**Gravitational interaction of antimatter**

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The [**gravitational interaction**](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbg) **of antimatter** with [matter](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTWF0dGVy) or [antimatter](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQW50aW1hdHRlcg) has not been conclusively observed by physicists. While the consensus among physicists is that gravity will attract both matter and antimatter at the same rate that matter attracts matter, there is a strong desire to confirm this experimentally.

Antimatter's rarity and tendency to [annihilate](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQW5uaWhpbGF0aW9u" \o "Annihilation) when brought into contact with matter makes its study a technically demanding task. Most methods for the creation of antimatter (specifically [antihydrogen](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQW50aWh5ZHJvZ2Vu" \o "Antihydrogen)) result in high-energy particles and atoms of high kinetic energy, which are unsuitable for [gravity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0eQ" \o "Gravity)-related study. In recent years, first ALPHA[[1]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS0x)[[2]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS0y) and then [ATRAP](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQVRSQVA" \o "ATRAP)[[3]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS0z) have trapped antihydrogen atoms at CERN; in 2012 ALPHA used such atoms to set the first free-fall loose bounds on the gravitational interaction of antimatter with matter, measured to within ±7500% of ordinary gravity[[4]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1hbW9sZV9ldF9hbC00)[[*citation needed*](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvV2lraXBlZGlhOkNpdGF0aW9uX25lZWRlZA)], not enough for a clear scientific statement about the sign of gravity acting on antimatter. Future experiments need to be performed with higher precision, either with beams of antihydrogen (AEGIS or GBAR) or with trapped antihydrogen (ALPHA).

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**Three hypotheses**

Thus far, there are three hypotheses about how *antimatter* gravitationally interacts *with normal matter*:

* **Normal [gravity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0eQ" \o "Gravity)**: The standard assumption is that gravitational interactions of matter and antimatter are identical.
* [**Antigravity**](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQW50aWdyYXZpdHk): Some authors argue that antimatter repels matter with the same [magnitude](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTWFnbml0dWRlXyh2ZWN0b3Ip" \o "Magnitude (vector)) as matter attracts itself. (see below).
* [**Gravivector**](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml2ZWN0b3I) **and [graviscalar](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3JhdmlzY2FsYXI" \o "Graviscalar)**: Later difficulties in creating [quantum gravity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvUXVhbnR1bV9ncmF2aXR5" \o "Quantum gravity) theories have led to the idea that antimatter may react with a slightly different magnitude.[[5]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1uaWV0bzg4LTU)

**Experiments**

**Supernova 1987A**

One source of experimental evidence in favor of normal gravity was the observation of [neutrinos](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTmV1dHJpbm9z" \o "Neutrinos) from [Supernova 1987A](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvU3VwZXJub3ZhXzE5ODdB" \o "Supernova 1987A). In 1987, three neutrino detectors around the world simultaneously observed a cascade of neutrinos emanating from a [supernova](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvU3VwZXJub3Zh" \o "Supernova) in the [Large Magellanic Cloud](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTGFyZ2VfTWFnZWxsYW5pY19DbG91ZA" \o "Large Magellanic Cloud). Although the supernova happened about 164,000 [light years](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTGlnaHRfeWVhcnM" \o "Light years) away, both neutrinos and antineutrinos seem to have been detected virtually simultaneously[[*clarification needed*](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvV2lraXBlZGlhOlBsZWFzZV9jbGFyaWZ5)]. If both were actually observed, then any difference in the gravitational interaction would have to be very small. However, neutrino detectors cannot distinguish perfectly between neutrinos and antineutrinos; in fact, [the two may be identical](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQW50aW5ldXRyaW5v" \o "Antineutrino). Some physicists conservatively estimate that there is less than a 10% chance that no regular neutrinos were observed at all. Others estimate even lower probabilities, some as low as 1%.[[6]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1wYWt2YXNhLTY) Unfortunately, this accuracy is unlikely to be improved by duplicating the experiment any time soon. The [last known supernova](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvU3VwZXJub3ZhX3JlbW5hbnRfRzEuOSUyQjAuMw" \o "Supernova remnant G1.9+0.3) to occur at such a close range prior to Supernova 1987A was around 1867.[[7]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS03)

**Fairbank's experiments**

Physicist [William Fairbank](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3cvaW5kZXgucGhwP3RpdGxlPVdpbGxpYW1fRmFpcmJhbmsmYWN0aW9uPWVkaXQmcmVkbGluaz0x" \o "William Fairbank (page does not exist)) attempted a laboratory experiment to directly measure the gravitational acceleration of both [electrons](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvRWxlY3Ryb24" \o "Electron) and [positrons](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvUG9zaXRyb24" \o "Positron). However, their [charge-to-mass ratio](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ2hhcmdlLXRvLW1hc3NfcmF0aW8" \o "Charge-to-mass ratio) is so large that electromagnetic effects overwhelmed the experiment.

It is difficult to directly observe gravitational forces at the particle level. For charged particles, the electromagnetic force overwhelms the much weaker gravitational interaction. Even antiparticles in neutral antimatter, such as antihydrogen, must be kept separate from their counterparts in the matter that forms the experimental equipment, which requires strong electromagnetic fields. These fields, e.g. in the form of atomic traps, exert forces on these antiparticles which easily overwhelm the gravitational force of Earth and nearby test masses. Since all production methods for antiparticles result in high-energy antimatter particles, the necessary cooling for observation of gravitational effects in a laboratory environment requires very elaborate experimental techniques and very careful control of the trapping fields.

**Cold neutral antihydrogen experiments**

Since 2010 the production of cold [antihydrogen](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQW50aWh5ZHJvZ2Vu" \o "Antihydrogen) has become possible at the [Antiproton Decelerator](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQW50aXByb3Rvbl9EZWNlbGVyYXRvcg" \o "Antiproton Decelerator) at [CERN](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ0VSTg). Antihydrogen, which is electrically neutral, should make it possible to directly measure the gravitational attraction of antimatter particles to the matter Earth. In 2013, experiments on antihydrogen atoms released from the ALPHA trap set direct, i.e. freefall, coarse limits on antimatter gravity.[[4]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1hbW9sZV9ldF9hbC00) These limits were coarse, with a relative precision of ± 100%, thus, far from a clear statement even for the sign of gravity acting on antimatter. Future experiments at CERN with beams of antihydrogen, such as AEGIS and GBAR, or with trapped antihydrogen such as ALPHA, have to improve the sensitivity to make a clear, scientific statement about gravity on antimatter.[[8]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS04)

**Superconductor-positron interactions**

A hypothesis originally suggested by early experiments with [positron](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvUG9zaXRyb24" \o "Positron) interactions with HTSCs suggests that under certain conditions the weak hypothetical antigravitational fields of the positrons could form into a beam. If so then a relatively simple device consisting of a YBCO or BSCCO disk with acoustic coupling to three or more transducers set up so that the vibrational pattern of the Cooper pair generating domains rotates around the centre axis under a weak electrical bias could form such a beam and be detected with relatively simple cooled accelerometers common to cellphones and other devices. [[9]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS05)

**Arguments against a gravitational repulsion of matter and antimatter**

When antimatter was first discovered in 1932, physicists wondered about how it would react to gravity. Initial analysis focused on whether antimatter should react the same as matter or react oppositely. Several theoretical arguments arose which convinced physicists that antimatter would react exactly the same as normal matter. They inferred that a gravitational repulsion between matter and antimatter was implausible as it would violate [CPT invariance](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ1BUX2ludmFyaWFuY2U), [conservation of energy](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ29uc2VydmF0aW9uX29mX2VuZXJneQ), result in [vacuum instability](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvVmFjdXVtX2luc3RhYmlsaXR5" \o "Vacuum instability), and result in [CP violation](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ1BfdmlvbGF0aW9u" \o "CP violation). It was also theorized that it would be inconsistent with the results of the [Eötvös](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTG9yJUMzJUExbmRfRSVDMyVCNnR2JUMzJUI2cw" \o "Loránd Eötvös) test of the [weak equivalence principle](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvV2Vha19lcXVpdmFsZW5jZV9wcmluY2lwbGU" \o "Weak equivalence principle). Many of these early theoretical objections were later overturned.[[10]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1uaWV0bzkxLTEw)

**The equivalence principle**

The [equivalence principle](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvRXF1aXZhbGVuY2VfcHJpbmNpcGxl" \o "Equivalence principle) predicts that the gravitational acceleration of antimatter is the same as that of ordinary matter. A matter-antimatter gravitational repulsion is thus excluded from this point of view. Furthermore, [photons](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvUGhvdG9u" \o "Photon), which are their own antiparticles in the framework of the Standard Model, have in a large number of astronomical tests ([gravitational redshift](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9yZWRzaGlmdA" \o "Gravitational redshift) and [gravitational lensing](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9sZW5zaW5n), for example) been observed to interact with the gravitational field of ordinary matter exactly as predicted by the [general theory of relativity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR2VuZXJhbF90aGVvcnlfb2ZfcmVsYXRpdml0eQ" \o "General theory of relativity). This is a feature that has to be explained by any theory predicting that matter and antimatter repel.

**CPT theorem**

The [CPT theorem](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ1BUX3RoZW9yZW0) implies that the difference between the properties of a matter particle and those of its antimatter counterpart is *completely* described by C-inversion. Since this C-inversion doesn't affect gravitational mass, the CPT theorem predicts that the gravitational mass of antimatter is the same as that of ordinary matter.[[11]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1jYWJib2xldDIwMTAtMTE) A repulsive gravity is then excluded, since that would imply a difference in sign between the observable gravitational mass of matter and antimatter.

**Morrison's argument**

In 1958, [Philip Morrison](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvUGhpbGlwX01vcnJpc29u" \o "Philip Morrison) argued that antigravity would violate [conservation of energy](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ29uc2VydmF0aW9uX29mX2VuZXJneQ" \o "Conservation of energy). If matter and antimatter responded oppositely to a gravitational field, then it would take no energy to change the height of a particle-antiparticle pair. However, when moving through a gravitational potential, the frequency and energy of light is shifted. Morrison argued that energy would be created by [producing](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvUGFpcl9wcm9kdWN0aW9u" \o "Pair production) matter and antimatter at one height and then annihilating it higher up, since the photons used in production would have less energy than the photons yielded from annihilation.[[12]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1tb3JyaXNvbi0xMg) However, it was later found that antigravity would still not violate the [second law of thermodynamics](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvU2Vjb25kX2xhd19vZl90aGVybW9keW5hbWljcw" \o "Second law of thermodynamics).[[13]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1jaGFyZGluOTMtMTM)

**Schiff's argument**

Later in 1958, [L. Schiff](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTGVvbmFyZF9JLl9TY2hpZmY" \o "Leonard I. Schiff) used quantum field theory to argue that antigravity would be inconsistent with the results of the [Eötvös experiment](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvRSVDMyVCNnR2JUMzJUI2c19leHBlcmltZW50" \o "Eötvös experiment).[[14]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1zY2hpZmYtMTQ) However, the renormalization technique used in Schiff's analysis is heavily criticized, and his work is seen as inconclusive.[[10]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1uaWV0bzkxLTEw) In 2014 the argument was redone by Cabbolet, who concluded however that it merely demonstrates the incompatibility of the Standard Model and gravitational repulsion.[[15]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1jYWJib2xldDIwMTQtMTU)

**Good's argument**

In 1961, [Myron L. Good](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTXlyb25fTC5fR29vZA) argued that antigravity would result in the observation of an unacceptably high amount of [CP violation](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ1BfdmlvbGF0aW9u" \o "CP violation) in the anomalous regeneration of [kaons](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvS2Fvbg).[[16]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1nb29kLTE2) At the time, CP violation had not yet been observed. However, Good's argument is criticized for being expressed in terms of absolute potentials. By rephrasing the argument in terms of relative potentials, [Gabriel Chardin](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3cvaW5kZXgucGhwP3RpdGxlPUdhYnJpZWxfQ2hhcmRpbiZhY3Rpb249ZWRpdCZyZWRsaW5rPTE" \o "Gabriel Chardin (page does not exist)) found that it resulted in an amount of kaon regeneration which agrees with observation.[[17]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1jaGFyZGluOTItMTc) He argues that antigravity is in fact a potential explanation for CP violation based on his models on K mesons. His results date back to 1992. Since then however, studies on CP violation mechanisms in the B mesons systems have fundamentally invalidated these explanations.

**Gerard 't Hooft's argument**

According to [Gerard 't Hooft](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR2VyYXJkXyUyN3RfSG9vZnQ" \o "Gerard 't Hooft), every physicist recognizes immediately what is wrong with the idea of gravitational repulsion: if a ball is thrown high up in the air so that it falls back, then its motion is symmetric under time-reversal; and therefore, the ball falls also down in opposite time-direction.[[18]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS10aG9vZnQyMDE0LTE4) Since a matter particle in opposite time-direction is an antiparticle, this proves according to 't Hooft that antimatter falls down on earth just like "normal" matter. However, Cabbolet replied that 't Hooft's argument is false, and only proves that an anti-ball falls down on an anti-earth – which is not disputed.[[19]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1DYWJib2xldDIwMTRiLTE5)

**Theories of gravitational repulsion**

As long as repulsive gravity has not been refuted experimentally, one can speculate about physical principles that would bring about such a repulsion. Thus far, three radically different theories have been published:

* The first theory of repulsive gravity was a quantum theory published by Kowitt.[[20]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1Lb3dpdHQtMjA) In this modified Dirac theory, Kowitt postulated that the positron is not a hole in the sea of electrons-with-negative-energy as in usual [Dirac hole theory](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvRGlyYWNfaG9sZV90aGVvcnk" \o "Dirac hole theory), but instead is a hole in the sea of electrons-with-negative-energy-and-positive-gravitational-mass: this yields a modified C-inversion, by which the positron has positive energy but negative gravitational mass. Repulsive gravity is then described by adding extra terms (mgΦg and mgAg) to the wave equation. The idea is that the wave function of a positron moving in the gravitational field of a matter particle evolves such that in time it becomes more probable to find the positron further away from the matter particle.
* Classical theories of repulsive gravity have been published by [Santilli](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvUnVnZ2Vyb19TYW50aWxsaQ" \o "Ruggero Santilli) and [Villata](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3cvaW5kZXgucGhwP3RpdGxlPU1hc3NpbW9fVmlsbGF0YSZhY3Rpb249ZWRpdCZyZWRsaW5rPTE" \o "Massimo Villata (page does not exist)).[[21]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1TYW50aWxsaS0yMQ)[[22]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS12aWxsYXRhLTIy)[[23]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS12aWxsYXRhMTMtMjM)[[24]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS12aWxsYXRhMTUtMjQ) Both theories are extensions of [General Relativity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR2VuZXJhbF9SZWxhdGl2aXR5" \o "General Relativity), and are experimentally indistinguishable. The general idea remains that gravity is the deflection of a continuous particle trajectory due to the curvature of spacetime, but antiparticles now 'live' in an inverted spacetime. The equation of motion for antiparticles is then obtained from the equation of motion of ordinary particles by applying the C, P, and T-operators (Villata) or by applying *isodual maps* (Santilli), which amounts to the same thing: the equation of motion for antiparticles then predicts a repulsion of matter and antimatter. It has to be taken that the *observed* trajectories of antiparticles are projections on *our* spacetime of the true trajectories in the inverted spacetime. However, it has been argued on methodological and ontological grounds that the area of application of Villata’s theory cannot be extended to include the microcosmos.[[25]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1jYWJib2xldDIwMTItMjU) These objections were subsequently dismissed by Villata.[[26]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS0yNg)
* The first non-classical, non-quantum physical principles underlying a matter-antimatter gravitational repulsion have been published by Cabbolet.[[11]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1jYWJib2xldDIwMTAtMTE)[[27]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1jYWJib2xldDIwMTEtMjc) He introduces the Elementary Process Theory, which uses a new language for physics, i.e. a new mathematical formalism and new physical concepts, and which is incompatible with both quantum mechanics and general relativity. The core idea is that nonzero rest mass particles such as electrons, protons, neutrons and their antimatter counterparts exhibit stepwise motion as they alternate between a particlelike state of rest and a wavelike state of motion. Gravitation then takes place in a wavelike state, and the theory allows, for example, that the wavelike states of protons and antiprotons interact differently with the earth’s gravitational field.

Further authors[[28]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1CbGFuY2hldC0yOA)[[29]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1IYWpkdWtvdmljLTI5)[[30]](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR3Jhdml0YXRpb25hbF9pbnRlcmFjdGlvbl9vZl9hbnRpbWF0dGVyI2NpdGVfbm90ZS1iZW5vaXQtbGV2eS0zMA) have used a matter-antimatter gravitational repulsion to explain cosmological observations, but these publications do not address the physical principles of gravitational repulsion.

**See also**

* [AEgIS](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQW50aXByb3Rvbl9EZWNlbGVyYXRvciNBRUdJUw)
* [Dark energy](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvRGFya19lbmVyZ3k)
* [Dark matter](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvRGFya19tYXR0ZXI)
* [General relativity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR2VuZXJhbF9yZWxhdGl2aXR5) (where gravity is a curvature of spacetime caused by matter and energy)

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	+ [F-theory](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvRi10aGVvcnk)
	+ [Heterotic string theory](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvSGV0ZXJvdGljX3N0cmluZ190aGVvcnk)
	+ [Type I string theory](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvVHlwZV9JX3N0cmluZ190aGVvcnk)
	+ [Type 0 string theory](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvVHlwZV8wX3N0cmluZ190aGVvcnk)
	+ [Bosonic string theory](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQm9zb25pY19zdHJpbmdfdGhlb3J5)
	+ [Type II string theory](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvVHlwZV9JSV9zdHJpbmdfdGhlb3J5)
	+ [Little string theory](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTGl0dGxlX3N0cmluZ190aGVvcnk)
* [Twistor theory](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvVHdpc3Rvcl90aGVvcnk)
	+ [Twistor string theory](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvVHdpc3Rvcl9zdHJpbmdfdGhlb3J5)
 |
| Generalisations /extensions of GR | * [Scale relativity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvU2NhbGVfcmVsYXRpdml0eQ)
* [Liouville gravity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTGlvdXZpbGxlX2dyYXZpdHk)
* [Lovelock theory](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTG92ZWxvY2tfdGhlb3J5X29mX2dyYXZpdHk)
* [(2+1)-dimensional topological gravity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvKDIlMkIxKS1kaW1lbnNpb25hbF90b3BvbG9naWNhbF9ncmF2aXR5)
* [Gauss–Bonnet gravity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvR2F1c3MlRTIlODAlOTNCb25uZXRfZ3Jhdml0eQ)
* [Jackiw–Teitelboim gravity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvSmFja2l3JUUyJTgwJTkzVGVpdGVsYm9pbV9ncmF2aXR5)
 |

 |
| **Pre-Newtoniantheories and**[**toy models**](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvVG95X21vZGVs) | * [Aristotelian physics](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQXJpc3RvdGVsaWFuX3BoeXNpY3M)
* [CGHS model](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ0dIU19tb2RlbA)
* [RST model](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvUlNUX21vZGVs)
* [Mechanical explanations](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTWVjaGFuaWNhbF9leHBsYW5hdGlvbnNfb2ZfZ3Jhdml0YXRpb24)
	+ [Fatio–Le Sage](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvTGVfU2FnZSUyN3NfdGhlb3J5X29mX2dyYXZpdGF0aW9u)
	+ [Entropic gravity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvRW50cm9waWNfZ3Jhdml0eQ)
* Gravitational interaction of antimatter
 |

[Categories](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvSGVscDpDYXRlZ29yeQ):

* [Antimatter](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ2F0ZWdvcnk6QW50aW1hdHRlcg)
* [Gravitation](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ2F0ZWdvcnk6R3Jhdml0YXRpb24)
* [Anti-gravity](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQ2F0ZWdvcnk6QW50aS1ncmF2aXR5)

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VOCABULARY:

conclusive:kesin,kati

conclusively:kesin olarak, kati olarak

inconclusive

consensus: fikir birliği, oybirliği

rare:ender, nadir, (et için) az pişmiş

rarity:enderlik, nadirlik

to [annihilate](http://www.wiki-zero.com/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvQW5uaWhpbGF0aW9u" \o "Annihilation):yoketmek, imha etmek

to demand: talep etmek

demanding: talep edici, talep eden

task: görev, ödev, iş

unsuitable: uygunsuzi, uygun olmayan, elverişsiz

bound: sınır, yasak bölge

trap: tuzak

to trap: tuzağa düşürmek, tuzak kurmak

thus far: şimdiye kadar, buraya kadar

cascade: çağlayan, şelale, kademeli dizi

to emanate:çıkmak,yayılmak

emanating: çıkan, yayılan

to detect: farketmek, sezmek,

virtual: zahiri, görünüşte

virtually:

to estimate: /estimeyt/ tahmin etmek, kestirmek, takdir etmek

estimate /estimıt/

accuracy: doğruluk, kesinlik, tamlık

accurate:/akürıt/ d

precision: doğruluk, kesinlik, tamlık, dakiklik, hassasiyet

unlikely: gayri muhtemel

likely: muhtemel

likelihood: ihtimal

to duplicate: /duplikeyt/ kopyasını yapmak,

duplicate:/duplikıt kopya, suret

duplicating:

prior to: den önce

to overwhelm:

counterpart: benzer, emsal,karşılık

to result in: neticelenmek

cooling: soğutma

to cool: soğutmak

to elaborate:/elaaboreyt/ özen göstermek, tafsilata girmek

elaborate:/elaabırıt/

coarse: kaba, kalın,

beam: ıiık hüzmesi, kalas

consisting of: den ibaret, den meydana gelen

couple:çift,

to couple: çiftlenmek, bağlamak, bağlanmak

coupling: çiftlenme, bağlanma, kuplaj

transducer:güç çevirici, enerji aktarımı yapan sistem

vibrate:titremek, titreşmek

domain: alan, saha, ilgi alanı, muhit

bias: bir cihaza tatbik edilen referans seviyesi voltajı

eğilim, önyargı

to arise:yükselmek, kalkmak, ortaya çıkmak

arose

to convince: ikna etmek

to infer:sonuç çıkarmak, anlam çıkarmak

implausible:inanılmaz, mantıksız, makul olmayan

plausible:

to violate:ihlal etmek,çiğnemek,

inconsistent: tutarsız

overturn: devirmek, yıkmak, geçersiz kılmak,tersine çevirmek,

=invalidate, destroy, reverse, upset

equivalence:eşdeğerlilik

to yield: vermek, sağlamak, ürün vermek,yol vermek

mere:sade, sırf

merely: sadece

compatable uyumlu, bağdaşan

incompatibility:uyumsuzluk,bağdaşmamazlık

compatibility:uyumluluk

acceptable kabul edilebilir

unacceptably: kabul edilemez olarak

acceptably:

anomalous:anormal, tuhaf, aykırı

regeneration:yenilenme,, yeniden oluşma

to criticize:tenkit etmek

to rephrase yeniden ifade etmek

to invalidate:geçersiz yapmak

to validate: geçerli kılmak

false:sahte, yanlış

to dispute:ihtilaf etmek,münakaşa etmek

to refute:yalanlamak, reddetmek, aksini ispatlamak

to speculate: tahminde bulunmak,

to bring about: sebep olmak,meydana getirmek

to modify: değişiklik yapmak

modified:

to invert: tersine çevirmek

inversion:

to evolve:evrilmek

indistinguishable:birbirinden fark (ayırt) edilemez

distinguishable:

to distinguish: birbirinden ayırt etmek, a

trajectory: yol,yörünge

ontological:varoluş ile alakalı veya üzerine kurulmuş

ground:yer, sebep, dayanak

microcosmos:

subsequent sonraki, müteakip

subsequently:

to dismiss:savmak, kovmak,salıvermek, görevden almak,

core:çekirdek, öz

to take place: olmak, vuku bulmak, meydana gelmek

address: adres

to address: hitap etmek