at the corners to complete four bonds. Double lines indicate two shared electrons.
*A special organic molecule called **chlorophyll** can absorb energy from red and violet photons to convert carbon dioxide and water molecules into hydrocarbons and oxygen. This process stores the energy from the photons in the bonds between the hydrogen and carbon.
* The unit of energy at the atomic scale is the electron volt. An ev is the energy one electron would get from a 1 volt battery
* Recombining the hydrocarbons with oxygen releases the energy. The energy released by burning a molecule of methane is 10 electron volts. *The energy released in an explosion of TNT is 39.3 Ev.



*When atoms share valence electrons, and they are cool enough to form solids, the atoms can arrange themselves into a repeating, 3-D pattern called a **crystal**.
*For example, when sodium and chlorine combine to form salt, the atoms arrange themselves into cubes. This pattern on the atomic size scale can repeat itself until it *becomes large enough to see on a human scale.
Like carbon, silicon has four valence electrons and can combine with a variety of other elements. In its pure form, each silicon atom combines with four others to form a crystal. A silicon crystal can be *large enough to slice into *thousands of thin wafers.

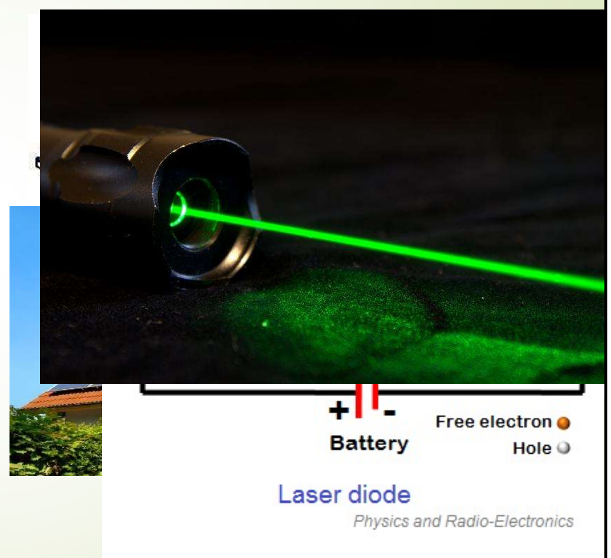


*Recall that materials which allow electric current to flow through them are called conductors and that those that do not are called insulators. Conductors are materials that have an unpaired valence electron that is shared among neighboring atoms. These electrons will move easily if pushed by other electric charges or magnetism. Most metals like copper, aluminum, gold, and silver are good conductors.
*Silicon crystals share electrons and conduct electric current, just not as well as metals. Silicon is a **semiconductor. ***
*Adding phosphorous or boron atoms to the crystals improves their conductivity which is called doping.

Diodes and Light

26

- Diode: Current flows one direction
- Light Emitting Diode, LED
- Photovoltaic or Solar cells
- Laser diodes



*A device that only conducts in one direction is a **diode**. A pair of n-type and p-type silicon crystals will allow current to flow if the n-type is connected to a negative source but not in the reverse direction.
*When an electron from the n-type side "drops" into a hole on the p-type side, it can give off a photon of light. If it is designed to allow the light to escape, it is a **light emitting diode** or **LED.**
***Recall that Einstein explained the photoelectric effect by stating that a photon has momentum and can knock an electron out of a metal surface. *A silicon diode can be designed that uses photons of light to knock electrons out of the holes on the p-type side to the n-type side, creating an electric current. *This type of diode is called a photovoltaic or solar cell.
*A diode can be made with mirrors on two sides that reflect the emitted light back and forth between them creating a standing wave of just one size wavelength. One of the mirrors isn't fully coated so some of the light escapes from that side. *This type of single-wavelength light is called a **laser**

Transistors Replace Tubes

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- Bardeen, Brattain, Shockley, 1947
- Transistors in radios
- Computers
  - 1958, IBM 709
  - 1960, IBM 7090

*In 1947, John Bardeen, Walter Brattain, and William Shockley worked together at Bell labs to *invent the transistor.*
*Transistors replace vacuum tubes as diodes, switches, and amplifiers. *Small, lightweight transistors, made portable radios practical.
*Early computers used vacuum tube diodes as on/off switches to represent binary numbers that consist of zeros and ones.
*In 1958, the IBM 709 computer used *vacuum tubes. It weighed a ton and used 100,000 watts of electric power.
*In 1960, the IBM 7090 came out. It had 50,000 transistors instead of vacuum tubes. It had six times the computing speed at half the price. It was used by businesses and by government agencies like NASA to calculate performance of rockets and satellites.

Integrated Circuits

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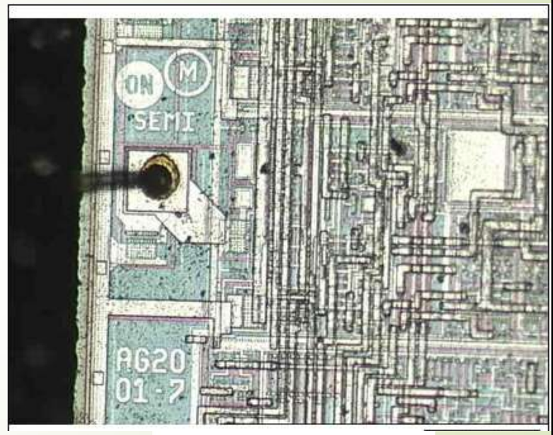
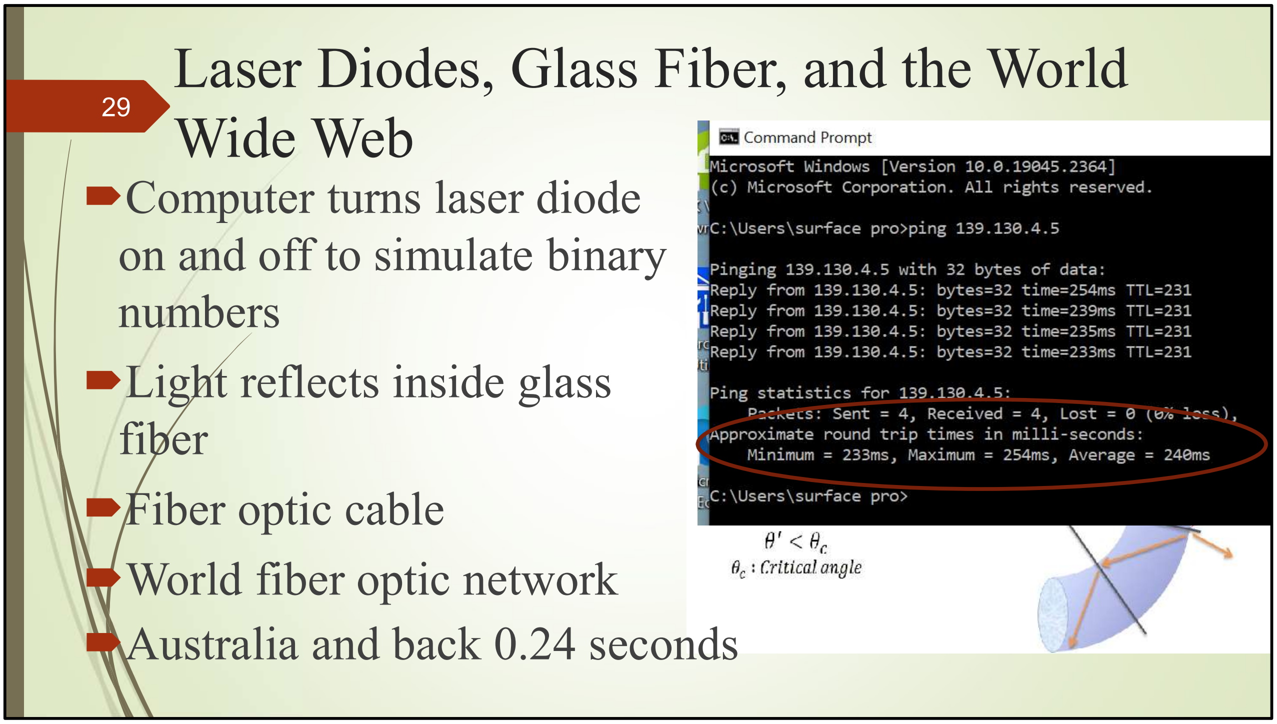
- Individual transistors replaced by integrated circuits
- Complex circuits are created in layers by photo engraving, doping, and deposition



*Individual transistors were replaced by a technique of *etching, doping, and depositing conductor metals to create entire computers with *millions of transistors on a single wafer of silicon.* In the following video, each small square, called a DIE, is an integrated circuit.



*Computers control laser diodes to convert binary numbers into flashes of laser light
*Recall that one of the wave properties is internal reflection. The laser reflects inside the glass fiber *unless the fiber bends too sharply and can follow it for miles.
*Several strands of glass fiber can be bundled inside a bundle of strong steel cables and laid on the ocean floor or between poles in your neighborhood to create a world wide web of communications.
*You can send a test message to a computer in Australia (139.130.4.5) and get a reply in less than a quarter of a second. [click the windows button and type **cmd**]
This is all possible because we have a better understanding of the physics of atoms.

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What experiences and insights can you share with us?

References

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- Early chemistry, khem: Link
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