Quantum Mechanics_Gravitation

Gravitation, or **gravity**, is a natural phenomenon by which all physical bodiesattract each other. It is most commonly recognized and experienced as the agent that gives weight to physical objects, and causes physical objects to fall toward the ground when dropped from a height.

It is hypothesized that the gravitational force is mediated by a massless spin-2particle called the graviton. Gravity is one of the four fundamental forces of nature, along with electromagnetism, and the nuclear strong force and weak force. Colloquially, gravitation is a force of attraction that acts between and on all physical objects with matter (mass) or energy. In modern physics, gravitation is most accurately described by the general theory of relativity proposed by Einstein, which asserts that the phenomenon of gravitation is a consequence of the curvature of spacetime. In pursuit of a theory of everything, the merging of general relativity and quantum mechanics (or quantum field theory) into a more general theory of quantum gravity has become an area of active research.Newton's law of universal gravitation postulates that the gravitational force of two bodies of mass is directly proportional to the product of their masses andinversely proportional to the square of the distance between them. It provides an accurate approximation for most physical situations including spacecraft trajectory. Newton's laws of motion are also based on the influence of gravity, encompassing three physical laws that lay down the foundations for classical mechanics.

During the grand unification epoch, gravity separated from the electronuclear force. Gravity is the weakest of the four fundamental forces, and appears to have unlimited range (unlike the strong or weak force). The gravitational force is approximately 10^{-38} times the strength of the strong force (i.e., gravity is 38 orders of magnitude weaker), 10^{-36} times the strength of the electromagnetic force, and 10^{-29} times the strength of the weak force. As a consequence, gravity has a negligible influence on the behavior of sub-atomic particles, and plays no role in determining the internal properties of everyday matter. On the other hand, gravity is the dominant force at the macroscopic scale, that is the cause of the formation, shape, and trajectory (orbit) of astronomical bodies, including those ofasteroids, comets, planets, stars, and galaxies. It is responsible for causing the Earth and the other planets to orbit the Sun; for causing the Moon to orbit the Earth; for the formation of tides; for natural convection, by which fluid flow occurs under the influence of a density gradient and gravity; for heating the interiors of forming stars and planets to very high temperatures; for solar system,galaxy, stellar formation and evolution; and for various other phenomena observed on Earth and throughout the universe. This is the case for several reasons: gravity is the only force acting on all particles with mass; it has an infinite range; always attractive and never repulsive; and cannot be absorbed, transformed, or shielded against. Even though electromagnetism is far stronger than gravity, electromagnetism is not relevant to astronomical objects, since such bodies have an equal number of protons and electrons that cancel out (i.e., a net electric charge of zero).

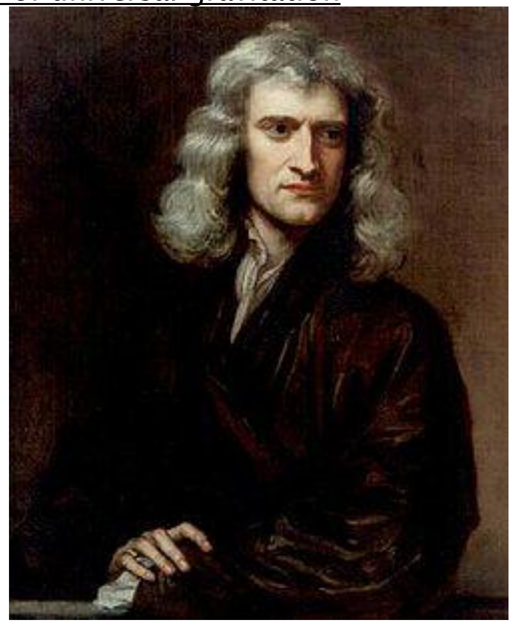
History of gravitational theory

Scientific revolution

Modern work on gravitational theory began with the work of Galileo Galilei in the late 16th and early 17th centuries. In his famous (though possibly apocryphal[1]) experiment dropping balls from the Tower of Pisa, and later with careful measurements of balls rolling down inclines, Galileo showed that gravitation accelerates all objects at the same rate. This was a major departure from Aristotle's belief that heavier objects accelerate faster.[2] Galileo postulated air resistance as the reason that lighter objects may fall slower in an atmosphere. Galileo's work set the stage for the formulation of Newton's theory of gravity.

Newton's theory of gravitation

Main article: Newton's law of universal gravitation



Sir Isaac Newton, an English physicist who lived from 1642 to 1727

In 1687, English mathematician Sir Isaac Newton published *Principia*, which hypothesizes the inverse-square law of universal gravitation. In his own words, “I deduced that the forces which keep the planets in their orbs must [be] reciprocally as the squares of their distances from the centers about which they revolve: and thereby compared the force requisite to keep the Moon in her Orb with the force of gravity at the surface of the Earth; and found them answer pretty nearly.”[3]

Newton's theory enjoyed its greatest success when it was used to predict the existence of Neptune based on motions of Uranus that could not be accounted for by the actions of the other planets. Calculations by both John Couch Adams andUrbain Le Verrier predicted the general position of the planet, and Le Verrier's calculations are what led Johann Gottfried Galle to the discovery of Neptune.

A discrepancy in Mercury's orbit pointed out flaws in Newton's theory. By the end of the 19th century, it was known that its orbit showed slight perturbations that could not be accounted for entirely under Newton's theory, but all searches for another perturbing body (such as a planet orbiting the Sun even closer than Mercury) had been fruitless. The issue was resolved in 1915 by Albert Einstein's new theory of general relativity, which accounted for the small discrepancy in Mercury's orbit.

Although Newton's theory has been superseded, most modern non-relativisticgravitational calculations are still made using Newton's theory because it is a much simpler theory to work with than general relativity, and gives sufficiently accurate results for most applications involving sufficiently small masses, speeds and energies.

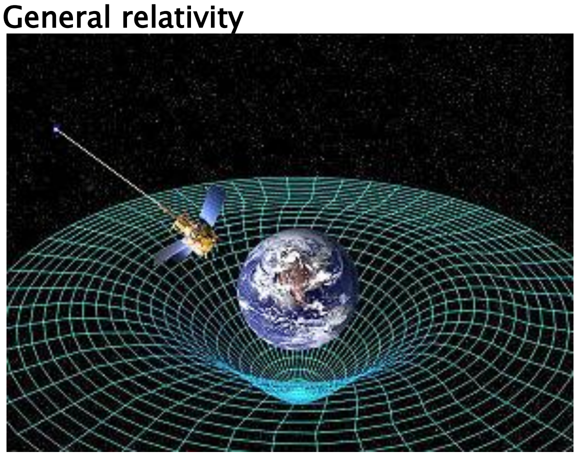
Equivalence principle

The equivalence principle, explored by a succession of researchers including Galileo, Loránd Eötvös, and Einstein, expresses the idea that all objects fall in the same way. The simplest way to test the weak equivalence principle is to drop two objects of different masses or compositions in a vacuum, and see if they hit the ground at the same time. These experiments demonstrate that all objects fall at the same rate when friction (including air resistance) is negligible. More sophisticated tests use a torsion balance of a type invented by Eötvös. Satellite experiments, for example STEP, are planned for more accurate experiments in space.[4]

Formulations of the equivalence principle include:

- The weak equivalence principle: *The trajectory of a point mass in a gravitational field depends only on its initial position and velocity, and is independent of its composition.*[5]
- The Einsteinian equivalence principle: *The outcome of any local non-gravitational experiment in a freely falling laboratory is independent of the velocity of the laboratory and its location in spacetime.*[6]
- The strong equivalence principle requiring both of the above.

General relativity



Two-dimensional analogy of spacetime distortion generated by the mass of an object. Matter changes the geometry of spacetime, this (curved) geometry being interpreted as gravity. White lines do not represent the curvature of space but instead represent thecoordinate system imposed on the curved spacetime, which would be rectilinear in a flat spacetime.

In general relativity, the effects of gravitation are ascribed to spacetimecurvature instead of a force. The starting point for general relativity is the equivalence principle, which equates free fall with inertial motion, and describes free-falling inertial objects as being accelerated relative to non-inertial observers on the ground.[7][8]In Newtonian physics, however, no such acceleration can occur unless at least one of the objects is being operated on by a force.

Einstein proposed that spacetime is curved by matter, and that free-falling objects are moving along locally straight paths in curved spacetime. These straight paths are called geodesics. Like Newton's first law of motion, Einstein's theory states that if a force is applied on an object, it would deviate from a geodesic. For instance, we are no longer following geodesics while standing because the mechanical resistance of the Earth exerts an upward force on us, and we are non-inertial on the ground as a result. This explains why moving along the geodesics in spacetime is considered inertial.

Einstein discovered the field equations of general relativity, which relate the presence of matter and the curvature of spacetime and are named after him. The Einstein field equations are a set of 10 simultaneous, non-linear, differential equations. The solutions of the field equations are the components of the metric tensor of spacetime. A metric tensor describes a geometry of spacetime. The geodesic paths for a spacetime are calculated from the metric tensor.

Notable solutions of the Einstein field equations include:

- The Schwarzschild solution, which describes spacetime surrounding a spherically symmetric non-rotating uncharged massive object. For compact enough objects, this solution generated a Black hole with a central Singularity. For radial distances from the center which are much greater than the Schwarzschild radius, the accelerations predicted by the Schwarzschild solution are practically identical to those predicted by Newton's theory of gravity.

- The Reissner-Nordström solution, in which the central object has an electrical charge. For charges with a geometrized length which are less than the geometrized length of the mass of the object, this solution produces black holes with two event horizons.
- The Kerr solution for rotating massive objects. This solution also produces black holes with multiple event horizons.
- The Kerr-Newman solution for charged, rotating massive objects. This solution also produces black holes with multiple event horizons.
- The cosmological Friedmann-Lemaître-Robertson-Walker solution, which predicts the expansion of the universe.

The tests of general relativity included the following:[9]

- General relativity accounts for the anomalous perihelion precession of Mercury.[10]
- The prediction that time runs slower at lower potentials has been confirmed by the Pound-Rebka experiment, the Hafele-Keating experiment, and the GPS.
- The prediction of the deflection of light was first confirmed by Arthur Stanley Eddington from his observations during the Solar eclipse of May 29, 1919.[11][12]Eddington measured starlight deflections twice those predicted by Newtonian corpuscular theory, in accordance with the predictions of general relativity. However, his interpretation of the results was later disputed.[13] More recent tests using radio interferometric measurements of quasars passing behind theSun have more accurately and consistently confirmed the deflection of light to the degree predicted by general relativity.[14] See also gravitational lens.
- The time delay of light passing close to a massive object was first identified byIrwin I. Shapiro in 1964 in interplanetary spacecraft signals.
- Gravitational radiation has been indirectly confirmed through studies of binarypulsars.
- Alexander Friedmann in 1922 found that Einstein equations have non-stationary solutions (even in the presence of the cosmological constant). In 1927 Georges Lemaître showed that static solutions of the Einstein equations, which are

possible in the presence of the cosmological constant, are unstable, and therefore the static universe envisioned by Einstein could not exist. Later, in 1931, Einstein himself agreed with the results of Friedmann and Lemaître. Thus general relativity predicted that the Universe had to be non-static—it had to either expand or contract. The expansion of the universe discovered by Edwin Hubble in 1929 confirmed this prediction.[15]

- The theory's prediction of frame dragging was consistent with the recent Gravity Probe B results.[16]
- General relativity predicts that light should lose its energy when travelling away from the massive bodies. The group of Radek Wojtak of the Niels Bohr Institute at the University of Copenhagen collected data from 8000 galaxy clusters and found that the light coming from the cluster centers tended to be red-shifted compared to the cluster edges, confirming the energy loss due to gravity.[17]

Gravity and quantum mechanics

Main articles: graviton and quantum gravity

In the decades after the discovery of general relativity it was realized that general relativity is incompatible with quantum mechanics.[18] It is possible to describe gravity in the framework of quantum field theory like the other fundamental forces, such that the attractive force of gravity arises due to exchange of virtualgravitons, in the same way as the electromagnetic force arises from exchange of virtual photons.[19][20] This reproduces general relativity in the classical limit. However, this approach fails at short distances of the order of the Planck length,[18] where a more complete theory of quantum gravity (or a new approach to quantum mechanics) is required.

Specifics

Earth's gravity

Main article: Earth's gravity

Every planetary body (including the Earth) is surrounded by its own gravitational field, which exerts an attractive force on all objects. Assuming a spherically symmetrical planet, the strength of this field at any given point is proportional to the planetary body's mass and inversely proportional to the square of the distance from the center of the body.

The strength of the gravitational field is numerically equal to the acceleration of objects under its influence, and its value at the Earth's surface, denoted *g*, is expressed below as the standard average. According to the Bureau International de Poids et

Mesures, International Systems of Units (SI), the Earth's standard acceleration due to gravity is:

g = 9.80665 m/s^2 (32.1740 ft/s^2).[21][22]

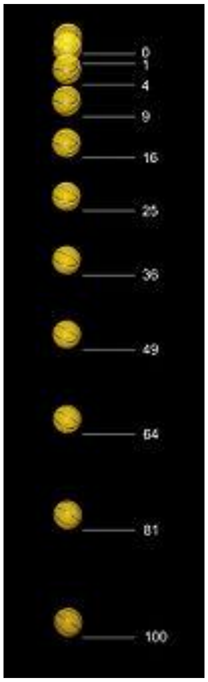
This means that, ignoring air resistance, an object falling freely near the Earth's surface increases its velocity by 9.80665 m/s (32.1740 ft/s or 22 mph) for each second of its descent. Thus, an object starting from rest will attain a velocity of 9.80665 m/s (32.1740 ft/s) after one second, approximately 19.62 m/s (64.4 ft/s) after two seconds, and so on, adding 9.80665 m/s (32.1740 ft/s) to each resulting velocity. Also, again ignoring air resistance, any and all objects, when dropped from the same height, will hit the ground at the same time.

If an object with comparable mass to that of the Earth were to fall towards it, then the corresponding acceleration of the Earth really would be observable.

According to Newton's 3rd Law, the Earth itself experiences a force equal in magnitude and opposite in direction to that which it exerts on a falling object. This means that the Earth also accelerates towards the object until they collide. Because the mass of the Earth is huge, however, the acceleration imparted to the Earth by this opposite force is negligible in comparison to the object's. If the object doesn't bounce after it has collided with the Earth, each of them then exerts a repulsive contact force on the other which effectively balances the attractive force of gravity and prevents further acceleration.

The force of gravity on Earth is the resultant (vector sum) of two forces: (a) The gravitational attraction in accordance with Newton's universal law of gravitation, and (b) the centrifugal force, which results from the choice of an earthbound, rotating frame of reference. At the equator, the force of gravity is the weakest due to the centrifugal force caused by the Earth's rotation. The force of gravity varies with latitude and becomes stronger as you increase in latitude toward the poles. The standard value of 9.80665 m/s^2 is the one originally adopted by the International Committee on Weights and Measures in 1901 for 45° latitude, even though it has been shown to be too high by about five parts in ten thousand.[23]This value has persisted in meteorology and in some standard atmospheres as the value for 45° latitude even though it applies more precisely to latitude of 45°32'33".[24]

Equations for a falling body near the surface of the Earth



Ball falling freely under gravity. See text for description.

Main article: Equations for a falling body

Under an assumption of constant gravity, Newton's law of universal gravitationsimplifies to $F = mg$, where m is the Mass of the body and g is a constant vector with an average magnitude of 9.81 m/s². The acceleration due to gravity is equal to this g. An initially stationary object which is allowed to fall freely under gravity drops a distance which is proportional to the square of the elapsed time. The image on the right, spanning half a second, was captured with a stroboscopic flash at 20 flashes per second. During the first $\frac{1}{20}$ of a second the ball drops one unit of distance (here, a unit is about 12 mm); by $\frac{2}{20}$ it has dropped at total of 4 units; by $\frac{3}{20}$, 9 units and so on.

Under the same constant gravity assumptions, the potential energy, E_p, of a body at height h is given by $E_p = mgh$ (or $E_p = Wh$, with W meaning weight). This expression is valid only over small distances h from the surface of the Earth. Similarly, the expression $h = \frac{v^2}{2g}$ for the maximum height reached by a vertically projected body with initial velocity v is useful for small heights and small initial velocities only.

Gravity and astronomy

The discovery and application of Newton's law of gravity accounts for the detailed information we have about the planets in our solar system, the mass of the Sun, the distance to stars, quasars and even the theory of dark matter. Although we have not traveled to all the planets nor to the Sun, we know their masses. These masses are obtained by applying the laws of gravity to the measured characteristics of the orbit. In space an object maintains its orbit because of the force of gravity acting upon it. Planets orbit stars, stars orbit Galactic Centers,galaxies orbit a center of mass in clusters, and clusters orbit in superclusters. The force of gravity exerted on one object by another is directly proportional to the product of those objects' masses and inversely proportional to the square of the distance between them.

Gravitational radiation

Main article: Gravitational wave

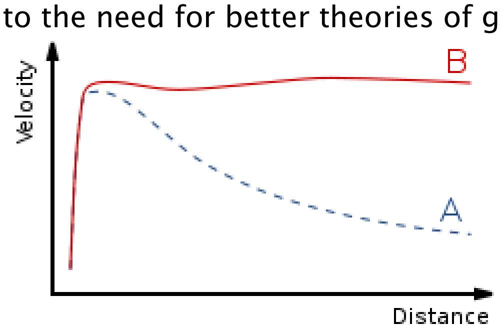
In general relativity, gravitational radiation is generated in situations where the curvature of spacetime is oscillating, such as is the case with co-orbiting objects. The gravitational radiation emitted by the Solar System is far too small to measure. However, gravitational radiation has been indirectly observed as an energy loss over time in binary pulsar systems such as PSR B1913+16. It is believed that neutron star mergers and Black hole formation may create detectable amounts of gravitational radiation. Gravitational radiation observatories such as the Laser Interferometer Gravitational Wave Observatory (LIGO) have been created to study the problem. No confirmed detections have been made of this hypothetical radiation.

Speed of gravity

In December 2012, a research team in China announced that it had produced measurements of the phase lag of Earth tides during full and new moons which seem to prove that the speed of gravity is equal to the speed of light.[25] The team's findings were released in the Chinese Science Bulletin in February 2013.[26]

Anomalies and discrepancies

There are some observations that are not adequately accounted for, which may point to the need for better theories of gravity or perhaps be explained in other ways.



Rotation curve of a typical spiral galaxy: predicted (**A**) and observed (**B**). The discrepancy between the curves is attributed to dark matter.

- **Extra fast stars**: Stars in galaxies follow a distribution of velocities where stars on the outskirts are moving faster than they should according to the observed distributions of normal matter. Galaxies within galaxy clusters show a similar pattern. dark matter, which would interact gravitationally but not electromagnetically, would account for the discrepancy. Various modifications to Newtonian dynamics have also been proposed.
- **Flyby anomaly**: Various spacecraft have experienced greater acceleration than expected during gravity assist maneuvers.
- **Accelerating expansion**: The metric expansion of space seems to be speeding up. Dark energy has been proposed to explain this. A recent alternative explanation is that the geometry of space is not homogeneous (due to clusters of galaxies) and that when the data are reinterpreted to take this into account, the expansion is not speeding up after all,[27] however this conclusion is disputed.[28]
- **Anomalous increase of the astronomical unit**: Recent measurements indicate that planetary orbits are widening faster than if this were solely through the sun losing mass by radiating energy.
- **Extra energetic photons**: Photons travelling through galaxy clusters should gain energy and then lose it again on the way out. The accelerating expansion of the universe should stop the photons returning all the energy, but even taking this into account photons from the cosmic microwave background radiation gain twice as much energy as expected. This may indicate that gravity falls off *faster*than inverse-squared at certain distance scales.[29]
- **Extra massive hydrogen clouds**: The spectral lines of the Lyman-alpha forestsuggest that hydrogen clouds are more clumped together at certain scales than expected and, like dark flow, may indicate that gravity falls off *slower* than inverse-squared at certain distance scales.[29]

Alternative theories

Main article: Alternatives to general relativity

Historical alternative theories

- Aristotelian theory of gravity

- Le Sage's theory of gravitation (1784) also called LeSage gravity, proposed byGeorges-Louis Le Sage, based on a fluid-based explanation where a light gas fills the entire universe.
- Ritz's theory of gravitation, *Ann. Chem. Phys.* 13, 145, (1908) pp. 267–271, Weber-Gauss electrodynamics applied to gravitation. Classical advancement of perihelia.
- Nordström's theory of gravitation (1912, 1913), an early competitor of general relativity.
- Whitehead's theory of gravitation (1922), another early competitor of general relativity.

Recent alternative theories

- Brans–Dicke theory of gravity (1961)
- Induced gravity (1967), a proposal by Andrei Sakharov according to which general relativity might arise from quantum field theories of matter
- In the modified Newtonian dynamics (MOND) (1981), Mordehai Milgrom proposes a modification of Newton's Second Law of motion for small accelerations
- The self-creation cosmology theory of gravity (1982) by G.A. Barber in which the Brans-Dicke theory is modified to allow mass creation
- Nonsymmetric gravitational theory (NGT) (1994) by John Moffat
- Tensor-vector-scalar gravity (TeVeS) (2004), a relativistic modification of MOND by Jacob Bekenstein
- Gravity as an entropic force, gravity arising as an emergent phenomenon from the thermodynamic concept of entropy.
- In the superfluid vacuum theory the gravity and curved space-time arise as acollective excitation mode of non-relativistic background superfluid.

References

- Halliday, David; Robert Resnick; Kenneth S. Krane (2001). *Physics v. 1*. New York: John Wiley & Sons. ISBN 0-471-32057-9.
- Serway, Raymond A.; Jewett, John W. (2004). *Physics for Scientists and Engineers*(6th ed.). Brooks/Cole. ISBN 0-534-40842-7.
- Tipler, Paul (2004). *Physics for Scientists and Engineers: Mechanics, Oscillations and Waves, Thermodynamics* (5th ed.). W. H. Freeman. ISBN 0-7167-0809-4.

Source: http://wateralkalinemachine.com/quantum-mechanics/?wiki-maping=Gravitation