==慣性及引力質量==

我們可以把質量分成三種概念：<ref>{{cite book

|first=Wolfgang|last=Rindler|authorlink=Wolfgang Rindler

|title=Relativity: Special, General and Cosmological

|year=2001

|publisher=Oxford University Press

|ISBN=0-19-850863-0

}} Section 1.12</ref>

\* ''慣性質量''是當有[[力]]作用在一個物體，並改變它的形態時，物體阻力的量度。較小慣性質量的物體在改變形態時較快，較大慣性質量的物體則較慢。

\* ''被動引力質量''是對一件物體和[[引力場]]的相互作用之力的量度。在相同的引力場中，較小被動引力質量的物體比較大被動引力質量的物體要經歷較小的力。

\* ''主動引力質量''是引力場作用在一個特定物體的力的量度。例如，[[月球]]上所經歷的引力場比在[[地球]]上的要小，因爲月球有較小的主動引力質量。

儘管慣性質量、被動和主動引力質量在概念上有分歧，但是並沒有實驗能明確的區分它們。

在[[經典力學]]裏，牛頓第三定律指出，被動和主動引力質量應該永遠相同（或至少成正比），但經典理論卻證明不出引力質量要等於慣性質量。這只是一種經驗常識。

[[阿爾伯特·愛因斯坦]]的[[廣義相對論]]研究開始于假設引力和慣性質量之間的對應並不是碰巧的：任何試驗都不可能探測到它們之間的區別（[[弱等效原理]]）<!-- because "acceleration" (due to an external force)-->。然而，在最終的理論裏，引力並不是一種力，因此並不受制于牛頓的第三定律，因此“慣性和主動引力質量[...]還是和以往一樣費解”。<ref>Rindler, ''supra'', end of Section 1.14</ref>

===慣性質量===

:''此部分包含使用[[微分]]的數學公式。''

''慣性質量''是以量度其對加速的阻力而得的一件物體的質量。

要知道一件物體的慣性質量，我們必須先使用[[經典力學]]和[[牛頓運動定律]]。遲些我們會看看如果考慮到比經典力學更精確的[[狹義相對論]]的話，質量的經典定義要如何更變。但是，狹義相對論的應用並不會改變“質量”根本上的意思。

根據牛頓第二定律，一個物體的質量為''m''，只要它遵從運動公式：

:<math> f = \frac{\mathrm{d}}{\mathrm{d}t} (mv) </math>

當中''f''為作用在這物體上的[[力]]，''v''為其[[速度]]。我們暫時抛開“何謂作用在物體上的力”這個問題。

現在，我們假設問題中的物體的質量固定。這假設，或稱[[質量守恆定律]]，是建基於以下理念：（一）質量是對一個物體所含的物質總量的量度，而（二）質量永遠不能無中生有或消失，只能分裂或結合。以上兩點對日常的所有事物都是言之有理，但是，要是我們考慮到[[狹義相對論]]的話，質量事實上能“無中生有”或“消失”。另一點值得注意的是，就算是在經典力學之中，把質量考慮成可以隨時間改變偶爾也十分有用。例如，一枝[[火箭]]在升空的時候質量正在下降。然而，這只是“大約”的，而且我們還要忽略所有進入或離開這個系統的物質。在火箭這個例子裏，導致火箭質量下降的，是被噴出的火箭推進劑。若然我們在量度整個火箭加上其推進劑的質量，則結論為：質量仍然守恆。

當一個物體的質量固定，牛頓第二定律變爲：

:<math> f = m \frac{\mathrm{d}v}{\mathrm{d}t} = m a </math>

當中''a''為這個物體的[[加速度]]。

以上公式描述質量如何影響一個物體的慣性。試想想兩件擁有不同質量的物體。如果我們對兩件物體施以同等的力度，那麽較大質量的那件會有較小的加速度，而較小質量的那件則會有較大的加速度。我們可以說，質量越大，物體對改變其形態的力有更強的阻力。

However, this notion of applying "identical" forces to different objects brings us back to the fact that we have not really defined what a force is. We can sidestep this difficulty with the help of Newton's third law, which states that if one object exerts a force on a second object, it will experience an equal and opposite force. To be precise, suppose we have two objects A and B, with constant inertial masses ''m<sub>A</sub>'' and ''m<sub>B</sub>''. We isolate the two objects from all other physical influences, so that the only forces present are the force exerted on A by B, which we denote ''f<sub>AB</sub>'', and the force exerted on B by A, which we denote ''f<sub>BA</sub>''. As we have seen, Newton's second law states that

:<math>f\_{AB} = m\_B a\_B \,</math> and <math>f\_{BA} = m\_A a\_A \,</math>

where ''a<sub>A</sub>'' and ''a<sub>B</sub>'' are the accelerations of A and B respectively. Suppose that these accelerations are non-zero, so that the forces between the two objects are non-zero. This occurs, for example, if the two objects are in the process of colliding with one another. Newton's third law then states that

:<math>f\_{AB} = - f\_{BA}. \,</math>

Substituting this into the previous equations, we obtain

:<math>m\_A = - \frac{a\_B}{a\_A} \, m\_B.</math>

Note that our requirement that ''a<sub>A</sub>'' be non-zero ensures that the fraction is well-defined.

This is, in principle, how we would measure the inertial mass of an object. We choose a "reference" object and define its mass ''m<sub>B</sub>'' as (say) 1 kilogram. Then we can measure the mass of any other object in the universe by colliding it with the reference object and measuring the accelerations.

=== Gravitational mass ===

''Gravitational mass'' is the mass of an object measured using the effect of a gravitational field on the object.

The concept of gravitational mass rests on [[Newton's law of universal gravitation|Newton's law of gravitation]]. Let us suppose we have two objects A and B, separated by a distance |'''r'''<sub>AB</sub>|. The law of gravitation states that if A and B have gravitational masses ''M<sub>A</sub>'' and ''M<sub>B</sub>'' respectively, then each object exerts a gravitational force on the other, of magnitude

:<math>|f| = {G M\_A M\_B \over |r\_{AB}|^2}</math>

where ''G'' is the universal [[gravitational constant]]. The above statement may be reformulated in the following way: if ''g'' is the acceleration of a reference mass at a given location in a gravitational field, then the gravitational force on an object with gravitational mass ''M'' is

:<math>f = Mg. \,</math>

This is the basis by which masses are determined by [[scale (measurement)|weighing]]. In [[Weighing scale#Spring scales|simple bathroom scales]], for example, the force ''f'' is proportional to the displacement of the [[spring (device)|spring]] beneath the weighing pan (see [[Hooke's law]]), and the scales are [[calibration|calibrated]] to take ''g'' into account, allowing the mass ''M'' to be read off. Note that a balance (see the subheading within [[Weighing scale]]) as used in the laboratory or the health club measures gravitational mass; only the spring scale measures weight.

=== Equivalence of inertial and gravitational masses ===

The equivalence of inertial and gravitational masses is sometimes referred to as the ''Galilean equivalence principle'' or ''[[weak equivalence principle]]''. The most important consequence of this equivalence principle applies to freely falling objects. Suppose we have an object with inertial and gravitational masses ''m'' and ''M'' respectively. If the only force acting on the object comes from a gravitational field ''g'', combining Newton's second law and the gravitational law yields the acceleration

:<math>a = \frac{M}{m} g.</math>

This says that the ratio of gravitational to inertial mass of any object is equal to some constant ''K'' [[if and only if]] ''all objects fall at the same rate in a given gravitational field''. This phenomenon is referred to as the ''universality of free-fall''. (In addition, the constant ''K'' can be taken to be 1 by defining our units appropriately.)

The first experiments demonstrating the universality of free-fall were conducted by [[Galileo Galilei|Galileo]]. It is commonly stated that Galileo obtained his results by dropping objects from the [[Leaning Tower of Pisa]], but this is most likely apocryphal; actually, he performed his experiments with balls rolling down [[inclined plane]]s. Increasingly precise experiments have been performed, such as those performed by [[Loránd Eötvös]], using the [[torsion balance]] pendulum, in [[1889]]. [[As of 2008]], no deviation from universality, and thus from Galilean equivalence, has ever been found, at least to the accuracy 1/10<sup>12</sup>. More precise experimental efforts are still being carried out.

[[Image:Apollo 15 feather and hammer drop.ogg|right|thumb|[[David Scott]] simultaneously dropping a hammer and a feather in the vacuum of the Moon during [[Apollo 15]].]]

The universality of free-fall only applies to systems in which gravity is the only acting force. All other forces, especially [[friction]] and [[air resistance]], must be absent or at least [[negligible]]. For example, if a hammer and a feather are dropped from the same height through the air on Earth, the feather will take much longer to reach the ground; the feather is not really in ''free''-fall because the force of air resistance upwards against the feather is comparable to the downward force of gravity. On the other hand, if the experiment is performed in a [[vacuum]], in which there is no air resistance, the hammer and the feather should hit the ground at exactly the same time (assuming the acceleration of both objects towards each other, and of the ground towards both objects, for its own part, is negligible). This can easily be done in a high school laboratory by dropping the objects in transparent tubes that have the air removed with a vacuum pump. It is even more dramatic when done in an environment that naturally has a vacuum, as [[David Scott]] did on the surface of the [[Moon]] during [[Apollo 15]].

A stronger version of the equivalence principle, known as the ''Einstein equivalence principle'' or the ''strong equivalence principle'', lies at the heart of the [[general relativity|general theory of relativity]]. Einstein's equivalence principle states that within sufficiently small regions of space-time, it is impossible to distinguish between a uniform acceleration and a uniform gravitational field. Thus, the theory postulates that inertial and gravitational masses are fundamentally the same thing.