# The principle effect of gravitational potential

The previous section has summarised the results we will deduce below.

We have defined gravitational potential $\Phi$ as the work which must be done against the force of gravity per unit mass to slowly remove an object to an infinite distance. This is always expressed as a negative quantity. When a mass $m$ falls from a height with a gravitational potential $\Phi$ to a height with potential $\Phi + \delta\Phi$, we say that the gravitational potential increases meaning that $\Phi$ increases in magnitude; $\Phi$ and $\delta\Phi$ being negative.

As we proceed to analyse the situation, it will become apparent that simple concepts and definitions do not necessarily still apply. If, as we assert, the energy $m|\delta\Phi|$ released comes from a reduction in the energy content $E = m\,c^2$ of the mass, how are we to understand the change in $m\,c^2$. We have been taught that the speed of light is a universal constant, but the transit times of radio signals passing close to the sun are observed to be delayed. The local measurement of the speed of light always gives the same answer because we are measuring distance and time with rulers and clocks which are effected in exactly the same way as the light. If we use the universal locally measured speed of light, then we must assume that the mass has decreased, say by $\delta m$. This is a loss in mass and $\delta m$ is negative. We can write:

$$c^2\,\delta m = m\,\delta\Phi$$

In the limit $\delta\Phi \rightarrow 0$ this becomes a differential equation which we can solve:

$$\frac{dm}{m} = \frac{d\Phi}{c^2}$$

$$ln\,(m) = \frac{\Phi}{c^2} + K$$

The boundary condition is that $m = m_0$ when $\Phi = 0$ giving $K = ln\,(m_0)$, then:

$$m = m_0\,e^{\frac{\Phi}{c^2}} \quad \text{which we can write as} \quad m_\Phi = m_0\,e^{\frac{\Phi}{c^2}}$$

We now find ourselves in a similar position to those physicists who first discovered that the mass of high speed electrons behaved in a strange way. They replaced the single word mass with three terms r*est mass*, *longitudinal mass* and *transverse mass*. After some years, they redefined mass in such a way that they only had *rest mass* and *relativistic mass*. The problem arose because of the different methods used for measuring mass: comparison with a standard mass, deflection of a charged particle in an electric field and deflection in a magnetic field.

The relationship $E = m\,c^2$ still holds, so the associated energies for a mass at rest are:

$$E_0 = m_0\,c^2 \qquad E_\phi = E_0\,e^{\frac{\Phi}{c^2}}$$

In our laboratory where the gravitational potential is $\Phi$, we can interpret these equations without ambiguity. The speed of light $c$ is the universal locally measured speed of light which always has the same numerical value (in a particular system of units). The mass $m_0$ is that which we measure with a beam balance against standard masses. The energy $E_0$ is the energy the mass would possess in the absence of a gravitational field and is the value we calculate using Einstein's relationship. The actual energy which remains is $E_\Phi$, but we have no way of measuring this because our unit of energy has also reduced in size. Just as we cannot measure the contraction in length of an object because the ruler has also contracted, we cannot measure the loss of

energy from within the laboratory.

We know that there is a reduction in the energy content because single atoms emit photons of light with an energy equal to the difference in energy levels of electron orbital states. This gravitational redshift gives us a window to look at the variation of energy within atoms with change in gravitational potential and these observations verify the validity of that equation $E_\phi = E_0 \, e^{\frac{\Phi}{c^2}}$. The Mössbauer effect is so sensitive that we can use it to see the difference in energy levels over distances as small as the height of a building.

The analysis we have used here applies only to objects at rest in a gravitational field because gravitational mass is equal to relativistic mass. A free falling mass does not loose energy and its mass remains constant. The energy released from its electric field changes into kinetic energy contained in the magnetic field generated by its motion. This energy is part of its relativistic mass. Since it has not been found necessary to apply a relativistic correction in orbital mechanics to allow for an increase in relativistic mass, we can assume that relativistic mass and passive gravitational mass are equal. When the free falling mass hits the surface of the source of the gravitational field, it looses its kinetic energy and its Einstein mass $m_e$ is reduced. Its physical mass $m_p$ remaining constant.

The gravitational field does not contain energy. It is an influence causing energy to be released from the mass of the object experiencing the force of gravity. The force exists because the released energy is able to do work against a resisting force and in increasing the kinetic energy of the falling mass.

This leads us to one of the great errors in modern physics which relates to light and gravity. An elementary charged particle in free fall experiences an energy transfer from potential energy stored in its electric field to kinetic energy stored in the magnetic field generated by its motion.

While we are happy with the concept that photons have mass, we overlook the fundamental difference between photons and matter. The electric fields of elementary charged particles exist in their own right. The electric fields of photons only exist because their electric intensity $E$ is generated by the motion of their magnetic flux (of flux density $B$). The kinetic energy of an elementary charged particle exists because of the magnetic intensity $H$ generated by the motion of its electric flux (of flux density $D$). In this sense, the photon is all kinetic energy because its electric and magnetic fields and do not exist in their own right, but only by virtue of of each other's motion. Because the photon is all kinetic energy, it is unaffected by gravity! As a photon moves through a gravitational field its energy is recycled and remains constant. It appears to change in energy content because local units of energy are affected by gravitational potential.

Planck's constant is unaffected by gravitational potential, so the photon with its preserved energy has a constant frequency. When we think we are measuring its frequency, we are in fact using its frequency to measure the local clock rate at various places along its path. The photon is not red shifted as it climbs through a gravitational field: rather, the atom which emitted it had a reduced energy content with reduced energy levels due to its position within the gravitation field. Gravitational redshift is not caused by motion through a gravitational field, but is the result of the effect of gravitational potential on the energy levels of the atoms which emit the light.

Since the units of length and time are now defined in terms of the wavelength and frequency of light, a photon carries with it the local values of the units of length and time from the region of the atom which emitted it. Photons from regions of different gravitational potential provide a window into the the effects of gravitational potential.