Laws of Science- A Compilation

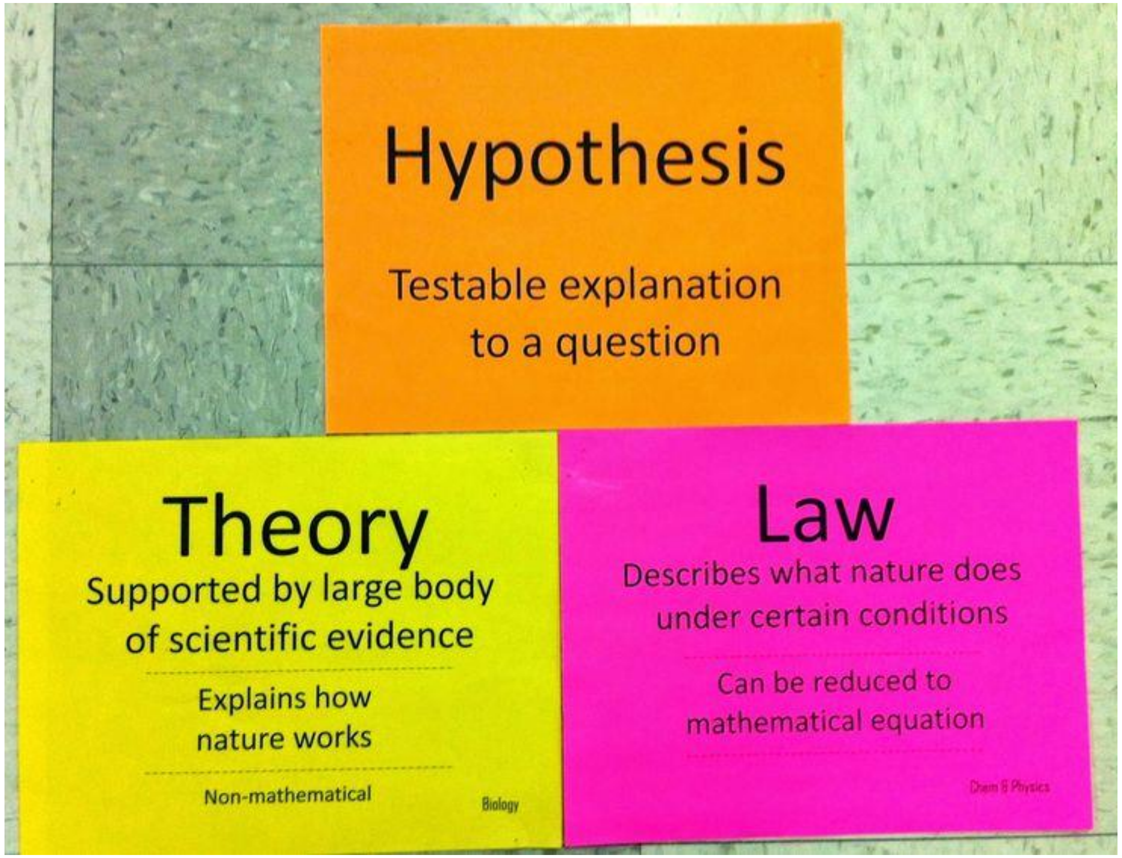
Scientists have many tools available to them when attempting to describe how nature and the universe at large work. Often they reach for laws and theories first. What's the difference? A **scientific law** can often be reduced to a mathematical statement, such as $E = mc^2$; it's a specific statement based on empirical data, and its truth is generally confined to a certain set of conditions. For example, in the case of $E = mc^2$, c refers to the speed of light in a vacuum.

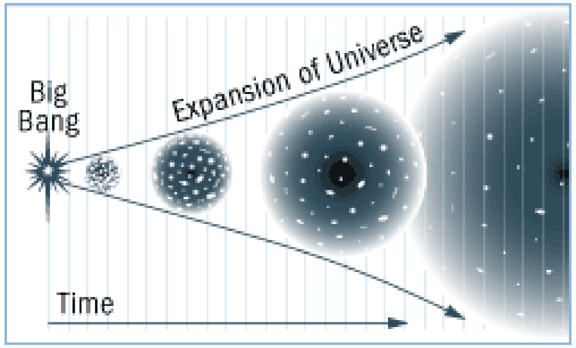
A **scientific theory** often seeks to synthesize a body of evidence or observations of particular phenomena. It's generally -- though by no means always -- a grander, testable statement about how nature operates. You can't necessarily reduce a scientific theory to a pithy statement or equation, but it does represent something fundamental about how nature works.

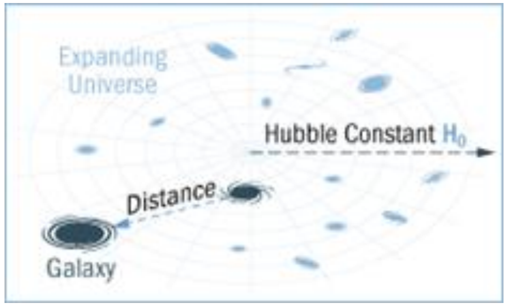
A **hypothesis** is a supposition or explanation (theory) that is provisionally accepted in order to interpret certain events or phenomena, and to provide guidance for further investigation. A hypothesis may be proven correct or wrong, and must be capable of refutation. If it remains unrefuted by facts, it is said to be verified or corroborated. In everyday language, the word hypothesis usually refers to an educated guess — or an idea that we are quite uncertain about. If there is a relation between the wave length of light and the photosynthesis rate, then light of different colours will cause the plant to make different amounts of oxygen- is an example of a hypothesis.

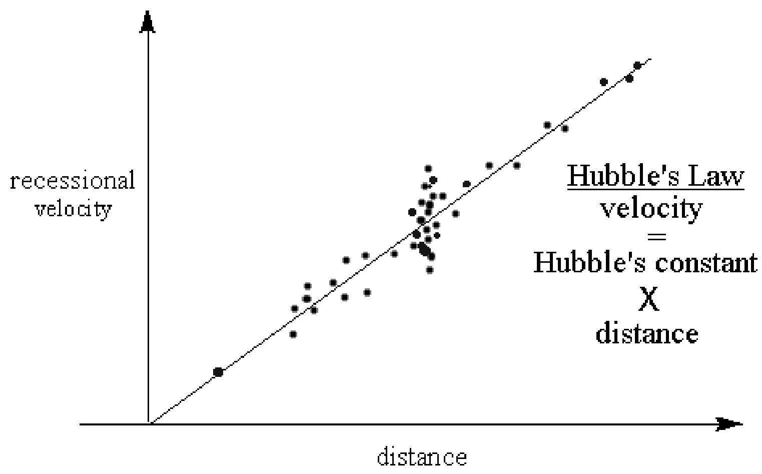
In mathematics, a **theorem** is a statement that has been proved on the basis of previously established statements, such as other theorems, and generally accepted statements, such as axioms. A theorem is a logical consequence of the axioms. The proof of a mathematical theorem is a logical argument for the theorem statement given in accord with the rules of a deductive system. The proof of a theorem is often interpreted as justification of the truth of the theorem statement. In light of the requirement that theorems be proved, the concept of a theorem is fundamentally deductive, in contrast to the notion of a scientific law, which is experimental.

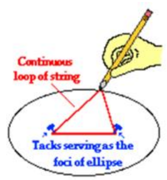
Both laws and theories depend on basic elements of the scientific method, such as generating a hypothesis, testing that premise, finding (or not finding) empirical evidence and coming up with conclusions. Eventually, other scientists must be able to replicate the results if the experiment is destined to become the basis for a widely accepted law or theory.


Hypothesis
Testable explanation to a question
Theory
Supported by large body of scientific evidence
Explains how nature works
Non-mathematical
Biology
Law
Describes what nature does under certain conditions
Can be reduced to mathematical equation
Chem & Physics

S. No.	Laws of Science	Illustration
1	**Big Bang Theory of the Universe** If you're going to know one scientific theory, make it the one that explains how the universe arrived at its present state. Based on research performed by **Edwin Hubble, Georges Lemaitre and Albert Einstein**, among others, the big bang theory postulates that the universe began almost 14 billion years ago with a massive expansion event. At the time, the universe was confined to a single point, encompassing all of the universe's matter. That original movement continues today, as the universe keeps expanding outward. The Big Bang theory is an effort to explain what happened at the very beginning of our universe. Discoveries in astronomy and physics have shown beyond a reasonable doubt that our universe did in fact have a beginning. Prior to that moment there was nothing; during and after that moment there was something: our universe. The big bang theory is an effort to explain what happened during and after that moment. According to the standard theory, our universe sprang into existence as "singularity" around 13.7 billion years ago. What is a "singularity" and where does it come from? Well, to be honest, we don't know for sure. Singularities are zones which defy our current understanding of physics. They are thought to exist at the core of "black holes." Black holes are areas of intense gravitational pressure. The pressure is thought to be so intense that finite matter is actually squished into infinite density (a mathematical concept which truly boggles the mind). These zones of infinite density are called "singularities." Our universe is thought to have begun as an infinitesimally small, infinitely hot, infinitely dense, something - a singularity. Where did it come from? We don't know. Why did it appear? We don't know. After its initial appearance, it apparently inflated (the "Big Bang"),	 From The Big Bang To The Present Day - Documentary HD **https://www.youtube.com/watch?v=4eKIjkk0NVY&t=3730s**

	expanded and cooled, going from very, very small and very, very hot, to the size and temperature of our current universe. It continues to expand and cool to this day and we are inside of it: incredible creatures living on a unique planet, circling a beautiful star clustered together with several hundred billion other stars in a galaxy soaring through the cosmos, all of which is inside of an expanding universe that began as an infinitesimal singularity which appeared out of nowhere for reasons unknown. This is the Big Bang theory.	
2	**Hubble's Law of Cosmic Expansion** Hubble's law, an equation that states: velocity = H_0 × distance. Velocity represents the galaxy's recessional velocity; H_0 is the Hubble constant, or parameter that indicates the rate at which the universe is expanding; and distance is the galaxy's distance from the one with which it's being compared. Hubble and his famous law helped to quantify the movement of the universe's galaxies. The dominant motion in the universe is the smooth expansion known as Hubble's Law. Recessional Velocity = Hubble's constant times distance $V = H_0 D$ Where V is the observed velocity of the galaxy away from us, usually in km/s H_0 is Hubble's "constant", in km/s/Mpc D is the distance to the galaxy in Mpc In 1929, Hubble estimated the value of the expansion factor, now called the Hubble constant, to be about 500 km/s/Mpc. Today the value is still rather uncertain, but is generally believed to be in the range of 45-90 km/s/Mpc.	 https://www.youtube.com/watch?v=1V9wVmO0Tfg https://www.youtube.com/watch?v=A-vHAxc6djs

	While in general galaxies follow the smooth expansion, the more distant ones moving faster away from us, other motions cause slight deviations from the line predicted by Hubble's Law. This diagram shows a typical plot of distance versus recessional velocity, with each point showing the relationship for an individual galaxy. In the example shown here, two things should be apparent: • Few of the points fall exactly on the line. This is because all galaxies have some additional residual motion in addition to the pure expansion. This is referred to as the "cosmic velocity dispersion" or "cosmic scatter" and is probably due to the fact that the gas clouds that formed the galaxies all had some small additional motion of their own. The recessional velocity of a galaxy at a particular distance inferred from Hubble's law is called the "Hubble velocity".  • About in the middle of the diagram, there are a bunch of galaxies that appear to be at about the same distance but are spread out a lot in	

	the velocity direction. This feature suggests the presence of a large cluster of galaxies, like the Virgo cluster. In addition to their "Hubble velocities", these galaxies have an extra velocity caused by their orbital motion around the centre of the cluster. Because clusters of galaxies are very massive, this orbital velocity can be very large, more than 1000 km/s. Therefore in the vicinity of nearby clusters of galaxies, we cannot use Hubble's law to determine accurately the distance to the galaxy.	
3	**Kepler's Laws of Planetary Motion** Kepler's three laws of planetary motion -- formed in the early 17th century -- describe how planets orbit the sun. The first law, sometimes called the law of orbits, states that planets orbit the sun elliptically. The second law, the law of areas, states that a line connecting a planet to the sun covers an equal area over equal periods of time. The third one, the law of periods, allows us to establish a clear relationship between a planet's orbital period and its distance from the sun. In the early 1600s, Johannes Kepler proposed three laws of planetary motion. Kepler was able to summarize the carefully collected data of his mentor - Tycho Brahe - with three statements that described the motion of planets in a sun-centered solar system. Kepler's efforts to explain the underlying reasons for such motions are no longer accepted; nonetheless, the actual laws themselves are still considered an accurate description of the motion of any planet and any satellite. **1. The Law of Ellipses** Kepler's first law - sometimes referred to as the law of ellipses - all planets orbit the sun in a path that resembles an ellipse, with the sun being located at one of the foci of that ellipse.	**The Law of Ellipse** 

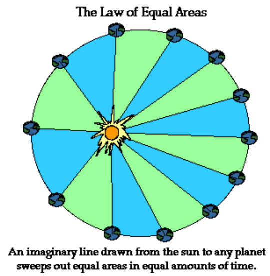
2. The Law of Equal Areas

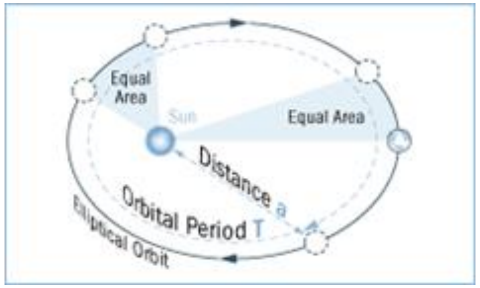
Kepler's second law - sometimes referred to as the law of equal areas - describes the speed at which any given planet will move while orbiting the sun. The speed at which any planet moves through space is constantly changing. A planet moves fastest when it is closest to the sun and slowest when it is furthest from the sun. Yet, if an imaginary line were drawn from the centre of the planet to the centre of the sun, that line would sweep out the same area in equal periods of time. For instance, if an imaginary line were drawn from the earth to the sun, then the area swept out by the line in every 31-day month would be the same. This is depicted in the diagram below. As can be observed in the diagram, the areas formed when the earth is closest to the sun can be approximated as a wide but short triangle; whereas the areas formed when the earth is farthest from the sun can be approximated as a narrow but long triangle. These areas are the same size. Since the base of these triangles are shortest when the earth is farthest from the sun, the earth would have to be moving more slowly in order for this imaginary area to be the same size as when the earth is closest to the sun.

3. The Law of Harmonies

Kepler's third law - sometimes referred to as the law of harmonies - compares the orbital period and radius of orbit of a planet to those of other planets. Unlike Kepler's first and second laws that describe the motion characteristics of a single planet, the third law makes a comparison between the motion characteristics of different planets. The comparison being made is that the ratio of the squares of the periods to the cubes of their average distances from the sun is the same for every one of the planets.

The Law of Equal Areas





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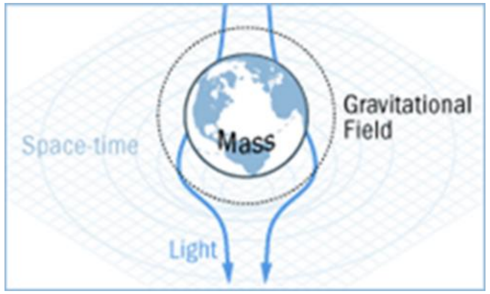
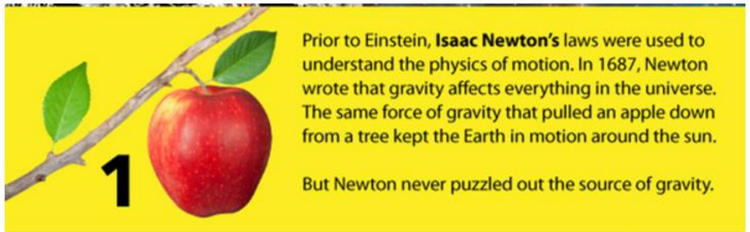
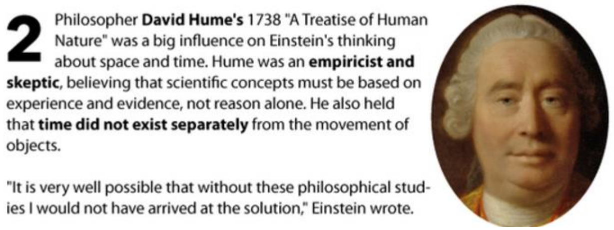
4

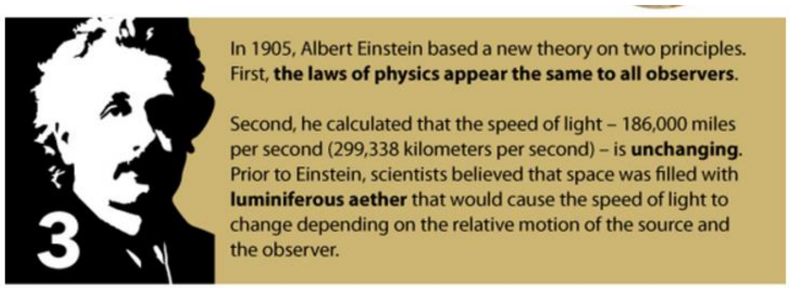
Theory of General Relativity

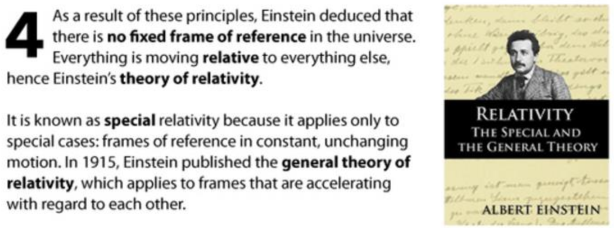
Einstein's major breakthrough was to say that space and time are not absolutes and that gravity is not simply a force applied to an object or mass. Rather, the gravity associated with any mass curves the very space and time (often called space-time) around it.
Einstein's theory of general relativity changed our understanding of the universe.

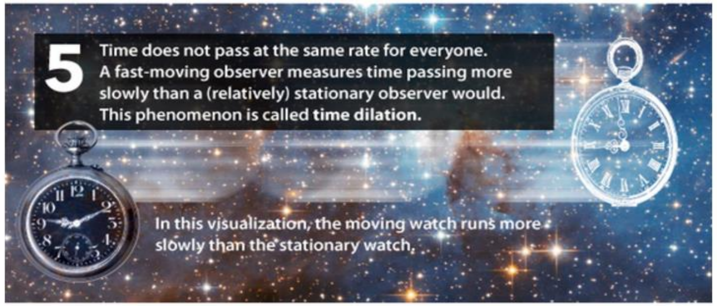




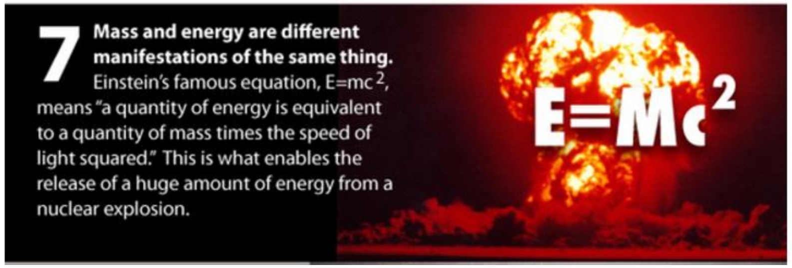


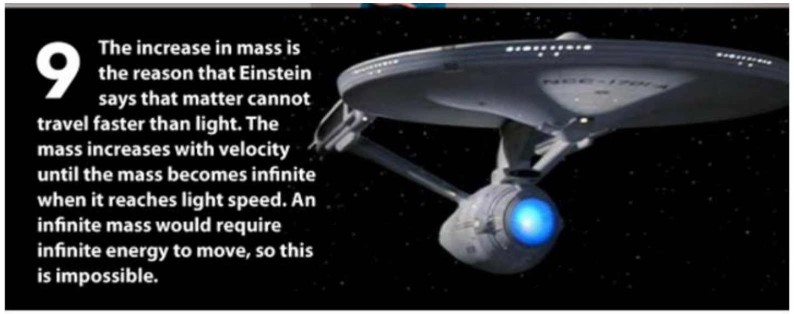






6 A fast-moving object appears **shorter** along the direction of motion, relative to a slow-moving one. This effect is very subtle until the object travels close to the speed of light.

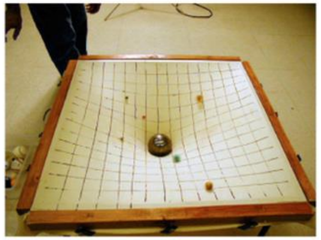




10 Space and time are part of one continuum, called space-time.

In Einstein's mathematics, space has three dimensions, and the fourth dimension is time. More recent theories presume extra dimensions that we do not perceive.

Space-time can be thought of as a grid or fabric. The presence of mass distorts space-time, so the rubber sheet model is a popular visualization.



Physical rubber sheet model. Photo: University of New Mexico Department of Physics and Astronomy

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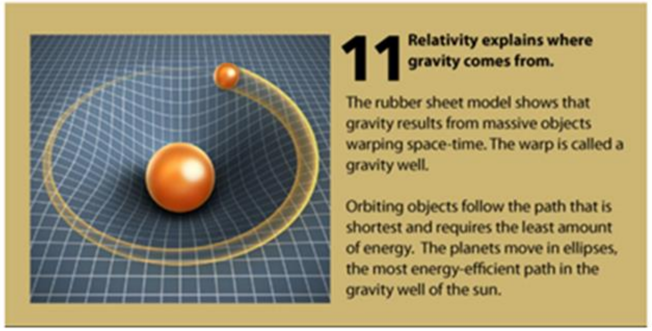

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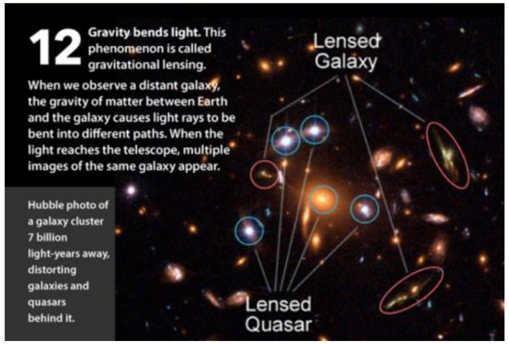

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Heisenberg's Uncertainty Principle
It states that the more precisely the position of some particle is determined, the less precisely its momentum can be known, and vice versa.

$$\Delta x \Delta p \geq \frac{h}{2\pi}$$

h Planck’s constant
x position
p momentum
Quantum Physics is a branch of physics which is the fundamental theory of nature at small scales and low energy levels of atoms and subatomic particles. Classical physics, the physics existing before quantum
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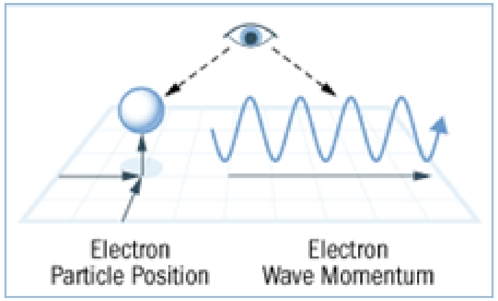

Is it a particle, a wave or both?
https://www.youtube.com/watch?v=S-4Yu3pB_dk
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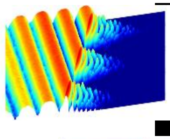
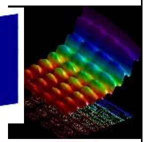
mechanics, derives from quantum physics as an approximation valid only at large (macroscopic) scales.

There are six concepts about quantum physics





1. Everything Is Made Of Waves; Also, Particles
2. Quantum Physics Is Discrete
3. Quantum Physics Is Probabilistic
4. Quantum Physics Is Non-Local
5. Quantum Physics Is (Mostly) Very Small
6. Quantum Physics Is Not Magic

Scientific inquiry into the wave nature of light began in the 17th and 18th centuries, when scientists such as **Robert Hooke, Christiaan Huygens and Leonhard Euler** proposed a wave theory of light based on experimental observations. In 1803, **Thomas Young**, an English polymath, performed the famous double-slit experiment that he later described in a paper titled on the nature of light and colours. This experiment played a major role in the general acceptance of the wave theory of light.

In 1838, Michael Faraday discovered cathode rays. These studies were followed by the 1859 statement of the black-body radiation problem by **Gustav Kirchhoff, the 1877** suggestion by **Ludwig Boltzmann** that the energy states of a physical system can be discrete, and the 1900 quantum hypothesis of Max Planck. Planck's hypothesis that energy is radiated and absorbed in discrete "quanta" (or energy packets) precisely matched the observed patterns of black-body radiation.

In 1896, **Wilhelm Wien** empirically determined a distribution law of black-body radiation, known as Wien's law in his honour. **Ludwig Boltzmann** independently arrived at this result by considerations of Maxwell's equations. However, it was valid only at high frequencies and underestimated the radiance at low frequencies. Later, Planck corrected this model using Boltzmann's statistical interpretation of thermodynamics and proposed what is now called Planck's law, which led to the development of quantum mechanics.

Following Max Planck's solution in 1900 to the black-body radiation problem (reported 1859), Albert Einstein offered a quantum-based theory to explain the photoelectric effect (1905, reported 1887). Around 1900-1910, the atomic theory and the corpuscular theory of light first came to be widely accepted as scientific fact; these latter theories can be viewed as quantum theories of matter and electromagnetic radiation, respectively.

Among the first to study quantum phenomena in nature were **Arthur Compton, C. V. Raman, and Pieter Zeeman**, each of whom has a quantum effect named after him. Robert Andrews Millikan studied the photoelectric effect experimentally, and Albert Einstein developed a theory for it. At the same time, Ernest Rutherford experimentally discovered the nuclear model of the atom, for which Niels Bohr developed his theory of the atomic structure, which was later confirmed by the experiments of Henry Moseley. In 1913, Peter Debye extended Niels Bohr's theory of atomic structure, introducing elliptical orbits, a concept also introduced by Arnold Sommerfeld. This phase is known as old quantum theory.
According to Planck, each energy element (E) is proportional to its frequency (ν):

$$E = h\nu$$

where h is Planck's constant.

Max Planck is considered the father of the quantum theory.

Planck cautiously insisted that this was simply an aspect of the processes of absorption and emission of radiation and had nothing to do with the physical reality of the radiation itself. In fact, he considered his quantum hypothesis a mathematical trick to get the right answer rather than a sizable discovery. However, in 1905 Albert Einstein interpreted Planck's quantum hypothesis realistically and used it to explain the photoelectric effect, in which shining light on certain materials can eject electrons from the material. He won the 1921 Nobel Prize in Physics for this work.

Einstein further developed this idea to show that an electromagnetic wave such as light could also be described as a particle (later called the photon), with a discrete quantum of energy that was dependent on its frequency.

The foundations of quantum mechanics were established during the first half of the 20th century by **Max Planck, Niels Bohr, Werner Heisenberg, Louis de Broglie, Arthur Compton, Albert Einstein, Erwin Schrödinger, Max Born, John von Neumann, Paul Dirac, Enrico Fermi, Wolfgang Pauli, Max von Laue, Freeman Dyson, David Hilbert, Wilhelm Wien, Satyendra Nath Bose, Arnold Sommerfeld,** and others. The Copenhagen interpretation of Niels Bohr became widely accepted.

In the mid-1920s, developments in quantum mechanics led to its becoming the standard formulation for atomic physics. In the summer of 1925, Bohr and Heisenberg published results that closed the old quantum theory. Out of deference to their particle-like behaviour in certain processes and measurements, light quanta came to be called photons (1926). From Einstein's simple postulation was born a flurry of debating, theorizing, and testing.

It was found that subatomic particles and electromagnetic waves are neither simply particle nor wave but have certain properties of each. This originated the concept of wave–particle duality.

By 1930, quantum mechanics had been further unified and formalized by the work of David Hilbert, Paul Dirac and John von Neumann with greater emphasis on measurement, the statistical nature of our knowledge of reality, and philosophical speculation about the 'observer'. It has since permeated many disciplines including quantum chemistry, quantum electronics, quantum optics, and quantum information science. Its speculative modern developments include string theory and quantum gravity theories. It also provides a useful framework for many features of the modern periodic table of elements, and describes the behaviours of atoms during chemical bonding and the flow of electrons in computer semiconductors, and therefore plays a crucial role in many modern technologies.

While quantum mechanics was constructed to describe the world of the very small, it is also needed to explain some macroscopic phenomena such as superconductors and superfluids.

The word quantum derives from the Latin, meaning "how great" or "how much". In quantum mechanics, it refers to a discrete unit assigned to certain physical quantities such as the energy of an atom at rest. The discovery that particles are discrete packets of energy with wave-like properties led to the branch of physics dealing with atomic and subatomic systems which is today called quantum mechanics. It underlies the mathematical framework of many fields of physics and chemistry, including condensed matter physics, solid-state physics, atomic physics, molecular physics, computational physics, computational chemistry, quantum chemistry, particle physics, nuclear chemistry, and nuclear physics. Some fundamental aspects of the theory are still actively studied.

Quantum mechanics is essential to understanding the behaviour of systems at atomic length scales and smaller. If the physical nature of an atom were solely described by classical mechanics, electrons would not orbit the nucleus, since orbiting electrons emit radiation and would eventually collide with the nucleus due to this loss of energy. This framework was unable to explain the stability of atoms. Instead, electrons remain in an uncertain, non-deterministic, smeared, probabilistic wave–particle orbital about the nucleus, defying the traditional assumptions of classical mechanics and electromagnetism.

	Quantum mechanics was initially developed to provide a better explanation and description of the atom, especially the differences in the spectra of light emitted by different isotopes of the same chemical element, as well as subatomic particles. In short, the quantum-mechanical atomic model has succeeded spectacularly in the realm where classical mechanics and electromagnetism falter. Broadly speaking, quantum mechanics incorporates four classes of phenomena for which classical physics cannot account: Quantization of certain physical properties Quantum entanglement Principle of uncertainty Wave–particle duality	
6	**Laws of Mechanics** **1. Newton’s Universal Law of Gravitation** Newton's law of universal gravitation is about the universality of gravity. Newton's place in the Gravity Hall of Fame is not due to his discovery of gravity, but rather due to his discovery that gravitation is universal. ALL objects attract each other with a force of gravitational attraction. Gravity is universal. This force of gravitational attraction is directly dependent upon the masses of both objects and inversely proportional to the square of the distance that separates their centers. Newton's conclusion about the magnitude of gravitational forces is summarized symbolically as	Determine the force of gravitational attraction between the earth (m = 5.98 x 10^{24} kg) and a 70-kg physics student if the student is standing at sea level, a distance of 6.38 x 10^{6} m from earth's center. The solution of the problem involves substituting known values of G (6.673 x 10-11 N m^2/kg^2), m_1 (5.98 x 1024 kg), m_2 (70 kg) and d (6.38 x 106 m) into the universal gravitation equation and solving for F_{grav}. The solution is as follows:

$$F_{grav} \propto \frac{m_1 * m_2}{d^2}$$

where F_{grav} represents the force of gravity between two objects

$\propto$ means "proportional to"

m_1 represents the mass of object 1

m_2 represents the mass of object 2

d represents the distance separating the objects' centers

Since the gravitational force is directly proportional to the mass of both interacting objects, more massive objects will attract each other with a greater gravitational force. So as the mass of either object increases, the force of gravitational attraction between them also increases. If the mass of one of the objects is doubled, then the force of gravity between them is doubled. If the mass of one of the objects is tripled, then the force of gravity between them is tripled. If the mass of both of the objects is doubled, then the force of gravity between them is quadrupled; and so on.

Since gravitational force is inversely proportional to the square of the separation distance between the two interacting objects, more separation distance will result in weaker gravitational forces. So as two objects are separated from each other, the force of gravitational attraction between them also decreases. If the separation distance between two objects is doubled (increased by a factor of 2), then the force of gravitational attraction is decreased by a factor of 4 (2 raised to the second power). If the separation distance between any two objects is tripled (increased by a factor of 3), then the force of gravitational attraction is decreased by a factor of 9 (3 raised to the second power).

The constant of proportionality (G) in the above equation is known as the **universal gravitation constant**. The precise value of G was determined experimentally by Henry Cavendish in the century after Newton's death. The value of G is found to be **$G = 6.673 \times 10^{-11}\ N\ m^2/kg^2$**

$$F_{grav} = \frac{(6.673 \times 10^{-11}\ N\ m^2/kg^2) \cdot (5.98 \times 10^{24}\ kg) \cdot (70\ kg)}{(6.38 \times 10^{6}\ m)^2}$$

$$F_{grav} = 686\ N$$

Force of Gravitational Attraction towards Earth for a 70-kg Physics Student at Various Locations

https://www.youtube.com/watch?v=391txUI76gM

2. Newton's First Law of Motion

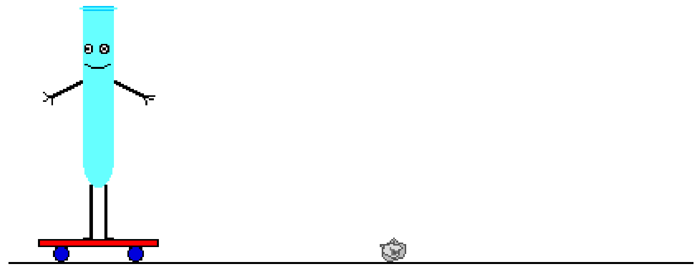
An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

This law is often called "the law of inertia".

First law of Motion

There is a natural tendency of objects to keep on doing what they're doing. All objects resist changes in their state of motion. In the absence of an unbalanced force, an object in motion will maintain this state of motion.

Let's study the "skater" to understand this a little better.



What is the motion in this picture?

What is the unbalanced force in this picture?

What happened to the skater in this picture?

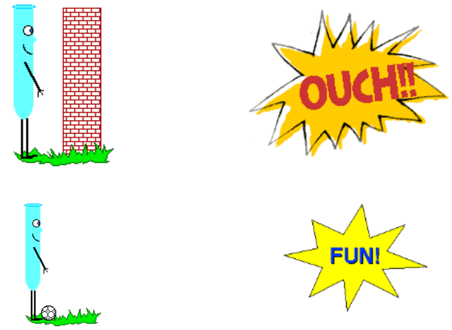
3. Newton's Second Law of Motion

Acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).

F = M A

Second Law of Newton

Everyone unconsciously knows the Second Law. Everyone knows that heavier objects require more force to move the same distance as lighter objects.

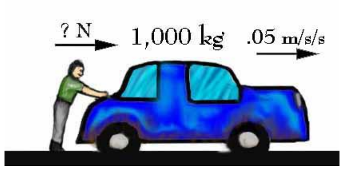
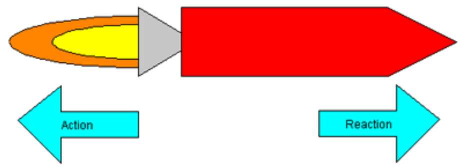


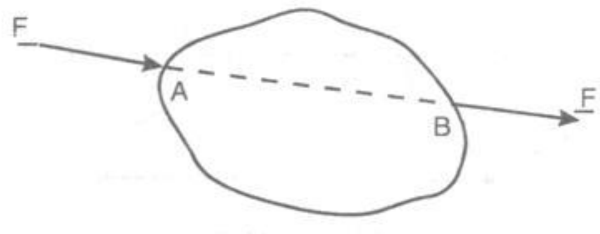
However, the Second Law gives us an exact relationship between force, mass, and acceleration. It can be expressed as a mathematical equation:

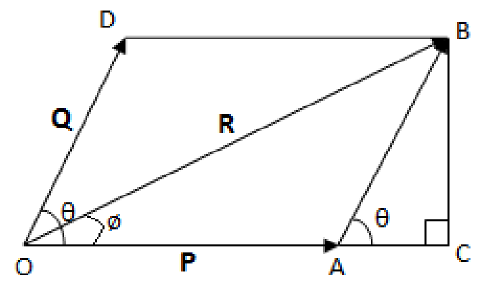
F = M A

or

FORCE = MASS times ACCELERATION

	4. Newton's Third Law of Motion For every action there is an equal and opposite re-action.	This is an example of how Newton's Second Law works:  Mike's car, which weighs 1,000 kg, is out of gas. Mike is trying to push the car to a gas station, and he makes the car go 0.05 m/s/s. Using Newton's Second Law, you can compute how much force Mike is applying to the car. **F=1,000 X 0.05** = 50 Newtons **Third Law of Motion** **F**or every force there is a reaction force that is equal in size, but opposite in direction. That is to say that whenever an object pushes another object it gets pushed back in the opposite direction equally hard.  Let's study how a rocket works to understand Newton's Third Law.  The rocket's action is to push down on the

	5. Law of Transmissibility of Forces It states that the state of rest or motion of a rigid body is unaltered if a force acting on the body is replaced by another force of the same magnitude and direction but acting anywhere on the body in the line of action of the replaced force.	ground with the force of its powerful engines, and the reaction is that the ground pushes the rocket upwards with an equal force https://www.youtube.com/watch?v=QffUhiX2uSg **Law of Transmissibility of Forces**  F is the force acting on a rigid body at point A. According to the law of transmissibility of forces, if the point of application of this force is shifted to another point B, which is on the line of action of the force F, the state of rest or the steady motion of the body is still unaltered. The following points are to be carefully noted: (i) This law is applicable only for rigid bodies, which is the subject matter of Civil Engineering. (ii) In case of subjects like the strength of materials in which deformable bodies are concerned, the law of transmissibility will not hold good, since the point of application of the forces completely alter the internal stresses in the deformable bodies. https://www.youtube.com/watch?v=4iRw0LXsgZY

	6. The Law of Parallelogram of Forces The law of parallelogram of forces states that if two vectors acting on a particle at the same time be represented in magnitude and direction by the two adjacent sides of a parallelogram drawn from a point their resultant vector is represented in magnitude and direction by the diagonal of the parallelogram drawn from the same point.	**Law of paralleogram of Forces** Let **P** and **Q** be two vectors acting simultaneously at a point and represented both in magnitude and direction by two adjacent sides OA and OD of a parallelogram OABD as shown in figure. Let θ be the angle between **P** and **Q** and **R** be the resultant vector. Then, according to parallelogram law of vector addition, diagonal OB represents the resultant of **P** and **Q**.  So, we have $\mathbf{R} = \mathbf{P} + \mathbf{Q}$ Now, expand A to C and draw BC perpendicular to OC. From triangle OCB,

$$OB^2 = OC^2 + BC^2$$
$$or, OB^2 = (OA + AC)^2 + BC^2 \quad ......(i)$$

In triangle ABC,

$$\cos\theta = \frac{AC}{AB}$$
$$or, AC = AB\cos\theta$$
$$or, AC = OD\cos\theta = Q\cos\theta \quad [\because AB = OD = Q]$$

Also,

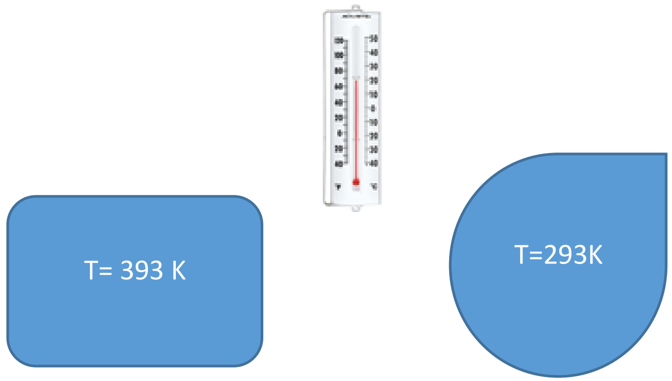
$$\text{Sin}\,\theta = \frac{BC}{AB}$$
$$or, BC = AB\ sin\,\theta$$
$$or\ BC = OD\sin\theta = Q\sin\theta \qquad [\because AB = OD = Q]$$

Magnitude of resultant:

Substituting value of AC and BC in (i), we get

$$R^2 = (P + Q\cos\theta)^2 + (Q\sin\theta)^2$$
$$or, R^2 = P^2 + 2PQ\cos\theta + Q^2\cos^2\theta + Q^2\sin^2\theta$$
$$or, R^2 = P^2 + 2PQ\cos\theta + Q^2$$
$$\therefore R = \sqrt{P^2 + 2PQ\cos\theta + Q^2}$$

which is the magnitude of resultant.

		Direction of resultant: Let ø be the angle made by resultant **R** with **P**. Then, From triangle OBC, $\tan\phi = \frac{BC}{OC} = \frac{BC}{OA + AC}$ $or, \tan\phi = \frac{Q\sin\theta}{P + Q\cos\theta}$ $\therefore \phi = \tan^{-1}(\frac{Q\sin\theta}{P + Q\cos\theta})$ which is the direction of resultant. https://www.youtube.com/watch?v=PO5EL9TB-v4
7.	**Laws of Thermodynamics** The four **laws of thermodynamics** define fundamental physical quantities (**temperature, energy, entropy and absolute entropy**) that characterize thermodynamic systems at thermodynamic equilibrium. The four laws of thermodynamics are: 1. **Zeroth law of thermodynamics:** If two systems are in thermal equilibrium with a third system, they are in thermal equilibrium with each other. This law helps define the notion of temperature.	**Zeroth Law of Thermodynamics** 

<table>
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<td>2. First law of thermodynamics: It is impossible to construct an engine which works in a cycle produces no other effect other than rising of a weight without some other form of energy disappearing simultaneously</td>
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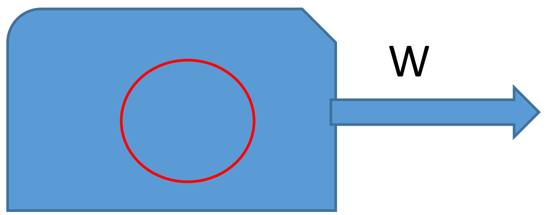
First Law of Thermodynamics

It is the law of conservation of energy. Energy can neither be created nor destroyed. It is always possible to convert one form of energy into the other form. It is impossible to construct a perpetual machine of first kind.

$$\oint \delta q = \oint \delta w$$

ΔQ-ΔW=ΔE for a closed system executing a thermodynamic process

$$\delta q - \delta w = \int pdv$$



No Input but only output

Such an Engine is Impossible

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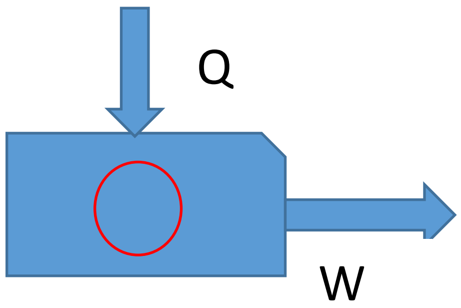
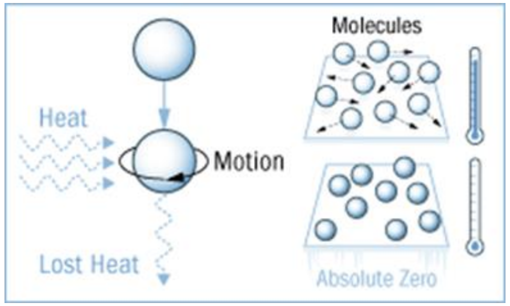
	3. **Second Law of thermodynamics**: It is impossible to construct an engine which works in a thermodynamic cycle produces no other effect other than raising of a weight exchanging heat with a single reservoir. (Kelvin Planck Statement)	**Second Law of Thermodynamics** It is not possible to convert all heat into work but reverse is possible. It is impossible to build an engine with 100% efficiency. It is impossible to build a perpetual motion machine of second kind. Heat itself cannot flow from low temperature region to high temperature region (Clausius Statement). $ds \geq 0$ for a thermodynamic cycle $ds \geq \int \frac{dq}{T}$ For a thermodynamic process  **Q=W is impossible**

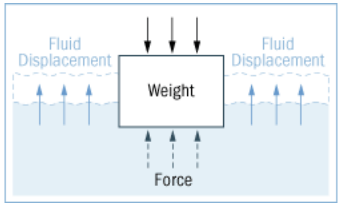
	4. **Third Law of thermodynamics**: At absolute zero temperature, the entropy of a crystalline object is zero	**Third Law of thermodynamics**  At absolute zero temperature, the molecules are not at in thermodynamic state, hence no chaos, hence zero entropy https://www.youtube.com/watch?v=8N1BxHgsoOw
8.	**Laws of Fluid Mechanics** **1. Pascal's Law** **Pascal's law** states that a pressure change occurring anywhere in a confined incompressible fluid is transmitted throughout the fluid such that the same change occurs everywhere.	**Pascal's Law** This principle is stated mathematically as: $$\Delta p = \rho g(\Delta h)$$ Δp is the hydrostatic pressure (given in pascals in the SI system), or the difference in pressure at two points within a fluid column, due to the weight of the fluid; ρ is the fluid density (in kilograms per cubic meter in the SI system);

g is acceleration due to gravity (normally using the sea level acceleration due to Earth's gravity, in SI in metres per second squared);

Δh is the height of fluid above the point of measurement, or the difference in elevation between the two points within the fluid column (in metres in SI).

2. **Archimedes Principle**
   Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object.

Archimedes Prinicple



https://www.youtube.com/watch?v=2ReflvqaYg8

3. **Euler's Equation**
   The Euler's equation for steady flow of an ideal fluid along a streamline is a relation between the velocity, pressure and density of a moving fluid. It is based on the Newton's Second Law of Motion. The integration of the equation gives Bernoulli's equation in the form of energy per unit weight of the following fluid.

Euler's Equation

It is based on the following assumptions:

- The fluid is non-viscous (i.e., the frictional losses are zero).
- The fluid is homogeneous and incompressible (i.e., mass density of the fluid is constant).
- The flow is continuous, steady and along the streamline.
- The velocity of the flow is uniform over the section.

		▪ No energy or force (except gravity and pressure forces) is involved in the flow. $$\frac{dP}{\rho} + VdV + gdz = 0$$
	4. Bernoulli's Equation On Integrating Euler's Equation, Bernoulli's equation is obtained (pressure head+ potential head+ kinetic head= constant)	**Bernoulli's Equation** $$\frac{p_1}{\rho_1} + gz_1 + \frac{v_1^2}{2} = \frac{p_2}{\rho_2} + gz_2 + \frac{v_2^2}{2}$$ https://www.youtube.com/watch?v=mmB-o5Auf-s
	5. Newton's Law of Viscosity The shear stress between adjacent fluid layers is proportional to the negative value of the velocity gradient between the two layers.	**Newton's Law of Viscosity** $\tau = -\mu \frac{\partial u}{\partial z}$; μ= Coefficient of absolute viscosity: Ns/m^2

9.	**Laws of Conservation** Conservation laws are fundamental to our understanding of the physical world, in that they describe which processes can or cannot occur in nature. For example, the conservation law of energy states that the total quantity of energy in an isolated system does not change, though it may change form. In general, the total quantity of the property governed by that law remains unchanged during physical processes. With respect to classical physics, conservation laws include **conservation of energy, mass (or matter), linear momentum, angular momentum, and electric charge**. **1. Conservation of Mass (Continuity Equation)** **2. Conservation of Momentum** **3. Conservation of Energy** **4. Conservation of Electric Charge**	
	1. Conservation of Mass The law of conservation of mass states that mass in an isolated system is neither created nor destroyed by chemical reactions or physical transformations	**a. Conservation of Mass as Applied to a Fluid** Mass entering per unit time = Mass leaving per unit time + Increase of mass in the control volume per unit time Mass entering per unit time = Mass leaving per unit time for steady flow $\dot{m}_{in} = \dot{m}_{out} + \frac{dm_{cv}}{dt}$ $\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$ $\frac{\partial \rho}{\partial t} + \nabla(\rho\overline{V}) = 0$ $\frac{\partial \rho}{\partial t} + \rho(\nabla\overline{V}) + \overline{V}(\nabla\rho) = 0$ $\frac{\partial \rho}{\partial t} + \overline{V}(\nabla\rho) + \rho(\nabla\overline{V}) = 0$ $\frac{D\rho}{Dt} + \rho(\nabla\overline{V}) = 0$

2. Conservation of Momentum

a. Conservation of momentum as Applied to a Solid
b. Conservation of momentum as Applied to a Fluid

a. Conservation of momentum as applied to a solid

For any collision occurring in an isolated system, momentum is conserved. The total amount of momentum of the collection of objects in the system is the same before the collision as after the collision.

If ρ=constant

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$\frac{\partial u}{\partial x} = 0 \; for \; 1D$$

$$\rho u A = constant$$

b. Chemical Reaction : Mass of Reactants = Mass of Products

$$CH_4 + 2O_2 = CO_2 + 2H_2O + Energy$$

12+4 + 2x32 =12+32 +2 (2+16)

80 = 80

Conservation of momentum (as applied to solids)

$$m_1V_1 + m_2V_2 = m_1V_1' + m_2V_2'$$

b. Momentum Equation (For fluids)

3. Conservation of Energy Equation

Conservation of Momentum (for fluids)

1. Incompressible fluids

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\rho f_1$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial P}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\rho f_2$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial P}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\rho f_3$$

2. In General

$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho u^2)}{\partial x}+\frac{\partial(\rho uv)}{\partial y}+\frac{\partial(\rho uw)}{\partial z}=-\frac{\partial p}{\partial x}+\frac{1}{Re_r}\left[\frac{\partial\tau_{xx}}{\partial x}+\frac{\partial\tau_{xy}}{\partial y}+\frac{\partial\tau_{xz}}{\partial z}\right]$$

$$\frac{\partial(\rho v)}{\partial t}+\frac{\partial(\rho uv)}{\partial x}+\frac{\partial(\rho v^2)}{\partial y}+\frac{\partial(\rho vw)}{\partial z}=-\frac{\partial p}{\partial y}+\frac{1}{Re_r}\left[\frac{\partial\tau_{xy}}{\partial x}+\frac{\partial\tau_{yy}}{\partial y}+\frac{\partial\tau_{yz}}{\partial z}\right]$$

$$\frac{\partial(\rho w)}{\partial t}+\frac{\partial(\rho uw)}{\partial x}+\frac{\partial(\rho vw)}{\partial y}+\frac{\partial(\rho w^2)}{\partial z}=-\frac{\partial p}{\partial z}+\frac{1}{Re_r}\left[\frac{\partial\tau_{xz}}{\partial x}+\frac{\partial\tau_{yz}}{\partial y}+\frac{\partial\tau_{zz}}{\partial z}\right]$$

The notations and symbols used are as defined in standard texts.

Conservation of Energy

$$\frac{\partial(E_r)}{\partial t}+\frac{\partial(uE_r)}{\partial x}+\frac{\partial(vE_r)}{\partial y}+\frac{\partial(wE_r)}{\partial z}$$
$$=-\frac{\partial(up)}{\partial x}-\frac{\partial(vp)}{\partial y}-\frac{\partial(wp)}{\partial z}-\frac{1}{Re_r Pr_r}\left[\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}\right]$$
$$+\frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\tau_{xx}+v\tau_{xy}+w\tau_{xz})+\frac{\partial}{\partial y}(u\tau_{xy}+v\tau_{yy}+w\tau_{yz})\right.$$
$$\left.+\frac{\partial}{\partial z}(u\tau_{xz}+v\tau_{yz}+w\tau_{zz})\right]$$

	4. Conservation of Charge In electromagnetic field theory, vector calculus can be used to express the law in terms of charge density ρ (in coulombs per cubic meter) and electric current density J (in amperes per square meter). This is called the charge continuity equation	**Conservation of Charge** $$\frac{\partial \rho}{\partial t} + \nabla . J = 0$$ The term on the left is the rate of change of the charge density ρ at a point. The term on the right is the divergence of the current density J at the same point. The equation equates these two factors, which says that the only way for the charge density at a point to change is for a current of charge to flow into or out of the point. This statement is equivalent to a conservation of four-current.
10.	**Laws of Heat Transfer** **1. Fourier Conduction Law** Fourier's equation of heat conduction: $$Q = -kA\left(\frac{dT}{dx}\right)$$ Where, 'Q' is the heat flow rate by conduction (W) 'k' is the thermal conductivity of body material ($W \cdot m^{-1} \cdot K^{-1}$) 'A' is the cross-sectional area normal to direction of heat flow (m^2) and 'dT/dx' is the temperature gradient ($K \cdot m^{-1}$). Negative sign in Fourier's equation indicates that the heat flow is in the direction of negative gradient temperature and that serves to make heat flow positive. Thermal conductivity 'k' is one of the transport properties. Other are the viscosity associated with the transport of momentum, diffusion coefficient associated with the transport of mass. Thermal conductivity 'k' provides an indication of the rate at which heat is transferred through a medium by conduction process.	**Fourier Conduction Equation** The general conduction equation in Cartesian co-ordinates is as follows $$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial Z}\right) + \dot{q} = \frac{1}{\rho C}\frac{\partial T}{\partial \tau}$$

2. Newton's Law of Cooling

Temperature difference in any situation results from energy flow into a system or energy flow from a system to surroundings. The former leads to heating, whereas latter leads to cooling of an object.
Newton's Law of Cooling states that the rate of temperature of the body is proportional to the difference between the temperature of the body and that of the surrounding medium. This statement leads to the classic equation of exponential decline over time which can be applied to many phenomena in science and engineering, including the discharge of a capacitor and the decay in radioactivity.
Newton's Law of Cooling is useful for studying water heating because it can tell us how fast the hot water in pipes cools off. A practical application is that it can tell us how fast a water heater cools down if you turn off the breaker when you go on vacation.

The following equation is also often called as Newton's Law of cooling

$$\dot{q} = \frac{\dot{Q}}{A} = h(T_w - T_\infty).$$

Where h is called convective heat transfer coefficient = kJ/m^2 K

Newton's Law of Cooling

Suppose that a body with initial temperature T_1°C, is allowed to cool in air which is maintained at a constant temperature T_2°C.
Let the temperature of the body be T°C at time t.
Then by Newton's Law of Cooling,

$$\frac{dT}{dt} = -k(T - T_2) \qquad (1)$$

Where k is a positive proportionality constant. Since the temperature of the body is higher than the temperature of the surroundings then $T-T_2$ is positive. Also the temperature of the body is decreasing i.e. it is cooling down and rate of change of

$$\frac{dT}{dt} < 0$$

temperature is negative.

The constant 'k' depends upon the surface properties of the material being cooled.
Initial condition is given by $T=T_1$ at $t=0$
Solving (1)

$$-kt = \log(T - T_2) - \log C$$

$$T - T_2 = Ce^{-kt} \qquad (2)$$

Applying initial condition; $C = T_1 - T_2$

Substituting the value of C in equation (2) gives

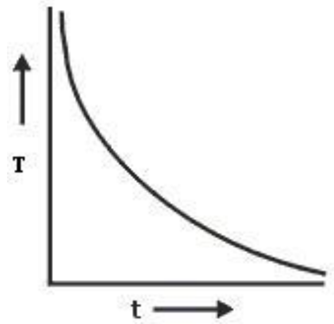
$$T = T_2 + (T_1 - T_2)e^{-kt}$$

This equation represents Newton's law of cooling.

If $k < 0$, lim t --> ∞, $e^{-kt} = 0$ and $T = T_2$,

Or we can say that the temperature of the body approaches that of its surroundings as time goes.

The graph drawn between the temperature of the body and time is known as cooling curve. The slope of the tangent to the curve at any point gives the rate of fall of temperature.

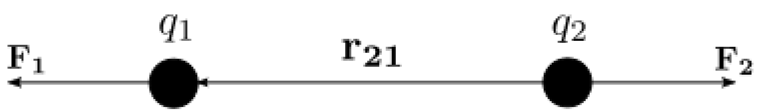


In general,

$$T(t) = T_A + (T_H - T_A)e^{-kt}$$

Where,
$T(t)$ = Temperature at time t,
T_A = Ambient temperature (temp of surroundings),
T_H = Temperature of hot object at time 0,
k = positive constant and
t = time.

	3. Stefan-Boltzmann Law of Radiation The Stefan–Boltzmann law describes the power radiated from a black body in terms of its temperature. Specifically, the Stefan–Boltzmann law states that the total energy radiated per unit surface area of a black body across all wavelengths per unit time (also known as the black body radiant emittance or radiant exitance), is directly proportional to the fourth power of the black body's thermodynamic temperature T: $q=\sigma T^4$ The constant of proportionality σ, called the Stefan–Boltzmann constant derives from other known constants of nature.	https://www.youtube.com/watch?v=O3N9XyTkSBI
11	**Laws of Mass Transfer** Mass transfer is the net movement of mass from one location, usually meaning stream, phase, fraction or component, to another. Mass transfer occurs in many processes, such as absorption, evaporation, drying, precipitation, membrane filtration, and distillation **1. Fick's First Law** It postulates that the flux goes from regions of high concentration to regions of low concentration, with a magnitude that is proportional to the concentration gradient (spatial derivative), or in simplistic terms the concept that a solute will move from a region of high concentration to a region of low concentration across a concentration gradient. $\boldsymbol{m = -D\frac{dC}{dx}}$ D= Diffusion coefficient of diffusivity= m^2/s m= diffusion flux= mol /m^2 s C=concentration in mol /m^3	https://www.youtube.com/watch?v=Hmfnolr47Zw

	2. Fick's Second Law **Fick's second law** predicts how diffusion causes the concentration to change with time. It is a partial differential equation which in one dimension reads: $$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2}$$	
12	**Laws of Electricity** **1. Coulomb's Law** The magnitude of the electrostatic force of attraction between two point charges is directly proportional to the product of the magnitudes of charges and inversely proportional to the square of the distance between them. The force is along the straight line joining them. If the two charges have the same sign, the electrostatic force between them is repulsive; if they have different signs, the force between them is attractive.  Coulomb's law can also be stated as a simple mathematical expression. The scalar and vector forms of the mathematical equation are $\lvert F\rvert = k_e \frac{\lvert q_1 q_2\rvert}{r^2}$ and $F_1 = k_e \frac{q_1\ q_2}{\lvert r_{12}\rvert 2}\widehat{r_{21}}$ respectively Where k_e is Coulomb's constant (k_e = 8.9875517873681764×10^9 N m^2 C^{-2}), q_1 and q_2 are the signed magnitudes of the charges, the scalar r is the distance between the charges, the vector $\mathbf{r}_{21} = \mathbf{r}_1 - \mathbf{r}_2$ is the vectorial distance between the charges, and $\hat{\mathbf{r}}_{21} = \mathbf{r}_{21}/\lvert\mathbf{r}_{21}\rvert$ (a unit vector pointing	

from q_2 to q_1). The vector form of the equation calculates the force $\mathbf{F}_1$ applied on q_1 by q_2. If $\mathbf{r}_{12}$ is used instead, then the effect on q_2 can be found. It can be also calculated using Newton's third law: $\mathbf{F}_2 = -\mathbf{F}_1$.

Units

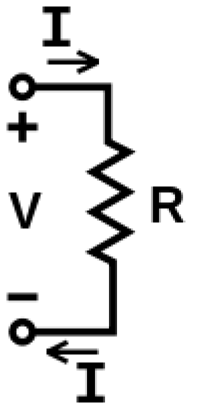
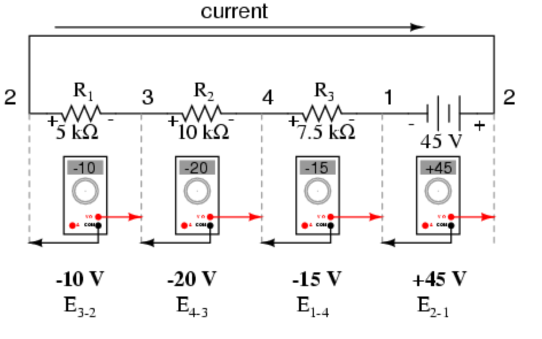
When the electromagnetic theory is expressed using the standard SI units, force is measured in Newtons, charge in coulombs, and distance in metres. Coulomb's constant is given by $k_e = \frac{1}{4\pi\varepsilon_0}$. The constant ε_0 is the permittivity of free space in $C^2\ m^{-2}\ N^{-1}$. And ε is the relative permittivity of the material in which the charges are immersed, and is dimensionless.

The SI derived units for the electric field are volts per meter, Newtons per coulomb, or tesla meters per second.

Coulomb's law and Coulomb's constant can also be interpreted in various terms:

- Atomic units. In atomic units the force is expressed in hartrees per Bohr radius, the charge in terms of the elementary charge, and the distances in terms of the *Bohr radius*.
- Electrostatic units or Gaussian units. In electrostatic units and Gaussian units, the unit charge (*esu* or statcoulomb) is defined in such a way that the Coulomb constant k disappears because it has the value of one and becomes dimensionless.

CGS units are often preferred in the treatment of electromagnetism, as they greatly simplify formulas.

	2. Ohm's Law Ohm's law states that the current through a conductor between two points is directly proportional to the voltage across the two points. Introducing the constant of proportionality, the resistance, one arrives at the usual mathematical equation that describes this relationship: $$I = \frac{V}{R}$$ Where I is the current through the conductor in units of amperes, V is the voltage measured across the conductor in units of volts, and R is the resistance of the conductor in units of ohms. More specifically, Ohm's law states that the R in this relation is constant, independent of the current **3. Kirchhoff's Voltage Law** "The algebraic sum of all voltages in a loop must equal zero"	**Ohm's Law**  **Kirchoff's Voltage Law** 

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4. Kirchhoff’s Current Law

“The algebraic sum of all currents entering and exiting a node must equal zero”
That is, if we assign a mathematical sign (polarity) to each current, denoting whether they enter (+) or exit (-) a node, we can add them together to arrive at a total of zero, guaranteed.

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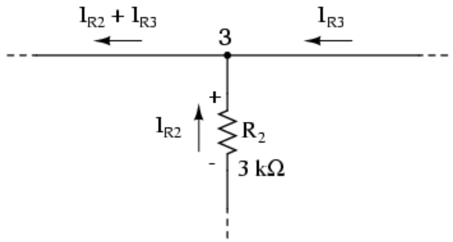
Kirchoff’s Current Law



$$I_{entering} + (-I_{exiting}) = 0$$

https://www.youtube.com/watch?v=m4jzgqZu-4s

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Laws of Electro Magnetism

Maxwell's equations are a set of partial differential equations that, together with the Lorentz force law, form the foundation of classical electromagnetism, classical optics, and electric circuits.

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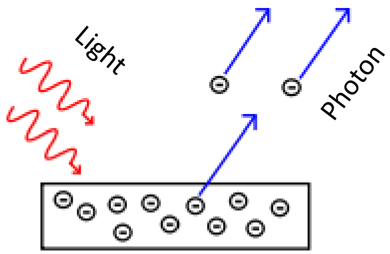
Name	Integral equations	Differential equations	Meaning
Gauss's law	$\oiint_{\partial\Omega} \mathbf{E} \cdot \mathrm{d}\mathbf{S} = \frac{1}{\varepsilon_0} \iiint_{\Omega} \rho \, \mathrm{d}V$	$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$	The electric flux leaving a volume is proportional to the charge inside.
Gauss's law for magnetism	$\oiint_{\partial\Omega} \mathbf{B} \cdot \mathrm{d}\mathbf{S} = 0$	$\nabla \cdot \mathbf{B} = 0$	There are no magnetic monopoles; the total magnetic flux through a closed surface is zero.
Maxwell–Faraday equation (Faraday's law of induction)	$\oint_{\partial\Sigma} \mathbf{E} \cdot \mathrm{d}\boldsymbol{\ell} = -\frac{\mathrm{d}}{\mathrm{d}t} \iint_{\Sigma} \mathbf{B} \cdot \mathrm{d}\mathbf{S}$	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	The voltage induced in a closed circuit is proportional to the rate of change of the magnetic flux it encloses.
Ampère's circuital law (with Maxwell's addition)	$\oint_{\partial\Sigma} \mathbf{B} \cdot \mathrm{d}\boldsymbol{\ell} = \mu_0 \iint_{\Sigma} \mathbf{J} \cdot \mathrm{d}\mathbf{S} + \mu_0 \varepsilon_0 \frac{\mathrm{d}}{\mathrm{d}t} \iint_{\Sigma} \mathbf{E} \cdot \mathrm{d}\mathbf{S}$	$\nabla \times \mathbf{B} = \mu_0 \left(\mathbf{J} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right)$	The magnetic field induced around a closed loop is proportional to the electric current plus displacement current (rate of change of electric field) it encloses.

14

Photoelectric Effect

The **photoelectric effect** or photo ionization is the emission of electrons or other free carriers when light is shone onto a material. Electrons emitted in this manner can be called photo electrons.



The energy of a photon could be calculated using Planck's equation:

$E_{photon} = h\nu$

Where E photon is the energy of a photon in Joules (J), h is Planck's constant (6.626×10^{-34} J.s) and ν is the frequency of light in Hz.

		Laws of photoelectric emission The experimental observations on photoelectric effect may be summarized as follows, which are known as the fundamental laws of photoelectric emission. 1. For a given photo sensitive material, there is a minimum frequency called the threshold frequency, below which emission of photoelectrons stops completely, however great the intensity may be. 2. For a given photosensitive material, the photo electric current is directly proportional to the intensity of the incident radiation, provided the frequency is greater than the threshold frequency. 3. The photoelectric emission is an instantaneous process. i.e. there is no time lag between the incidence of radiation and the emission of photo electrons. 4. The maximum kinetic energy of the photo electrons is directly proportional to the frequency of incident radiation, but is independent of its intensity. https://www.youtube.com/watch?v=4EkogMWJJFg
15	**Thermoelectric Effect** The **thermoelectric effect** is the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference. At the atomic scale, an applied	

temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side.

This effect can be used to generate electricity, measure temperature or change the temperature of objects. Because the direction of heating and cooling is determined by the polarity of the applied voltage, thermoelectric devices can be used as temperature controllers.

The term "thermoelectric effect" encompasses three separately identified effects: the **Joule effect**, **Seebeck effect**, **Peltier effect**, and **Thomson effect**.

1. **Joule Effect:** It is the irreversible conversion of electrical energy into thermal energy:
   $Q_J = I^2R$

2. **Seebeck Effect:** It refers to the production of an electromotive force in a thermocouple under the condition of zero electric current
   $V = emf = \int_{T_2}^{T_1} S_{ab} dT = S_{ab}\,(T_1 - T_2)$
   S_{ab} is known as Seebeck Coefficient

3. **Peltier Effect**: When a current flows across an isothermal junction of two dissimilar materials, there is either an evolution or absorption of heat at the junction and such an effect is Peltier effect
   $Q_p = \pi_{ab} I = S_{ab} T I$

4. **Thomson Effect:** When an electric current flows through a material having a temperature gradient, there is an evolution or absorption of heat and this effect is known as Thomson Effect.
   $$\boldsymbol{\sigma} = \frac{\frac{dQ_T}{dL}}{\left(\frac{dT}{dL}\right) I}$$

	Laws of thermocouples: **Law of homogenous materials** This was originally known as the Law of Homogeneous Metals. A homogeneous wire is one that is physically and chemically the same throughout. This law states that a thermocouple circuit that is made with a homogeneous wire cannot generate an emf, even if it is at different temperatures and thicknesses throughout. In other words, a thermocouple must be made from at least two different materials in order to generate a voltage. A change in the area of the cross section of a wire, or a change in the temperature in different places in the wire, will not produce a voltage. **Law of intermediate materials** This was originally known as the Law of Intermediate Metals. The sum of all of the emfs in a thermocouple circuit using two or more different metals is zero if the circuit is at the same temperature. This law is interpreted to mean that the addition of different metals to a circuit will not affect the voltage the circuit creates. The added junctions are to be at the same temperature as the junctions in the circuit. For example, a third metal such as copper leads may be added to help take a measurement. This is why thermocouples may be used with digital multimeters or other electrical components. It is also why solder may be used to join metals to form thermocouples. **Law of successive or intermediate temperatures** A thermocouple made from two different metals produces an emf, E_1, when the metals are at different temperatures, T_1 and T_2, respectively. Suppose one of the metals has a temperature change to T_3, but the other remains at T_2. Then the emf created when the thermocouple is at temperatures T_1 and T_3 will be the summation of the first and second, so that $E_{new} = E_1 + E_2$.	**https://www.youtube.com/watch?v=ZwXtPW0gdD0**

16

Models of Solid Mechanics

A material has a rest shape and its shape departs away from the rest shape due to stress. The amount of departure from rest shape is called deformation, the proportion of deformation to original size is called strain. If the applied stress is sufficiently low (or the imposed strain is small enough), almost all solid materials behave in such a way that the strain is directly proportional to the stress; the coefficient of the proportion is called the modulus of elasticity. This region of deformation is known as the linearly elastic region.

It is most common for analysts in solid mechanics to use linear material models, due to ease of computation. However, real materials often exhibit non-linear behaviour. As new materials are used and old ones are pushed to their limits, non-linear material models are becoming more common.

There are four basic models that describe how a solid responds to an applied stress:

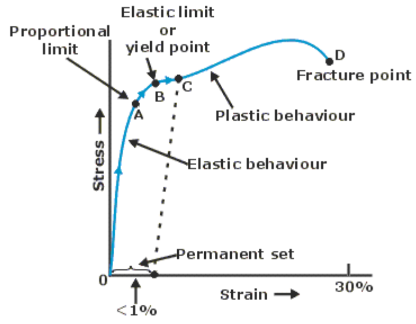
Elasticity – When an applied stress is removed, the material returns to its unreformed state. Linearly elastic materials, those that deform proportionally to the applied load, can be described by the linear elasticity equations such as Hooke's law.

Viscoelasticity – These are materials that behave elastically, but also have damping: when the stress is applied and removed, work has to be done against the damping effects and is converted in heat within the material resulting in a hysteresis loop in the stress–strain curve. This implies that the material response has time-dependence.

Plasticity – Materials that behave elastically generally do so when the applied stress is less than a yield value. When the stress is greater than the yield stress, the material behaves plastically and does not return to its previous state. That is, deformation that occurs after yield is permanent.

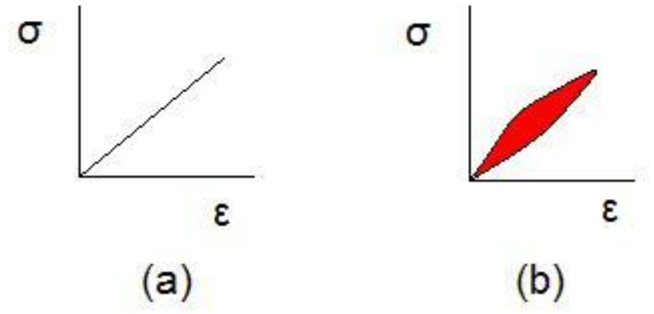
Thermoelasticity - There is coupling of mechanical with thermal responses. In general, Thermoelasticity is concerned with elastic solids

Elasticity and Plasticity



A typical stress-strain curve for a ductile metal

Elasticity vs Viscoelasticity



The red area is a hysteresis loop and shows the amount of energy lost (as heat) in a loading and unloading cycle.

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<td>under conditions that are neither isothermal nor adiabatic. The simplest theory involves the Fourier's law of heat conduction, as opposed to advanced theories with physically more realistic models</td>
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Moduli of Elasticity

$$\mathrm{E} = \text{Young's Modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{\sigma}{\epsilon}$$

$$\mathrm{G} = \text{Rigidity Modulus} = \frac{\text{Shear Stress}}{\text{Shear Strain}} = \frac{\tau}{\gamma}$$

$$\mathrm{K} = \text{Bulk Modulus} = \frac{\text{Normal Stress}}{\text{Volumetric Strain}} = \frac{\sigma}{\frac{\Delta V}{V}}$$

$$\vartheta = \text{Poisson's Ratio} = \frac{\text{Lateral Strain}}{\text{Longitudinal Strain}} = \frac{\frac{\delta d}{d}}{\frac{\delta l}{l}}$$

Equations of Motion

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + F_x = \rho \frac{\partial^2 u_x}{\partial t^2}$$

$$\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + F_y = \rho \frac{\partial^2 u_y}{\partial t^2}$$

$$\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \sigma_z}{\partial z} + F_z = \rho \frac{\partial^2 u_z}{\partial t^2}$$

These are 3 independent equations with 6 independent unknowns

Strain displacement equations:

$$\epsilon_{ij} = \frac{1}{2}(u_{j,i} + u_{i,j})$$

$$\epsilon_x = \frac{\partial u_x}{\partial x} \qquad \gamma_{xy} = \frac{1}{2}\left[\frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}\right]$$

$$\epsilon_y = \frac{\partial u_y}{\partial y} \qquad \gamma_{yz} = \frac{1}{2}\left[\frac{\partial u_y}{\partial z} + \frac{\partial u_z}{\partial y}\right]$$

$$\epsilon_z = \frac{\partial u_z}{\partial z} \qquad \gamma_{zx} = \frac{1}{2}\left[\frac{\partial u_z}{\partial x} + \frac{\partial u_x}{\partial z}\right]$$

Constitutive Equations

$$\boldsymbol{\sigma_{ij} = C_{ijkl}\epsilon_{kl}}$$

https://www.youtube.com/watch?v=2icfdyelx5M

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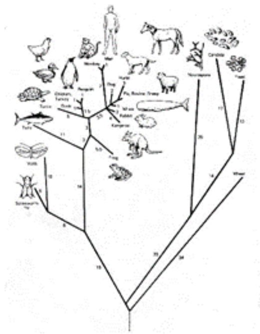
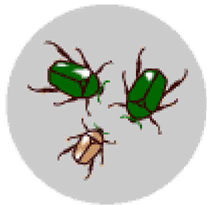
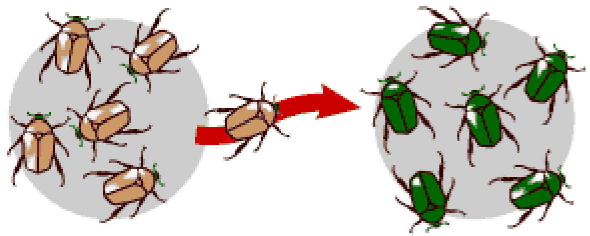
17	**Evolution and Natural Selection** According to most scientists, all life on Earth has a common ancestor. But in order to produce the immense amount of difference among all living organisms, certain ones had to evolve into distinct species. **Darwin's Theory** Darwin's theory of evolution entails the following fundamental ideas. The first three ideas were already under discussion among earlier and contemporaneous naturalists working on the "species problem" as Darwin began his research. Darwin's original contributions were the mechanism of natural selection and copious amounts of evidence for evolutionary change from many sources. He also provided thoughtful explanations of the consequences of evolution for our understanding of the history of life and modern biological diversity. Species (populations of interbreeding organisms) change over time and space. The representatives of species living today differ from those that lived in the recent past, and populations in different geographic regions today differ slightly in form or behaviour. These differences extend into the fossil record, which provides ample support for this claim. All organisms share common ancestors with other organisms. Over time, populations may divide into different species, which share a common ancestral population. Far enough back in time, any pair of organisms shares a common ancestor. For example, humans shared a common ancestor with chimpanzees about eight million years ago, with whales about 60 million years ago, and with kangaroos over 100 million years ago. Shared ancestry explains the similarities of organisms that are classified together: their similarities reflect the inheritance of traits from a common ancestor. Evolutionary change is gradual and slow in Darwin's view. This claim was supported by the long episodes of gradual change in organisms in the fossil	 **Mutation** A mutation could cause parents with genes for bright green coloration to have offspring with a gene for brown coloration. That would make genes for brown coloration more frequent in the population than they were before the mutation.  **Migration** Some individuals from a population of brown beetles might have joined a population of green beetles. That would make genes for brown coloration more frequent in the green beetle population than they were before the brown beetles migrated into it.

	record and the fact that no naturalist had observed the sudden appearance of a new species in Darwin's time. Since then, biologists and palaeontologists have documented a broad spectrum of slow to rapid rates of evolutionary change within lineages. The primary mechanism of change over time is natural selection, elaborated below. This mechanism causes changes in the properties (traits) of organisms within lineages from generation to generation. The Process of Natural Selection **Darwin's process of natural selection has four components.** **Variation.** Organisms (within populations) exhibit individual variation in appearance and behaviour. These variations may involve body size, hair colour, facial markings, voice properties, or number of offspring. On the other hand, some traits show little to no variation among individuals—for example, number of eyes in vertebrates. **Inheritance**. Some traits are consistently passed on from parent to offspring. Such traits are heritable, whereas other traits are strongly influenced by environmental conditions and show weak heritability. **High rate of population growth**. Most populations have more offspring each year than local resources can support leading to a struggle for resources. Each generation experiences substantial mortality. **Differential survival and reproduction**. Individuals possessing traits well suited for the struggle for local resources will contribute more offspring to the next generation. From one generation to the next, the struggle for resources (what Darwin called the "struggle for existence") will favor individuals with some variations over others and thereby change the frequency of traits within the population. This process is natural selection. The traits that confer an advantage to those individuals who leave more offspring are called adaptations.	 **Genetic drift** Imagine that in one generation, two brown beetles happened to have four offspring survive to reproduce. Several green beetles were killed when someone stepped on them and had no offspring. The next generation would have a few more brown beetles than the previous generation — but just by chance. These chance changes from generation to generation are known as genetic drift.  **Natural selection** Imagine that green beetles are easier for birds to spot (and

	In order for natural selection to operate on a trait, the trait must possess heritable variation and must confer an advantage in the competition for resources. If one of these requirements does not occur, then the trait does not experience natural selection. (We now know that such traits may change by other evolutionary mechanisms that have been discovered since Darwin's time.) Natural selection operates by comparative advantage, not an absolute standard of design. "…as natural selection acts by competition for resources, it adapts the inhabitants of each country only in relation to the degree of perfection of their associates" (Charles Darwin, On the Origin of Species, 1859). During the twentieth century, genetics was integrated with Darwin's mechanism, allowing us to evaluate natural selection as the differential survival and reproduction of genotypes, corresponding to particular phenotypes. Natural selection can only work on existing variation within a population. Such variations arise by mutation, a change in some part of the genetic code for a trait. Mutations arise by chance and without foresight for the potential advantage or disadvantage of the mutation. In other words, variations do not arise because they are needed.	hence, eat). Brown beetles are a little more likely to survive to produce offspring. They pass their genes for brown coloration on to their offspring. So in the next generation, brown beetles are more common than in the previous generation.  All of these mechanisms can cause changes in the frequencies of genes in populations, and so all of them are mechanisms of evolutionary change. However, natural selection and genetic drift cannot operate unless there is genetic variation — that is, unless some individuals are genetically different from others. If the population of beetles were 100% green, selection and drift would not have any effect because their genetic make-up could not change.
18	**Gas Laws** **1. Boyle's Law** The absolute pressure exerted by a given mass of an ideal gas is inversely proportional to the volume it occupies if the temperature and amount of gas remain unchanged within a closed system.	**Boyle's Law** $P \propto \frac{1}{V}$ or PV=C

	2. Charles' Law The volume of a closed system of gas is directly proportional to absolute temperature when pressure is held constant.	**Charle's Law** $$V \propto T$$ $$\frac{V}{T} = k$$ or where: *V* is the volume of the gas, *T* is the temperature of the gas (measured in kelvins), *k* is a constant
	3. Gay-Lussac's Law: The Pressure Temperature Law The pressure of a closed system of gas is directly proportional to absolute temperature when volume is held constant	**Gay-Lussac's Law** $$\boldsymbol{P \propto T}$$ $$\boldsymbol{\frac{P}{T} = k}$$
	4. Avogadro's Law Equal volumes of gases at the same temperature and pressure contain equal numbers of molecules.	**Avogadro's Law** This means that the volume-amount fraction will always be the same value if the pressure and temperature remain constant. V1 / n1 = V2 / n2 = V3 / n3 etc. Avogadro's number n.

		The number of molecules in a mole of a substance, approximately 6.0225 × 10 23. Also called Avogadro's constant .
	5. Combined Gas Law Combining Boyle's Law and Charle's Law $V \propto \frac{T}{P}$	**Combined Gas Law** PV/T=C
	6. Ideal Gas Equation	**Ideal Gas Equation** PV=n$\Re$T; $\Re$= PV/nT $\Re$= Universal Gas Constant=8.3143 kJ/kg-mol K P= 1.01325 bar T=273 K V=22.4 m3 R-Specific Gas Constant=$\Re$/M; where is molecular weight of a given gas
	7. Dalton's Law of Partial Pressures Dalton's Law of Partial Pressures states that the total pressure of a mixture of non-reacting gases is the sum of their individual partial pressures.	**Dalton's Law of Partial Pressures** $P_{total} = P_a + P_b + P_c + ...$ $P_{total} = n_aRT / V + n_bRT / V + n_cRT / V + ...$
	8. Gas Law for non- ideal gas Vander Waal's Equation	**Vander Waal's Equation** $(P + \frac{n^2a}{V^2})(V - nb) = nRT$