The Origin of Mass

The inertial mass of matter is caused by the fact that every <u>expanded</u> object has necessarily an inertial behaviour

... even if its constituents do not have any mass at all. This is the consequence of the finite speed of light by which the binding forces between them propagate.

1. Summary

In today's physics – the Standard Model – it is assumed that the fundamental particles which build up our matter do originally have no mass. So since quite a long time the physicists are looking for a reason why matter has an inertial behaviour. - The search for the Higgs boson is an example of it. However, there is an easy and very fundamental way to explain the inertial mass.

If two particles are bound to each other in a way that the binding field enforces a specific distance then, at every change of the position of one of them, it needs a finite time caused by the finite speed of light to make the other particle moving. This delay is sufficient to explain the inertial behaviour.

It turns out that the inertial mass of an elementary particle is given by the universal equation

$$m = \hbar / (R\, c)$$

Also the relativistic increase of mass at motion and as a consequence the mass energy equivalence (Einstein) is perfectly explained by this mechanism.

So, the origin of mass is no longer a mystery in physics.

2. The Physical Model for the Inertial Mass

If a physical object has an expansion, then this can have two possible reasons:

a) The planet case: The constituents have mass and orbit each other. The centrifugal inertial force is in balance with the attracting force. Examples of it are the planetary system of the sun and the atomic model of Bohr
b) The multi-pole case: The constituents are bound to each other on one hand and kept at a separation on the other hand by a multi-pole field, which originates in each of the constituents. A classical example of it is the atoms constituting a molecule.

In the case considered here only the alternative b) is usable, because our goal is to explain the existence of mass in a configuration where the basic constituents have no mass.

So we will investigate the situation of two fundamental ("Basic") particles, which have no mass and which are bound at a separation r_0 to each other. Such a bind at a distance is, as we have explained, realised by a multi-pole field. That means that one particle (*B*) resides in the minimum of the field potential of the other one (*A*) and vice versa as shown in the figure 2.1. *U* is the binding potential for both.

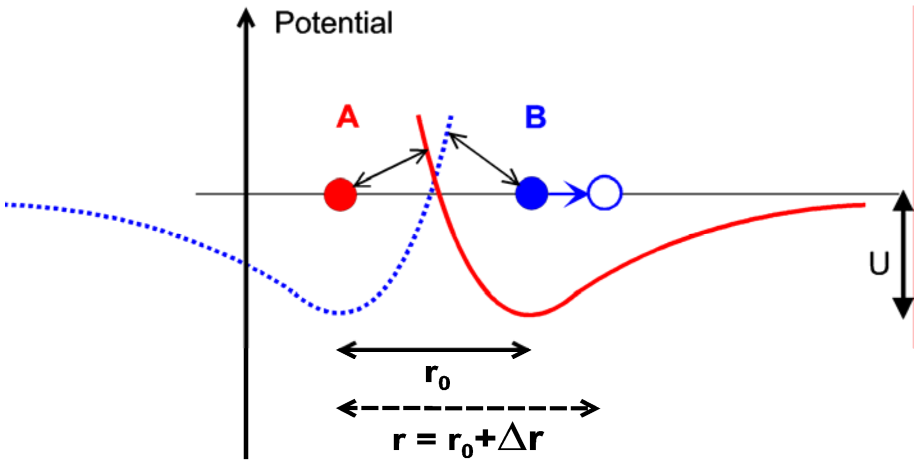

Figure 2.1:

The field of particles *A* and *B* bound to each other to maintain a separation r_0

If now one of the particles, e.g. particle *A*, is kept at a fixed position and the other one, particle *B*, is moved towards particle *A* or away from *A*, the field tries to move particle *B* back to the original distance r_0 from *A*, so there is a force necessary for the displacement. There is an *ANIMATION* (in the html version) which shows for a better imagination how a potential minimum causes a force.

Now the other situation: If both particles are not fixed in any way and one particle, e.g. *B*, is moved by an external force, the other particle will follow. However, this will not happen instantaneously. The field change, caused by the changed position of particle *B*, can only be propagated at the speed of light c. That means that for the time

$$\Delta t = r/c \tag{2.1}$$

the particle *A* is still kept at its position by the “old” field of particle *B*, which did not change yet. Also the field of particle *A* is unchanged at the position of particle *B* and so tries to keep particle *B* at its place. That means that a force is necessary to move the particle *B*.

Then, after the time Δt, the change of the field of particle *B* will reach particle *A*, which will now move with the field to a position, which corresponds to the new position of particle *B*. As a consequence, after another time Δt the field at the position of particle *B* caused by particle *A* will follow according to the new position of particle *A*, and the force acting on the displaced particle *B* will finally disappear. Now both particles will move and no force is necessary any longer.

We will now show in detail how this works to give a better imagination, why two particles positioned at a separation to each other have an inertial behaviour. We start with the initial situation, where each particle rests force-free in the potential field of the other particle. Particle *B* (figure 2.2) is force-free in the potential minimum of *A*, which is symbolised by the contracted spring at its right side.

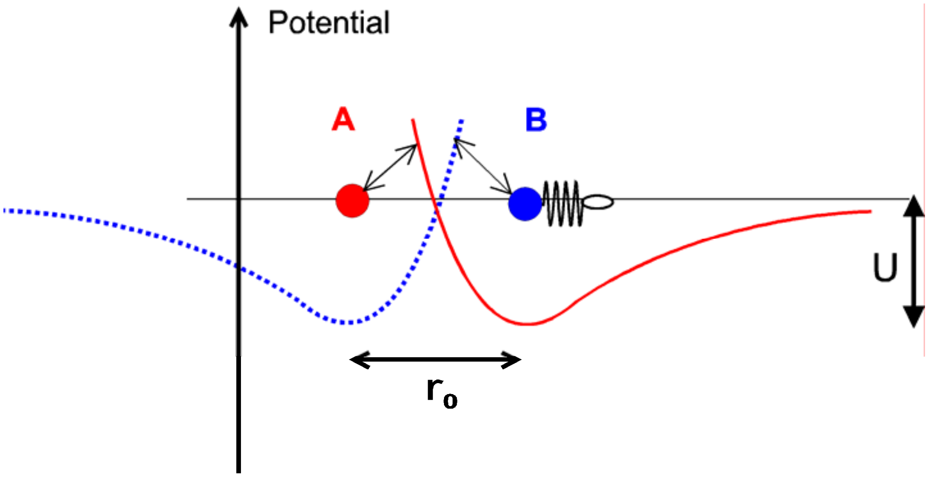

Figure 2.2

Particles *A* and *B* in a force-free equilibrium state

As a next step, particle *B* is displaced by a certain amount to the right (figure 2.3). This means that *B* is removed from the potential minimum, so a force is needed, which is visualised by the expansion of the spring. (Remark: A sudden change of the position of *B* is assumed here, which is not really physical but helps to understand the process more easily.)

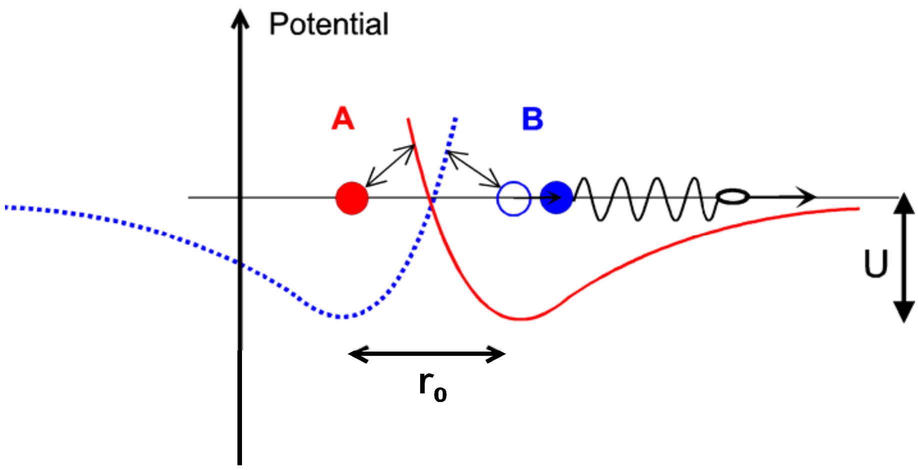

Figure 2.3

Particle *B* pulled out of the potential minimum using a force

As a consequence of the displacement of *B*, the field of *B* follows *B* to the right. This happens at the speed of light *c*. So, after the time of ½ Δt, the field change has moved half way to *A* (figure 2.4).

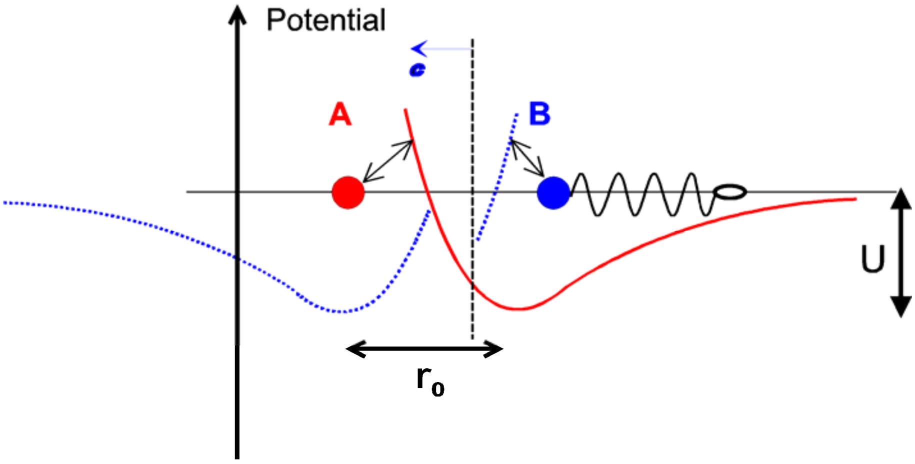

Figure 2.4

Field displacement of *B* half way towards *A*

Then, after the time of *1 Δt*, the field change reaches particle *A* (figure 2.5). At this moment, particle *A* moves instantaneously to the right into the new position of the potential minimum.

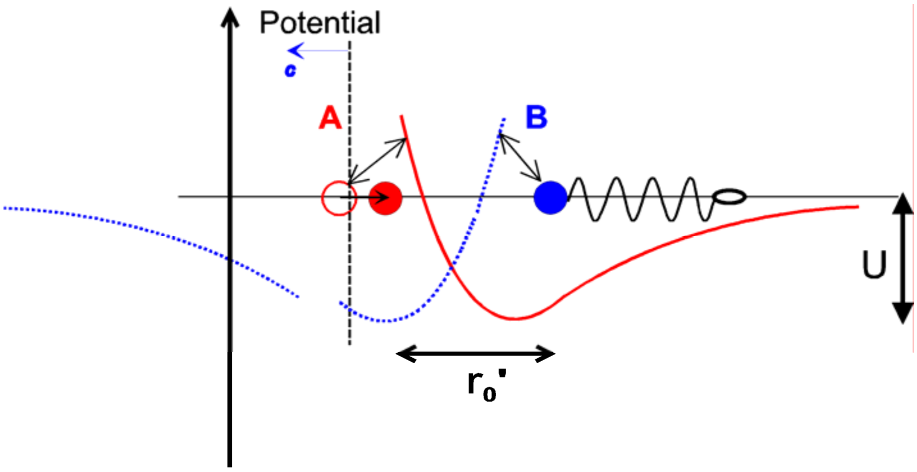

Figure 2.5

Field displacement of *B* reaching *A*

As a further consequence, the field of *A* moves to the right. So, after another ½ *Δt*, i.e. after 1 ½ *Δt* over all, it passes half way the distance to *B* (figure 2.6).

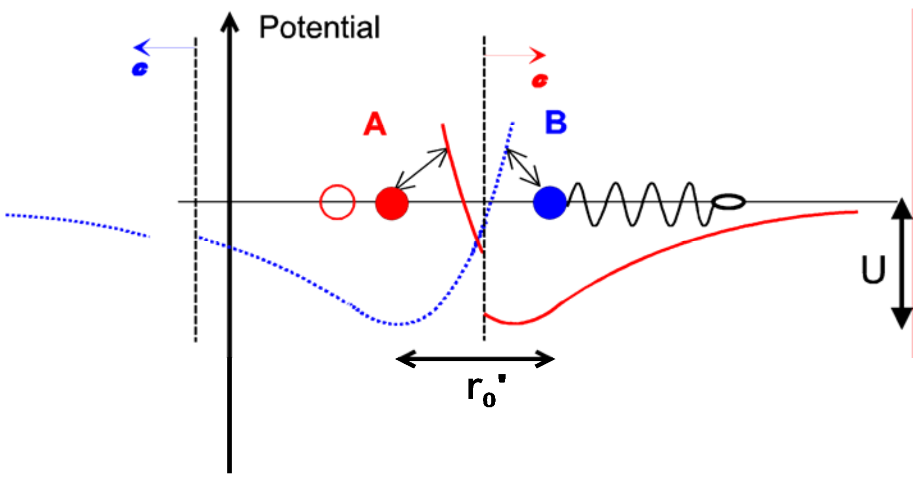

Figure 2.6

Field displacement of *A* half way to *B*

Finally, after the time of *2 Δt*, the repositioned field of *A* reaches *B*, so that now *B* is in the potential minimum of *A*. That means that there is no longer a force necessary to keep *B* at its new position as it is visualised by a contracted spring now (figure 2.7).

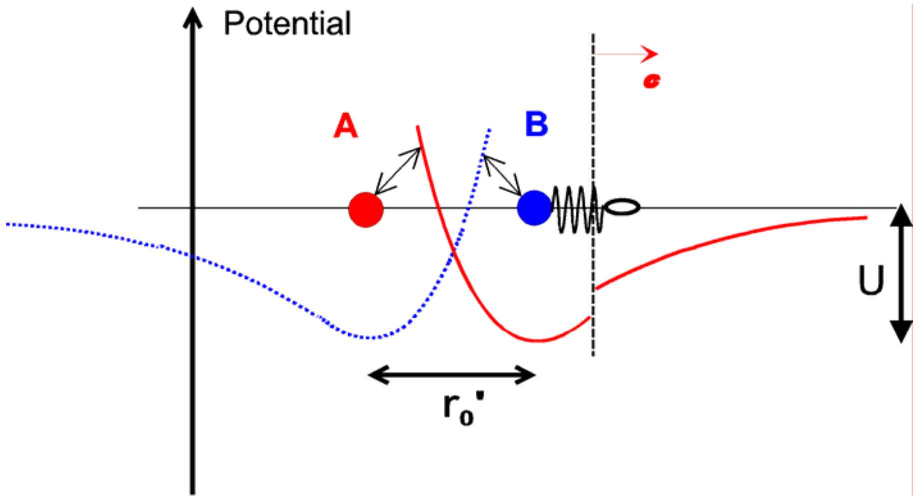

Figure 2.7

Field displacement of *A* reaching *B*

The full cycle of the changes of positions and fields shows, that there is an *intermediate* force necessary to put this configuration of 2 particles to a new position.

In truth, the configuration is not only placed to a new position, but it is in motion now. This is a consequence of the relativistic contraction of fields at motion. When the fields of *B* and *A* moved as a consequence of the displacement of both particles, these fields contracted. So, at the end of the cycle both particles are positioned at a reduced distance *r'*. The new distance of *r'* is a stable configuration only if the configuration is moving and vice versa.

The process of the field propagation, which was presented here as discrete steps, is available as a continuous *ANIMATION* (in the html version). Please press the PLAY button in the animation window to start the field propagation.

This phenomenon, that for a certain time a force is necessary to cause a change of the state of motion, is the physical phenomenon of inertial mass.

To calculate this effect quantitatively, it is necessary to know the structure of the binding field between both particles.

3. Quantitative Determination of the Mass of an Elementary Particle

For the structure of this field we will use the *ansatz* that the simplest kind of a multi-pole field for the binding field between both particles applies. It corresponds to the figures above:

$$F = Kq^2 \cdot \frac{r - r_0}{r^3} \,,$$

or equivalently

$$F = Kq^2 \cdot \frac{\Delta r}{r^3} \,, \tag{3.1}$$

where F is the force caused by the field, K is the field constant and q some kind of charge (a non-electric charge!) of the particles; r is the distance of the multi-pole configurations of both particles to each other and r_0 the equilibrium distance (corresponding to $\Delta r=0$), where the force disappears.

In the following we will only consider small accelerations, where 'small' means that during the time Δt the acceleration ends up at a speed change $\Delta v \ll c$. For these changes we can assume the denominator of (3.1) to be constant for the time Δt.

Now the case shall be considered that, from a specific moment on, the particle *B* is accelerated at a constant rate. Then for the time

$$\Delta t = r/c$$

after the start of the acceleration the particle *A* will not get any notice of this position change and the corresponding field change, and it is kept at its position. Then, just after this initial period of Δt, the particle *A* will also be accelerated constantly. The acceleration of particle *A* will follow the acceleration of particle *B* with this delay of Δt. This delay causes a constant additional displacement between the particles, which results in a constant force between them. - This is a situation, which corresponds to figure 2.3 with all parts moving.

Assuming a constant acceleration *a*, the particle *B* will move during this mentioned time Δt along the distance

$$\Delta r = \frac{1}{2} \cdot a \cdot \Delta t^2 \tag{3.2}$$

which adds now to the equilibrium distance. Caused by this additional distance Δr, the retarding force on particle *B in the direction of motion,* F_r , will increase to the value

$$F_r = Kq^2 \cdot \frac{1}{r^3} \cdot \Delta r \,.$$

This means that the force F_r, as a consequence of the first portion of the time delay, Δt_1 (ref. to 3.2), has reached the value

$$F_r = Kq^2 \cdot \frac{1}{r^3} \cdot \frac{1}{2} \cdot a \cdot \Delta t_1^{\,2} \,. \tag{3.3}$$

After the time Δt_1 particle *A* will start to move. The change of its field in forward direction will in turn need the time

$$\Delta t_2 = r/c$$

to propagate back to particle *B*. After this time, the force F_r on the particle *B* will reach its final value.

So the overall time until a stationary state is achieved is

$$\Delta t = \Delta t_1 + \Delta t_2 = 2 \cdot r/c \,. \qquad (3.4)$$

Now Δt (3.4) is inserted to replace Δt_1 in eq. (3.3) which results in

$$F_r = 2 \cdot Kq^2 \cdot \frac{1}{r} \cdot a \cdot \frac{1}{c^2} \,.$$

According to the definition of Newton, the inertial mass is:

$$m_r = \frac{F_r}{a}$$

and therefore:

$$m_r = 2 \cdot Kq^2 \cdot \frac{1}{r} \cdot \frac{1}{c^2} \,.$$

We now come back to eq. (3.1), and we have to consider that the full force

$$F_r = Kq^2 \cdot \frac{1}{r^3} \cdot \Delta r$$

is only effective if both basic particles are positioned in a line parallel to the direction of the force applied.

For an arbitrary motion of the elementary particle in the 3 dimensional space and also caused by the orbital motion inside, the basic particles are positioned to each other at varying angles in relation to the direction of the forced motion, so only a portion of this force is effective.

The magnitude of the portion depends on the 3-dimensional shape of the binding field.

We will at this place not calculate the integral over all directions but use a symbolic factor *I* as a representation for the integration result.

$$< F >= F_r \cdot I \,.$$

Further down we will present an easy way to determine this factor *I*.

This integration factor inserted into eq. (3.3) yields now the averaged force *<F>*

$$< F >= I \cdot Kq^2 \cdot \frac{1}{r^3} \cdot \frac{1}{2} \cdot a \cdot \Delta t^2 \,. \qquad (3.5)$$

Again eq. (3.4) is inserted to replace Δt. This insertion results in

$$< F >= 2I \cdot a \cdot Kq^2 \cdot \frac{1}{r} \cdot \frac{1}{c^2} \,.$$

And again, we use the definition of Newton for the inertial mass:

$$m = \frac{<F>}{a}$$

and so we get for the effective mass:

$$\boxed{m = 2I \cdot Kq^2 \cdot \frac{1}{r} \cdot \frac{1}{c^2}} \tag{3.6}$$

This now is the inertial mass of an object derived from the delay, by which field forces between charges are propagated.

Please note that ***r*** is the distance between the basic particles in the configuration. So, for an elementary particle built by 2 constituents it is the diameter of the particle.

This result has the following remarkable aspects:

1. It yields the fact that the quotient of force and acceleration is constant at non relativistic velocities. Therefore this is a deduction of Newton's law of motion. For Newton, this law had the property of an axiom.
2. The result shows, that the mass is inversely proportional to the size of an elementary particle *r*.

The value of the constant *I* will be determined further down.

4. The Relativistic Change of the Mass of an Elementary Particle

The increase of the mass of a *moving* body can also be deduced by the way presented above. This is done by taking into account that, in the moving state, the propagation delay of the field, the slope of the field, and the strength of the field has to be adapted to the relativistic conditions of the motion. So the following replacements have to be used:

The relativistic contraction of fields in motion causes the following change:

$$Kq^2 \rightarrow (Kq^2)' = Kq^2 / \gamma^2 , \tag{4.1}$$

where γ is the Lorentz factor

$$\gamma = 1/\sqrt{1 - v^2/c^2} \; .$$

The relativistic contraction of objects in motion causes the following change:

$$r \rightarrow r' = r / \gamma \, . \tag{4.2}$$

The slope of the force *F* in the vicinity of the equilibrium distance is in eq. (3.1)

$$F = K \cdot q^2 \cdot \frac{\Delta r}{r^3}$$

represented by the fractional part $\Delta r / r^3$. This has to be changed relativistically

$$\frac{\Delta r}{r^3} \rightarrow \left(\frac{\Delta r}{r^3} \right)' = \gamma \cdot \frac{\Delta r}{r^3} \tag{4.3}$$

which follows from differentiating the left part of (4.3) around the position of equilibrium.

Further on we have to replace

$$\Delta t \rightarrow \Delta t'$$

which is now dependent on the direction of motion.

For the acceleration in the non-relativistic range, the 'one way' propagation speed from one particle to the other one is as it has been used earlier,

$$\Delta t_1 = \Delta t_2 = r/c \,.$$

However, at a relativistic speed, there is

$$\Delta t_1 = r'/(c-v)\,;\ \Delta t_2 = r'/(c+v)$$

for the forward and return speed respectively.

So, the round trip time in the relativistic case is:

$$\Delta t' = \Delta t_1 + \Delta t_2 = r'(\frac{1}{c-v} + \frac{1}{c+v}) = r'\frac{2}{c} \cdot \frac{c^2}{c^2 - v^2} \,.$$

Using the definition of γ we get

$$\Delta t' = 2 \cdot \gamma^2 \cdot r'/c \ ;$$

replacing *r′* by eq. (4.2) we get

$$\Delta t' = 2 \cdot \gamma \cdot r/c \,. \qquad (4.4)$$

The formula for the inertial force (3.5) changes in the relativistic case to:

$$m' = \frac{1}{2} \cdot I \cdot (Kq^2)' \cdot \frac{1}{r'^3} \cdot \Delta t'^2 \,.$$

When replacing now the (..)' values according to (4.1), (4.2), (4.3), and using (4.4), there is:

$$m' = \frac{1}{2} \cdot I \cdot \frac{1}{\gamma^2} Kq^2 \cdot \frac{\gamma}{r^3} \cdot 4 \cdot \gamma^2 \ \frac{r}{c^2}^{\ 2}$$

or

$$m' = 2I \cdot \gamma \cdot Kq^2 \cdot \frac{1}{r} \cdot \frac{1}{c^2} \,. \qquad (4.5)$$

That means for *m’* if compared with the original equation (3.6) for *m:*

$$m' = \gamma \cdot m \,. \qquad (4.6)$$

So the derivation above ends up with an increase to the mass by a factor of γ.

5. The Mass Energy Equivalence

From eq. (4.6) (with an altered notion of *m* -> m_0 *and m ’* -> *m*):

$$m = m_0 \Big/ \sqrt{1 - v^2/c^2}$$ or equivalently

$$m = m_0 \sqrt{c^2/(c^2 - v^2)} \qquad (5.1)$$

it follows that an increase of the velocity of an object, which of course means an increase of its energy, will also increase its mass. The relation between mass and energy, which is the most famous relation given by Einstein, will now be quantitatively deduced.

Eq. (5.1) is squared and reordered to:

$$m^2 v^2 = m^2 c^2 - {m_0}^2 c^2 \,.$$

When using the definition of momentum

$$p = mv$$

there is

$$p^2 = m^2c^2 - m_0{}^2c^2 .$$

Now the change of the momentum *p* resulting from a change of mass at motion is found by differentiation:

$$2pdp = 2mc^2dm ,$$

which, using again *p = mv*, yields

$$vdp = c^2dm . \qquad (5.2)$$

Energy is defined by Newton as follows:

$$dE = Fdx = \frac{dp}{dt}dx = \frac{dx}{dt}dp = vdp \qquad (5.3)$$

If this definition of *dE* is inserted into eq. (5.2) there directly follows:

$$dE = c^2dm . \qquad (5.4)$$

If this is integrated now starting with *E=0* at *m=0*, we end up with the well known result:

$$\boxed{E = mc^2}. \qquad (5.5)$$

So also this famous and important formula is derived from basic principles, whereas Einstein has referred to the theory of Maxwell and performed a thought (*gedanken)* experiment using the momentum of a reflected light pulse to deduce this formula, originally restricted to light.

Note:

If you follow the idea, that the mass energy equivalence is just a consequence of the set up of an elementary particle, then this has a remarkable further consequence: As a reverse conclusion the mass energy equivalence may not be valid below the level of an elementary particle. I.e. for the constituents of an elementary particle and their interactions, energy mass equivalence as well as energy conservation does not work!

6. The Final Equation

In the Basic Particle Model it is assumed, that the Basic Particles orbit each other at the orbital speed *c* and at a certain orbital frequency, which depends on the radius. The field, which binds the basic particles to each other, propagates into all directions. So, outside of this orbit an alternating field exists, the frequency of which is identical to the orbital frequency.

Now we can determine this frequency *v* from the known parameters of the configuration, i.e. the elementary particle.

We use the simple geometric relation

$$\nu = \frac{c}{\pi \cdot r} \quad \text{or} \quad r = \frac{c}{\pi \cdot \nu} \qquad (6.1)$$

where *r* is the distance of the basic particles, i.e. twice the radius of the orbit.

The frequency *v* is clearly the de Broglie frequency, because it is the frequency of the alternating field, which causes e.g. the interference behaviour of a particle at a double slit.

(Historical remark: Louis de Broglie predicted such interference behaviour of all particles at scattering. He assumed a wave surrounding each elementary particle. The reason for this wave is now explained as a consequence of the Basic Particle Model.)

In eq. (3.6)

$$m = 2I \cdot Kq^2 \cdot \frac{1}{r} \cdot \frac{1}{c^2}$$

we replace *r* by use of eq. (6.1) and reorder the result; this yields

$$m \cdot c^2 = 2I \cdot \frac{1}{c} \cdot Kq^2 \cdot \pi \cdot \nu \,. \qquad (6.2)$$

In chapter 5 we have shown that

$$E = mc^2 \,.$$

We can further use the known relation

$$E = h \cdot \nu \,.$$

Both equations unified yield

$$m \cdot c^2 = h \cdot \nu \,. \qquad (6.3)$$

If this is used to replace the left side of (6.2) we get

$$h = 2I \cdot \pi \cdot \frac{1}{c} \cdot Kq^2 \,. \qquad (6.4)$$

We will now use the more common version of the Planck constant:

$$\hbar = h/2\pi \,. \qquad (6.5)$$

(Remark for the html-version: $\hbar$ is the Planck constant *h*-bar, misprinted by some browsers.)

Eq (6.4) changes to

$$\hbar = I \cdot \frac{1}{c} \cdot Kq^2 \,. \qquad (6.6)$$

Using now eq. (3.6) and (6.6) and replacing the distance of the basic particles *r* by the radius of the orbit *R* = *r/2*, we end up with the formula

$$\boxed{m = \frac{\hbar}{R \cdot c}} \qquad (6.7)$$

for the mass of an elementary particle constituted by 2 Basic Particles.

This is now a universal relation for the mass of an elementary particle. Note that it does not have any free or unknown parameters.

7. The Particle Angular Momentum (Spin)

Equation (6.7) can be reordered to

$$m \cdot R \cdot c = 1 \cdot \hbar \,. \qquad (7.1)$$

The left side is the classical definition of the angular momentum (spin) for *v* = *c*.

The right side fulfils the expectation to the spin of an elementary particle in so far as it is independent of any particular particle properties; so it has a universal value.

The factor 1 on the right side is not satisfying at the first glance as the measured spin corresponds to a factor of ½. It can, however, not be a surprise. Eq. (7.1) would be the angular momentum of the configuration of two objects, which orbit each other at the speed *c* and at a distance of *2R* and represent half of the classical mass of an elementary particle each. The configuration of the Basic Particle Model is, however, different in the way, that both objects do not have any classical mass.

In spite of this lack of a conventional mass, the orbiting basic particles have an inertial behaviour. The path on which they move is destined by the field of the other partner. This is different from the classical case. There are directions, which a basic particle can follow without the effect of any force, and there are other directions where a force, corresponding to the inertial mass of the entire configuration, is effective. The average angular momentum *s* will be in the interval

$$0 < s < \hbar .$$

So, the result is compatible with a factor of ½.

8. Conclusion

If the binding field inside an elementary particle is as assumed regarding its range dependency and regarding its strength, then this model of the origin of inertial mass is the quantitatively correct explanation of the mass of elementary particles.

If for the strength of the binding field within the elementary particle the appropriate value is assumed in accordance to the Planck-Einstein relation, then this model of the origin of the inertial mass is the quantitatively correct explanation of the mass of elementary particles.

The relativistic behaviour of the inertial mass as well as the energy mass equivalence, the most famous formula of Einstein, are immediate consequences of this model. Further on, the constancy of the spin and the correct value of the magnetic moment of a charged elementary particle are consequences of the Basic Model of Matter. These results are, according to the statement in text books about physics, only achievable by quantum mechanics. The model, however, shows that they can be understood classically.

And, by the way, there is no need for the assumption of further mass mechanisms like the Higgs fields.

NOTE to the concept:

The concept of the Basic Model of Matter was presented initially at the Spring Conference of the German Physical Society (Deutsche Physikalische Gesellschaft) on 24 March 2000 in Dresden.
by Albrecht Giese.

Comments are welcome.

2010-08-19