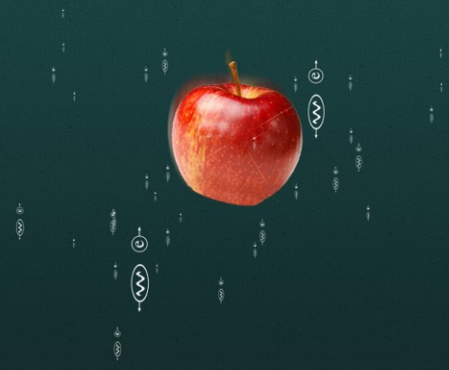
The Enigma of Gravity

An insight into the origin and nature
of an architectural phenomenon
of the universe



Written by

Bernard Paul Badham

The Enigma of Gravity

An insight into the origin and nature of an architectural phenomenon of the universe.

PREVIEW

Bernard Paul Badham

'Fundamental problems require fundamental solutions.'

ISBN: 978-1-291-28998-5

CONTENTS

Introduction

What follows is a collection of thoughts and ideas on the nature of the universe, matter, light, time and gravity. This book is not to be considered as an absolute proof of the theories expounded within concerning the nature and cause of gravity, but rather an exploration of our understanding of classical and modern physics illuminated by a mixture of my own ponderings, scientific reasoning, numerous calculations, experiments and teaching experience and most importantly of all: my imagination. The ultimate aim of the physics explored in this book is to understand the true cause and nature of one of the most elusive, weakest, and yet most important forces in the universe: gravity.

The style of the book is one of questioning, tracing the traditional classical views of the nature of the physical universe and incorporating our modern quantum mechanical views of physical phenomena. This book is dedicated to my son Luke, who has listened with interest to many of my expounded theories of physics, for, without his encouragement this book would never have been written. It is also dedicated to many of my past students who have inspired me by their freshness of thought, interest and questions. The explorative dialogue is aimed primarily at students of physics and indeed any who desire a deeper and more satisfying understanding of the universe around us. The content is presented in much the same way as I have taught, with questioning, reasoning, and presentation of the known facts.

Although much proof, both theoretical and mathematical is presented in this book where necessary, the mathematical proofs and calculations are kept separate from the flow of the text and are included for those students who will find the exercises most useful in their own studies. I have deliberately avoided using references in the book as much of the physics presented is standard and modern. It is in revisiting and questioning this physics which brings us to a deeper understanding, and in doing so, by taking down the building blocks of what we know and understand and rebuilding them do we sometimes get the true picture. I have simply taken a very large jigsaw puzzle put together over many centuries by intellectual giants of physics and put them back together with logic and hopefully inspired but reasoned imagination. This is not a complete work in itself as I have not included all my writings,

thoughts and experimental results, but only those which are necessary to complete the journey of discovery into the true nature of gravity.

It is my hope that you will find it a rewarding and enjoyable experience discovering anew the nature of our remarkable universe and that you will arrive at the same satisfying place as I of understanding what gravity really is.

Bernard Paul Badham

Stuck on a Rock

Humankind has been living on planet Earth for millions of years and almost all of that time our meager and mortal existence has been confined to the surface of this rocky world. It is only in recent history through the inventions of adventurous scientists and engineers have we been able to take to the air and then to finally fly to the Moon. In a sense we have been and are prisoners of our own world. It took an immense amount of research, knowledge, technology, money and chemical *power* to send men and women into space and to ultimately get the three astronauts of Apollo 11 to the Moon.

What keeps us here is of course gravity. That strange and mysterious force of nature so well described by Isaac Newton and Albert Einstein, but even with their great mathematical accomplishments we are not much wiser concerning the true nature and cause of this imprisoning force.

To lift a load against the force of gravity takes energy, and energy costs. It took the whole mass and fuel of the enormous Saturn V rocket to lift its little payload of Command Module, Service Module and Lunar Module into orbit about the Earth. It seems we are stuck in a *gravity well* and to leave this planet we have to claw our way out by any and every means possible. One very real question remains: when we are moving against gravity what exactly are we moving against? Although Newton described gravity as a force, an impulse given to a mass near another mass, Einstein declared gravity to *be* acceleration. Neither of these brilliant scientists tackled the real physical problem of what causes gravity and why and how it acts.

Gravity is described as an 'action at a distance' force, an invisible force which acts through the void of empty space, in other words it appears to act through nothing! It is no longer enough to say, as Einstein did, that mass tells space-time how to curve and space-time tells a mass how to move.

Until we understand the true nature of gravity and how to nullify its effects we will remain:

Stuck on a rock.

CHAPTER ONE
The Perception of Time

Ever since I can remember I have been fascinated by the vastness and incredible beauty of our wonderful universe and particularly one of its most elusive forces, the force of gravity. Even though I quickly learned about Newton's laws which describe accelerated motion and later Einstein's mathematical descriptions of the nature of space-time I was still left wanting. Gravity, like magnetism, was one of those mysterious invisible forces, which left me wondering how and why these forces act.

To start this incredible journey of discovery into understanding the fundamental nature of the universe we begin with time itself. We are all familiar with the concept of time, for without it how would we ever get things done? But time remains as elusive as the true nature of gravity – it is one of the hardest things as a physicist to define. I remember as a child being told by my elder sister the old adage 'a watched kettle never boils' and understanding what she meant when making a pot of tea for the family one evening, standing there in the kitchen waiting for the kettle to boil on the gas stove seemed to take forever and what was even more frustrating there was nothing I could do, or so I thought at the time, to make the kettle boil any faster. Finding the experience too much to tolerate I left the kitchen and returned to the living room to watch TV and guess what? It seems no sooner than I had made myself comfortable, that the little kettle on the stove started whistling, 'maybe she was right,' I thought. So what was going on here? Even *at the time*, I knew the *adage* or *my personal perceived experience* of the event wasn't true, what made it so real was my *perception of time*, not time itself. So then, how do we actually perceive time? Well let's start with what we all recognise as something which marks out the pace of time: a clock.

Clocks come in all shapes, types and sizes but they all essentially do the same thing, *mark the passage of time*. My *all time* favorite clock is the grandfather clock, what a wonderful piece of machinery, clock making is not just a science it is an art and if you ever open up the back of a large clock, or even a small one for that matter and take a look inside at its intricate workings of winding cogs you will agree. My first

experience of a grandfather clock was when visiting an uncle of mine in his old Hereford country cottage, it was evening time and the log fire was roaring in the stone fireplace illuminating the quaint little living room with its soft flickering light and placed on the table behind me was one of those quaint old oil lamps. The soft dancing shadows being cast around the room as my parents talked were just as charming as the *tick-tock* of the tall grandfather clock set against the living room wall. I remember looking up at its ornate face; the clock stood taller than I, and watching the long brass pendulum swing hypnotically to and fro, the sound and sight of the brass pendulum gracefully beating out the passage of time was magical.

Tick – tock, tick – tock, tick – tock

The experience of this audible beat of time, where each *tick* and *tock* was governed by the swing of the pendulum was somehow wonderfully soothing and relaxing. If you ever have trouble sleeping my advice is to buy a grandfather clock and listen to its rhythmic *tick-tock* while relaxing in a comfortable chair, preferably with the heat of a log fire in front of you and with no other distractions except the flicker of the flames.

Tick – tock, tick – tock, tick – tock

Listening to the clock and watching the pendulum swinging to and fro gives the impression that time marches on evenly and uninterrupted, and so by this premise my boiling kettle would have taken the same time to boil whether I was watching it or not.

Tick – tock, tick – tock, tick – tock

So what exactly governs our perception of time? First there is our *psychological perception of time*, which is relative of course to what we are doing when we are experiencing the passage of time, 'time flies' when we are enjoying ourselves, but seems to go by slowly when for instance we are waiting in a queue. Secondly, there is the *biochemical awareness of time*: On the scientific biological level the speed of the chemical reactions in our brain, our thought processes, govern our perception of time.

Chemical reactions involve interactions of electromagnetic fields between atoms and the speed of these interacting fields is governed by the speed of light, which is the constant (c) equal to 3×10^8 *m/s, an incredible speed of over one hundred thousand kilometres and hour!*

It is the constant ticking away of these reactions, at the speed of light, that give us a constant biological perception of the passage of time. It is interesting to note here that if we could change the speed of light then the speed of our thinking processes would also change, if increased then we would think faster, but so would all the physical processes in the world around us work faster, so we would not notice any change at all!

The kettle would actually boil faster, but because we are thinking faster it would seem to take just as long!

Lastly, there is what we call *absolute time*, the thing clocks measure. So what exactly is absolute time? There are various answers to this fundamental question: 'Well time is the *time* it takes for the Earth to spin around once which takes 24 hours!' 'Time is something governed by clocks!' 'Time is the interval between one regular event and another!'

Interestingly enough is the fact that time *can* be measured and since it can be measured, this makes it a fundamental physical quantity. One revolution of the Earth about its axis with reference to the Sun is what we call one solar day, 24 hours. This time duration of one solar day was divided up by the ancient Egyptians into 12 hours of day and 12 hours of night. The passing of day time hours were marked by the movements of the sun and water clocks, whereas the night time hours were marked by the movements of the stars. The priests of ancient Egypt would call out the hours from the temple rooftops each time a specific star crossed the line of sight of a fixed apparatus.

If the day is measured with respect to the 'fixed stars' we get a sidereal day, which is actually shorter than the solar day: The duration of a sidereal day is 23 hours, 56 minutes and 04.0905 seconds with respect to the Mean Solar Time of Greenwich Meridian time. The sidereal day is shorter because the Earth *moves* in its orbit around the sun as it revolves about its axis. As we know today one revolution of the Earth in its orbit about the sun is what we class as one year, 365.2422 days or 365 days, 5 hours, 48 minutes and 45 seconds.

Absolute time is a very difficult thing to define, ancient philosophers and scientists grappled with the subject of time: The ancient Greek philosopher, Heraclitus said: 'Everything flows and nothing abides; everything gives way and nothing stays fixed. You cannot step twice into the same river, for other waters and yet others, go fluxing on.

Time is a child, moving counters in a game; the royal power is a child's.' Another ancient Greek philosopher, Antiphon said: 'Time is not a reality, but a concept or a measure.' St Augustine confessed: 'What then is time? If no one asks me, I know: if I wish to explain it to one that *asketh*, I know not.'

A dictionary definition gives time as: 'A non-spatial continuum in which events occur in apparently irreversible succession from the past through the present to the future.' Or 'An interval separating two points on this continuum; a duration.' An encyclopaedic definition gives it as: 'Time is part of the fundamental structure of the universe, a dimension in which events occur in sequence, and time itself is something that can be measured.'

All of these definitions are of course unsatisfactory to varying degrees, so what exactly is time? I once asked my youngest son this question and he gave the best answer I have ever heard: 'Dad, time is change!' a simple but very real answer, for without time there can be no change. So a time interval is an interval of change. So what governs the rate at which things change? This we know and have already stated: *the speed of light!*

The speed of light governs change, therefore governs time

Things change at the speed of light: all fundamental forces, electromagnetic and gravitational, act at the speed of light. So in this sense: time *is* the speed of light! Or more exactly:

Time is fundamental change at the speed of light

But what is even more interesting is that according to Einstein, relatively speaking, time is not constant, only the speed of light in a vacuum is constant and that: speed and gravity affects time, this is what he calls time dilation, at high near light velocities or in a strong gravitational field time slows down relative to a stationary observer or someone in a weak gravitational field, for each observer in their own frame of reference time runs at its normal speed. This constancy of the speed of light and time for each observer in their own frame of reference brings order and harmony to the universe.

Albert Einstein was a giant of logic, reasoning and imagination, there has never since been a scientist like him. He was a truly intellectual giant, for 100 years later, his theories still stand. Einstein's time dilation, due to the effects of speed and gravity, *are* very real.

Navigation satellites in orbit travelling at high velocities and where gravity is weaker than on Earth have to compensate for these time differences. So why does speed and gravity affect time? These are two very important fundamental questions; let's answer the first why gravity affects time:

In a strong gravitational field the speed of light is reduced and since the speed of light governs time, gravitational fields affects time.

Why speed has an effect on time will be answered later when we have looked at the physical nature of space though which objects move.

These time dilation affects are very small, almost immeasurable, but they *have* been measured using modern atomic clocks. What would happen to our grandfather clock in different strength gravitational fields? There are two affects:

1. The large and noticeable affect due to the change in the gravitational acceleration of free fall.

2. The small but measurable affect of time dilation.

In a strong gravitational field, the free fall acceleration of a swinging pendulum of a grandfather clock increases, so the clock would visibly tick faster, on the Moon for instance where gravity is one sixth that of Earth's a pendulum clock would tick slower (one sixth slower). This difference we would notice.

The time dilation due to changes in gravity we would only notice between different frames of reference and in any way if we could observe this affect it would be very small. What about our boiling kettle in different gravitational fields? Well on the surface of the Earth where gravity is strong and time runs slower, the kettle would take longer to boil, but we would not notice this because light speed is less and therefore our brain's thought processes, the chemical reactions, are running slower by an equal amount. If we take the kettle to the top of a mountain where gravity is less and time runs faster, the kettle would boil quicker, but again we would not notice this in our own frame of reference. Is there any way we can make the kettle boil quicker? Yes, but not in our own frame of reference!

One solution to this problem is to place the kettle inside a magical box were gravity is decreased artificially to zero, we would then observe the kettle boiling quicker, but because the time difference between zero gravity and Earth's gravity is minute, it would still seem to take just as

long, we need a bigger gravitational difference between our frame of reference and the kettle inside the box. The problem is we would probably have to lie down while we are waiting for the kettle to boil because if we were in an artificially increased gravitational field we would weigh more!

Creating an artificial gravitational field is a holy grail for physics. If we could control gravity then we could travel through space and time. Yes, we are talking about time machines and spacecraft travelling at warp speeds, the speed of light and more. At last we may be able to travel to the stars and travel through time!

CHAPTER TWO
The Nature of Light

Our journey into the nature of the universe will take us down many roads of classical and modern physics, some seeming irrelevant and off the track, but every fact of physics we examine will be essential in our eventual understanding of why a mass produces a gravitational field - gravity's causal agent. In other words: How matter warps space-time.

If we can understand how gravity works, then we may be on the road to creating artificially our own gravity field.

Whoever controls gravity can control space and time!

This is a fairly mind blowing statement, absurd even, a pipe dream perhaps? But whoever makes this breakthrough in the world of physics will go down in history. It will be the next quantum leap for humankind, for with the knowledge of how to warp space-time is the ability to achieve one of mankind's ultimate goals - to travel to the stars, anywhere in space and possibly time.

There are a few physicists undertaking theoretical research into the holy grail of physics - the creation of a gravitational field. Some say it is impossible, while others have claimed limited success. A few years ago the American government announced that they were about to spend millions of dollars on a gravitational field project. Most of the theories used in this book are based on real physics, but the world of physics is changing, what was once thought impossible now takes on the guise of the probable. This is an adventure into the universe of space and time, which, according to Einstein are variable, not constant. The one thing in this universe he said which remains constant is the speed of light (c) in a vacuum: In metric units, c (in a vacuum) is exactly:

299,792,4588 metres per second

In more familiar units it is a phenomenal: 1,079,252,848.8 km/h, over a thousand million kilometres an hour. Travelling at this speed we could whiz around the whole circumference of the Earth 7.49 times a second! Although this gives us the impression that the speed of light is

instantaneous here on Earth over terrestrial distances, when it comes to the size of the universe light speed is pretty slow. For instance it takes 1.28 seconds for light to reach the moon from Earth, this delay was significant for the communication of Houston ground control and Apollo 8 when it became the first spacecraft to orbit the Moon: For every question, Houston had to wait nearly 3 seconds for the answer to arrive, even when the astronauts replied immediately.

The following is a list of flight times for light from the sun reaching astronomical objects:

Earth	8.32 minutes
Mars	12.7 minutes
Pluto	5.48 hours

Nearest star: Proxima Centauri: 4.2 years!

This shows us that interstellar space travel is only possible if we could travel at near light speeds or even greater if that were possible, what we call *superluminal speeds*. To travel across our own galaxy, the Milky Way, at the speed of light would take 100,000 years and to get to the nearest galaxy, to ours, Andromeda, would take 2.9 million years.

The strange thing is that through a transparent or translucent material medium, like glass or air, light appears to have a different speed than in a vacuum, this causes its direction of propagation to change; the ratio of c in the medium to the observed velocity in a vacuum is called the *refractive index* of the medium. This travelling at different speeds through different media is called *refraction*, let us look at this property of refraction of light in more detail as later it will become important in our understanding of space-time dilation.

Refraction is the change in direction of a wave due to a change in its speed. This is seen when a wave passes from one medium to another. Refraction of light is the most commonly seen example, but any type of wave can refract when it interacts with a medium, for example when sound waves travel through materials of different density. At the boundary between different media, the wave's velocity is altered, and as a result of an uneven change in speed across the wave front it changes direction. Analogy:

Imagine yourself running past a lamp post and just us you pass it you reach out your right hand to try and catch it, the result is reduced pace and a change of direction – you swing to the right.

In refraction there is a wavelength increase if the medium is less dense and a decrease if the medium is denser, but in both cases the wave's frequency remains constant. For example, a light ray will refract as it enters and leaves glass, the understanding of this concept led to the invention of lenses and the refracting telescope. Refraction is also responsible for rainbows and for the splitting of white light into a rainbow-spectrum as it passes through a glass prism. Glass has a higher refractive index than air and the different colours of light, of different frequencies, travel at different speeds (dispersion), causing them to be refracted at different angles, so that you can see them. Violet light slows down in glass more than red light, this bigger change in its speed causes violet light to bend (refract more) than red light.

The speed of light in air is only slightly less than *c*, in a denser medium, such as water and glass, light can slow much more, to fractions such as 3/4 and 2/3 of *c*. respectively. Through diamond, light is much slower — only about 124,000 kilometres per second, less than ½ of *c*.

Why then is the speed of light in a medium such as glass much less than the speed of light in a vacuum?

The reason for this slowing down of light as it enters a denser medium is fundamental in our understanding of gravitational fields.

When light enters a substance such as glass from a vacuum, travelling at c, the individual particles of light (photons) interact with the glass atoms. The atoms act like antennae and absorb the photons and then after a specific time interval (Δt) they transmit them. This time delay gives light an apparent reduction in speed, *in between* the atoms there is still the vacuum of space where the speed of light is constant (c). When the light photons leave the glass medium they continue at high speed, at c.

Dispersion of Red and Violet Light

Let us look again at the dispersion of red and violet light in water from air and see if we can explain the differences in speed. We first calculate their respective speeds in water using known values of refractive index (n).

$$n_{air} = 1.000 \quad n_{red} = 1.331 \quad n_{violet} = 1.344$$

1. Speed of red light (v_r) in water

$$= c/n = 2.998 \times 10^8 ms^{-1}/1.331$$

$$\text{Velocity Red Light } v_r = 2.252 \times 10^8 m/s$$

2. Speed of violet light (v_v) in water

$$= c/n = 2.998 \times 10^8 ms^{-1}/1.344$$

$$\text{Velocity Violet Light } v_v = 2.231 \times 10^8 m/s$$

It can be seen from the calculation that violet light has a slightly slower speed in water than red light and therefore there is a bigger change in the speed for violet light entering water from air, this bigger change in speed causes more refraction – a bigger direction change.

But why does violet light travel slower through water than red light? Surely the answer to this question must be related to why light slows down when travelling through a dense medium and this is related to the photon absorption time (Δt) by the atoms of the medium. Since violet light slows down more, then the photonic absorption time for violet light must be greater than the absorption time for red light. Assuming this is true then we must ask: why is the absorption time greater? Violet light has a shorter wavelength (400nm) compared to red (700nm), using the wave speed formula we can calculate their respective frequencies and energies:

Red light frequency f_r

$$= c/\lambda = 2.998 \times 10^8 ms^{-1}/700 \times 10^{-9} m$$

$$= 4.283 \times 10^{14} s^{-1}$$

Violet light frequency f_v

$$= c/\lambda = 2.998 \times 10^8 ms^{-1}/400 \times 10^{-9} m$$

$$= 7.495 \times 10^{14} s^{-1}$$

Now we can calculate the energy of each photon using the Photon Energy equation E = hf:

Where h is Planck's constant (h) = 6.626×10^{-34}Js:

Red photon energy (E)

$$= hf = 6.626 \times 10^{-34}\text{Js} \times 4.283 \times 10^{14}\text{s}^{-1}$$

$$= 2.838 \times 10^{-19}\text{J}$$

Violet photon energy (E)

$$= hf = 6.626 \times 10^{-34}\text{Js} \times 7.495 \times 10^{14}\text{s}^{-1}$$

$$= 4.966 \times 10^{-19}\text{J}$$

We can see that since violet light has a higher frequency of oscillation than red light, each photon of violet light carries more energy than red light photons. It seems therefore: the more energy a photon carries the greater the absorption time and therefore the slower the speed through the medium – this answers the question why violet light is refracted more than red light. Now one question remains: why does a photon carrying more energy have a greater absorption time? When an atom absorbs photons of light this shifts the electrons around the atoms to higher orbital energy levels – this is called an electron energy transition. In this higher energy state the electron orbit is unstable and within nanoseconds the electron will drop back down to its lowest energy state (ground state) and emit the photon on its way again. The time for this process is called the transition time (Δt). It seems logical to assume the higher the energy of the photon the higher the energy jump and therefore the longer the transition time – think of throwing a ball higher into the air, the more energy you give it, the higher it will go and the longer it will take to come back down. In this case the higher the photon energy the slower the propagation speeds through the medium.

Classically, considering electromagnetic radiation to be like a wave, the charges of each atom (primarily the electrons) interfere with the electric and magnetic fields of the radiation, slowing its progress. [The full quantum-mechanical explanation is essentially the same, but has to cope with the discrete particle nature of light: the Electric fields in the atoms create phonons in the media, and the photons mix with the phonons. The resulting mixture, called a polariton, travels with a speed different from light.]

Here is an important principle to remember:

Light speed c in a vacuum is a constant, but in different media its speed can change.

But what exactly is light? Understanding the nature of light is fundamental for our understanding of the nature of matter, energy, gravity and space-time. To help us understand any phenomena we look at its measurable physical properties and effects. Classical physics states: that light is an electro-magnetic wave, which is visible to the naked eye (what we call visible light), but light in a technical or scientific context, is electromagnetic radiation of *any* wavelength. Red light has a longer wavelength (lower frequency) than blue light: The wavelength of red light is around 650 nanometres i.e. 650 x 10^{-9}m. The wavelength of blue light is 450 nm. The visible spectrum of light includes the familiar colours of the rainbow.

The electromagnetic spectrum encompasses all electromagnetic waves including waves which are invisible to the naked eye, these include radio waves, microwaves etc. All of these waves have the same basic properties of light; they can be reflected, and refracted. The three basic dimensions of light (all electromagnetic radiation) are: Intensity (I) measured in Watts per metre squared, or alternatively amplitude (a), which is related to the perception of brightness of the light and the height of the wave. Frequency (f) measured in wave cycles per second (s^{-1} or Hertz, Hz). Wavelength (λ) measured in metres, perceived by humans as the colour of the light, and Polarization (angle of vibration), which is only weakly perceptible by humans under ordinary circumstances.

The wave speed (v) can be calculated by using the equation:

$$\text{Wave speed} = \text{frequency} \times \text{wavelength}$$

$$V = f\lambda$$

When we are talking about light and other electromagnetic radiation which travels at the speed of light we use the symbol (c), so:

$$c = f\lambda$$

Due to the wave-particle duality nature of light, light simultaneously exhibits properties of both waves and particles. The elementary particle that defines light is the photon. A photon is a packet (quantum) of electromagnetic energy. The electromagnetic energy (E)

of a photon at a particular wavelength λ (in a vacuum) and its associated frequency (f) can be calculated:

Photon energy = Planck's constant x frequency

$$E = hf$$

The value of Planck's constant is: 6.626 0693 x 10^{-34} Js.

Question: What is the electromagnetic energy of a photon of red light of wavelength 650nm?

$$E = hf$$

$$E = 6.6261 \times 10^{-34}\text{Js} \times 650 \times 10^{-9}\text{m}$$

Answer: The electromagnetic energy of a red photon of light = 4.04 x 10^{-40} joules

Planck's constant (h) is a fundamental constant of the universe, it determines in this case the energy of an oscillating electromagnetic wave and as we shall see later it governs many other phenomena including the smallest size attainable: 10^{-35}m, what we call Planck length: It is interesting to note here that Planck's constant (h), the speed of light (c) and Newton's gravitational constant (G) are related.

Question: How many photons does a 100 Watt light bulb radiate per second?

A 100 Watt red light bulb radiates 100 Joules of photonic energy per second.

Number of photons per second = Energy per second/energy per photon

$$= 100\text{J}/4.07 \times 10^{-40}\text{J} = 2.46 \times 10^{41}$$

photons per second!

Answer: A 100 watt red light bulb radiates about 25 billion, billion, billion, billion, billion photons per second!

Note: In physics there are theoretical limits on size etc, one such theoretical limit is called Planck length. The Plank Length limits the smallest theoretical particles which can exist. Planck Particles which are 10^{20} times smaller than a proton have a mass which is about 13 x 10^{18} times heavier than the mass of a proton:

In quantum physics the more massive a particle

the smaller its size!

Planck length, denoted by Lp, is the unit of length about 10^{20} times smaller than the size of a proton in an atomic nucleus. The Planck length is a natural unit because it can be defined from three fundamental physical constants: the speed of light (c), Planck's constant (h) and the gravitational constant (G)

Question: how can Planck length be calculated using the constants of light speed and gravity?

Answer:

$$L_p = \text{square root } (hG/2\pi c^3)$$

$$= \text{sqrt } (6.626 \times 10^{-34}\text{Js} \times 6.673 \times 10^{-11}/2\pi \times 2.998 \times 10^{8}\text{m/s})$$

$$L_p = 1.616 \times 10^{-35}\text{m}$$

It is interesting to note here that the limit of Planck length is based on the gravitational constant G, which cannot be derived from other constants, G can only be determined by physical measurement.

Let us investigate the electro-magnetic nature of light, because this is fundamental in understanding the true nature of matter, energy, space-time and gravity. We will start with Einstein's mass-energy equivalence:

This simply states that mass and energy are equivalent, mass can be formed from energy and vice versa – matter and energy are interchangeable.

A simple example: a photosynthetic plant locks up light energy which has been radiated from the sun over the vacuum of 'empty' space. The green photosynthetic pigment, chlorophyll, traps this electromagnetic light energy into the energy rich carbohydrates, glucose and starch which we use for food. Photosynthesis traps electromagnetic light energy into mass. This is an example of an energy-mass conversion; any object which absorbs light energy increases its mass.

Since Einstein we understand that:

Matter can be transformed into electromagnetic wave energy

Electromagnetic wave energy can be transformed into matter!

Einstein's mass-energy equivalence equation:

$$E = m\,c^2$$

This equation tells us how much electromagnetic energy we can get from a mass:

Energy = mass x speed of light squared

Multiplying the mass by the speed of light squared means that it takes an awful lot of energy to make one kilogram of mass or in one kilogram of mass there is an immense amount of energy. In a one kilogram mass there is: 90,000,000,000,000,000 Joules of electromagnetic energy:

Electro-magnetic energy trapped in 1 kg of matter:

$$E = mc^2 = 1 \text{ kg} \times (2.998 \times 10^8 \text{m/s})^2$$

$$\text{Energy} = 8.998 \times 10^{16} \text{ Joules}$$

This principle is proved every time you strike a match - a tiny amount of matter is converted into electromagnetic energy - heat and light. The heat is in the form of electromagnetic infra-red waves and the kinetic (movement) energy of the gas particles. The same thing happens whenever we burn anything.

Mass-energy conversions happen in all chemical reactions.

It's what keeps us alive - our body 'burns' food chemically to release the mass-energy. A more dramatic example of mass-energy conversion is an atomic bomb. Nuclear power plants do the same thing - radioactive uranium is split (fission) into two simpler elements which are less massive together than the original uranium. This missing mass is converted into pure energy, mostly in the form of moving (kinetic) heat energy. The Sun and all other stars are the most efficient machines at converting matter into energy. They do this by the process of nuclear fusion in the core of the star. Here 4 hydrogen atoms are fused into 1 helium atom. The helium atom is less massive than the 4 hydrogen atoms; hence the mass difference gets converted into pure electromagnetic energy (gamma rays). On a smaller everyday scale the mass-energy conversions are tiny:

1. Heating a 1kg copper pot from 0°C to 100°C takes around 40kJ of energy. This is equivalent to a mass increase of 10^{-13}kg, a tiny increase in mass, but still present and real.

2. Hitting a tennis ball from a velocity of 0m/s to 50m/s gives it about 125 joules of kinetic energy, this is equivalent to a mass increase of 1.4×10^{-15}kg.

3. Energy absorbed per second by the Earth from the Sun is a staggering 1.74 x 10^{17}J, this is equivalent to a mass increase in the Earth of 1.93kg per second. Don't worry the Earth is not getting bigger by 60.82 million kg a year, because most of this mass-energy is re-radiated back out into space.

The sun in its core converts mass to energy at a phenomenal rate: 4.26 million metric tons per second! This energy is released in the form of high energy neutrinos and high frequency gamma rays. The neutrinos, which neutrally charged, almost massless particles, pass through solid matter and leave the sun effortlessly. About 65 billion neutrinos from the sun pass through 1 square centimetre of the Earth's surface every second! Very few of these will interact with the Earth, almost all pass straight through as if the Earth was not there, matter is transparent to neutrino radiation. Apparently it takes on average 1 million years for a gamma photon made in the core to reach the sun's surface, this is because it is being continually absorbed and re-transmitted by matter particles in random directions. By the time this gamma radiation emerges from the sun its energy has been reduced into longer wavelength radiation: the electromagnetic spectrum, including visible light. It's an amazing thing to realize that a lot the sun's light we see today was made in its core a million years ago.

Electromagnetism

Let's get back to the electromagnetic nature of light, to do this we need to understand electro-magnetism. We have all played with magnets and built simple electrical circuits, so we have an experience and notion of electricity and magnetism.

Magnetism and Magnetic Fields

Let's talk about magnetism first. We understand that magnets have magnetic poles, a north-pole (N) and a south pole (S) and that two like poles (N-N) repel each other and so do two south poles (S-S). Opposite poles (N-S) attract. Magnetism is a force in that it can attract or repel, *unlike gravity which can only attract*. This is one of the odd things about gravity, it is always an attractive force – herein lies a clue to its nature. We are all familiar with the school experiment at sprinkling iron filings a piece on paper placed over a bar magnet. The iron filings

form a pattern around the magnet which appears as loops extending from one pole to the other, this demonstrates the magnetic field around the magnet, think of it as a magnetic force field. The magnetic field has strength and direction, the closeness of the lines of force in a field diagram shows the strength of the field and the arrows show the direction. The magnetic field is stronger near the poles and the direction of the field flux (flow) from the North Pole (N) to the South Pole (S).

The direction of the magnetic field is determined by placing a compass in the field and seeing which way it points. The strength of the magnetic field is a measure of the force it exerts on another magnet like a compass needle. If we place two magnets together, a north pole (N) and a south pole (S) then the field lines line up directly between the poles. With two magnets in repulsion the field lines push away from each other and produce a neutral point in the centre space between the magnetic poles, here the opposite direction of the fields cancel each other out. The fields are still there, but a magnetic particle at this point is equally pulled in both polar directions and therefore does not move. The point of all this is to show that a magnetic field (abbreviated as B) has direction.

An electromagnetic wave is made up of two oscillating fields, an electric field (E) and a magnetic field (B). The magnetic field (B) changes direction every half wavelength i.e. twice during one oscillation of the wave. The oscillation of the wave is its electromagnetic energy.

The more it oscillates per second (frequency) the more electromagnetic energy the wave has.

We saw *this in the equation* $E = hf$

Increase the frequency and the energy of the wave increases. Think about waving a flag, to make it oscillate quicker you have to put more effort (energy) into it. What about the electric field? Magnetism and electricity go hand in hand, we can't have one without the other, so let's talk about electric fields.

Electricity and Electric Fields

Let us start this by reminding ourselves what electricity is. If we connect a lamp to a battery, electricity (electric current) travels through the wires and the lamp - the electrical energy heats up the lamp until it

is white hot. The small filament in the lamp gives off heat and light energy.

Question: what exactly is travelling through the wires?

Answer: negatively charged electrons.

But what are electrons? Electrons are the negatively charged particles which 'orbit' the positively charged nucleus of an atom. The nucleus contains positive protons and electrically neutral neutrons. The atom is normally electrically neutral with the same number of negative and positive charged particles:

Number of electrons = Number of protons

In metal conductors such as copper many of the outer electrons of the atom are free to move, we call these 'free electrons.' It is these free electrons which are pushed around the circuit by the battery voltage. The more voltage the more the electrons are pushed. The negative terminal of the battery is a supply of free electrons – here the electrons are repelled from each other - because they have the same charge (-). This is a bit like two magnetic poles repelling each other. The free electrons trying to get away from each other travel through the wire - they jump from atom to atom in the wire. At the same time as being pushed through the wire by their repulsion of each other, they are also attracted to the positive (+) terminal of the battery which is deficient of electrons. So the battery supplies a push-pull on the electrons moving them through the circuit from (-) to (+). The electrons drift through the metal lattice, colliding with the atoms and giving up some of their energy as electromagnetic heat and light radiation.

Charged particles like magnets have a force field around them, electric field lines in this case. The direction of the electric field (E) is the direction a positively charged particle would move if placed in the field, repelled from the positive and attracted to the negative.

If we replace the lamp with two metal plates with an air gap in between them, the electrons are pushed by the (-) terminal and build up on one of the plates - the plate becomes negatively (-) charged. At the same time the (+) terminal of the battery attracts away electrons from the other plate - leaving it with a positive (+) charge. The end result is one of the plates is negatively (-) charged and the other plate is positively (+) charged. The electrons on the negative plate are attracted to the positive plate but cannot flux across the air gap because air is an

insulator - it would take a very high voltage (strong attractive force) for the electrons to force their way through the atoms of the air insulator, if the voltage is high enough we would see them jump the gap as an electric spark!

This type of device is called a capacitor - it stores charge. What is interesting is that between the plates (+) and (-) plates we have an electric field (E)

The direction of the field is from positive (+) to negative (-).

The strength of this electric field depends on the voltage of the battery, the dimensions of the plates and the type and size of gap between them. The *electric field (E) between the plates can exert a force on any charged particle* placed between the plates. A positively charged (+) particle placed between the plates will move (accelerate) towards the negative plate and conversely, a negatively charged (-) particle with be attracted towards the positive plate.

In an electromagnetic wave the electric field is oscillating in tune with the magnetic field - they are inseparable and linked. The electric field generates the magnetic field and vice versa. Another thing to note about the electric (E) and magnetic (B) fields is that they are always at right angles to each other. E and B are also at right angles to the direction the wave travels - this is what we call a transverse wave.

Question: how is electromagnetic radiation produced?

Answer: one important way is by the acceleration of charged electrons.

When an electron accelerates, changes direction or speed, it radiates electromagnetic wave energy. This is how radio waves were first produced. In, 1864, James Clerk Maxwell predicted the existence of radio waves by means of mathematical model. Twenty four years later, in 1888, bolstered by Maxwell's theory, Heinrich Hertz first succeeded in showing experimental evidence of radio waves by his spark-gap radio transmitter. This experiment stimulated Marchese Guglielmo Marconi, who first achieved signal transmission by means of radio waves over 10 m in 1895 and over the Atlantic Ocean in 1901. It was Reginald Fessenden who first succeeded in transmitting continuous wave (CW) for voice telecommunication. These very early transmitters included a battery power supply, a high voltage induction coil (transformer) with a buzzer-type interrupter in the transformer's

primary circuit, a spark gap connected across the secondary coil, and an UHF dipole antenna connected across the spark gap. The transmitted frequency was around 400 million Hertz (microwaves).

The capacitor charges up to a high voltage and is discharged across the rotary gap – a spark, the discharge current excites the antenna and charge (electrons) oscillate back and forth (accelerating) in the antenna at the antenna's natural frequency. Because the electrons are in a constant state of acceleration they radiate electromagnetic radiation. The electromagnetic wave oscillates at the same frequency (around 3 x 10^9 Hz) as the current in the antenna. The antenna is made up of two rod conductors, an electric dipole. Each half of the dipole is of opposite charge to the other and with a high voltage difference and alternates positive (+) to negative (-). During the A.C. voltage cycle the potential difference between the two halves is high enough for a spark. The electric field around the dipole is doughnut shaped and in the same direction as the vertical dipole. As the field oscillates, changes direction, its electromagnetic energy disperses at the speed of light forming an electromagnetic wave. We must remember of course that there is also an oscillating magnetic field at right angles to this oscillating electric field.

Summary

The Seven Fundamental Properties of Electromagnetic Waves:

1. All electromagnetic waves travel at the speed of light (c)

2. Electromagnetic waves can travel through the vacuum of space

3. The speed of an electromagnetic wave in a vacuum is a universal constant (c)

4. The wave oscillates with electro-magnetic energy at a frequency (f)

5. The electromagnetic energy (E) is directly proportional to the frequency (f)

6. The wave has an oscillating electric (E) and magnetic field (B).

7. The electric and magnetic fields oscillate at right angles to each other and the direction of the wave travel.

Mass-Energy Equivalence: *By Einstein's* $E = mc^2$*:*

Matter can be transformed into electromagnetic energy

Electromagnetic energy can be transformed into matter

The fact that matter (mass) and energy are interchangeable is an important milestone, for until we can understand what matter is truly made of we cannot understand why a mass produces a gravitational field.

CHAPTER 3
A Weighty Problem

Isaac Newton was a giant in our understanding of the physical universe. He laid down the fundamental laws of motion and forces, particularly the force of gravity as we understand it today.

It is strange to think that all mass (substance) is condensed electromagnetic wave energy, but daily we see and experience these mass energy conversions: Whenever we light a fire the bound up mass-energy stored in the fuel is released as heat and light (electromagnetic) energy. Burning, coal, oil or gas which are fossil fuels, releases the mass-energy stored by living organisms millions of years ago. These organisms, primarily plants, trapped the sun's electromagnetic light energy while they lived. Now we burn their fossils to release their stored mass-energy. A motor car burns petroleum (made from oil) to release stored mass-energy. The energy of the chemical combustion of the fuel in the presence of oxygen is released as heat energy.

This type of energy comes from the breaking and making of chemical bonds between the atoms. The mass differences between the products and the reactants due to the breaking and forming of new chemical bonds, is released as energy. The energy is released in the form of kinetic (movement) energy of the molecules which we see as heat. This is just like releasing a squashed spring where the stored strain energy is released causing the spring to fly off at velocity. These excited atoms release this energy in the form of Infra Red radiation, in fact all matter particles above a temperature of absolute zero (0K, -273 Celsius), radiate heat waves, the more excited the atoms (hotter), the higher the frequency/energy of the radiation which is emitted.

So how does condensed electromagnetic wave energy which makes up mass generate a gravitational field? Let's start with Isaac Newton's views on the subject. In 1679, Newton returned to his earlier work on mechanics, i.e., gravitation and its effect on the orbits of planets. He published his results in De Motu Corporum (1684). This contained the beginnings of the laws of motion that would inform the Principia: *The Philosophiae Naturalis Principia Mathematica* (now known as the Principia)

was published on 5 July 1687). In this work Newton stated the three universal laws of motion that were not to be improved upon for more than two hundred years. He used the Latin word gravitas (weight) for the force that would become known as gravity, and defined the law of universal gravitation.

Note: Newton's laws of motion, as you shall see later in the book, prove invaluable to understanding the nature of our universe, space, matter and time and his laws give us an insight into the physical nature of gravity and the mechanism by which it works. In every scientific theory there is a cornerstone of truth which holds the whole together, it took many months of searching while writing this book to find a cornerstone of truth on which the quantum gravitational theory expressed in the later chapters holds true, and to my surprise and delight, it was Newton's laws of motion, specifically his second law, written some four hundred years earlier which became the cornerstone.

Newton's law of universal gravitation

Newton's law of universal gravitation states the following:

Every mass object in the Universe attracts every other mass object with a force directed along the line of centres of mass for the objects.

The force between two masses is proportional to the product of their masses and inversely proportional to the square of the separation between the centres of mass of the two objects.

Given that the force is along the line through the two masses, the law can be stated symbolically as follows.

$$F = - G m_1 m_2 / r^2$$

Where:

F is the magnitude of the (attractive) gravitational force between two objects,

G is the universal gravitational constant: $G = 6.673 \times 10^{-11}\ Nm^2kg^{-2}$,

m_1 and m_2 are the masses of first and second object,

and r is the distance between the objects.

It can be seen that this force F is always negative, and this means that it is always an attractive force unlike other forces in the universe, electrostatic and magnetic, which can be both attractive and repulsive. The gravitational attraction between the masses is proportional to the

product of the masses of each object, but there is an inverse square relationship with the measured distance between the centres of the masses.

If the masses m_1 and m_2 are doubled the force increases: $2 \times 2 = 4$ times

If the distance between the masses is doubled the force decreases:

$1/2 \times 1/2 = 1/4$ ie deceases 4 times

Gravity is classed as the weakest of the four known forces but it acts to infinity. The weight of an object on the surface of a planet is determined by the mass of the object and its location in the planet's gravitational field:

$$\text{Weight of an object} = mg$$

Where 'm' is the mass of the object and 'g' is the gravitational field strength on the surface of the planet:

$$\text{Gravitational field strength } g = GM/r^2$$

Question: what is the magnitude of the gravitational field strength 'g' at the surface of the Earth?

Answer: If M is the mass of the planet Earth, then, for the surface of the Earth the gravitational field strength 'g' is:

$$\text{Weight} = m \times GM/r^2$$

$$= 6.67259 \times 10^{-11} Nm^2Kg^{-2} \times 5.976 \times 10^{24} kg/(6.378 \times 10^6 m)^2$$

$$g = 9.802 \text{ N/kg (newtons per kilogram)}$$

Question: what is the magnitude of acceleration for a 1kg mass in free fall?

Answer: by Newton's Second Law of Motion:

$$\text{Acceleration} = \text{force/mass}$$

$$a = F/m = 9.802/1$$

$$a = g = 9.802 \text{ m/s}^2$$

$$\text{Acceleration of free fall } g = 9.802 \text{ m/s}^2$$

What this means is that near the Earth's surface a free falling mass, with no air friction, will increase its velocity by 9.802 m/s every second. We refer to this acceleration as 'g' - gravitational acceleration. This gravitational acceleration 'g' of 9.802 m/s^2 is a constant for all masses

in free fall no matter what the mass, for as we double the mass of an object, the gravitational force on it from the Earth doubles, so although the object is twice as difficult to accelerate, there is double the force, producing the same acceleration for all masses in free fall.

In free fall all objects fall at the same rate

To prove 'g' is constant for different masses try this little experiment:

1. Fall with air resistance: drop a coin and a small piece of paper together; the coin will hit the ground first because the air drag affects the paper more.

2. Free fall: Now place the small piece of paper on top of the coin to shield it from the air resistance and then drop the coin. Both hit the ground together!

This concept that light objects fall at the same rate as heavy ones was first demonstrated by Galileo Galilei (1564-1642): He is said to have dropped balls of different masses from the Leaning Tower of Pisa to demonstrate that their time of descent was independent of their mass (excluding the limited effect of air resistance). This was contrary to what Aristotle had taught: that heavy objects fall faster than lighter ones, in direct proportion to weight.

The Importance of Gravity

Gravity is a force which acts between any two masses, *anything that has mass (substance) has gravity*.

Gravity acts between all masses in the universe

It is the gravitational force which keeps a cup on a table, causes an object to fall, keeps the Moon and planets in orbit, and keeps the stars together in our galaxy the Milky Way. It is the force of gravity which powers the Sun and any other star.

Question: how does gravity power stars?

Answer: a star such as our sun tries to collapse under its own gravity; this creates enormous pressures and temperatures in the core of the Sun making it hot enough in the core to drive nuclear fusion. The surface temperature of the sun is 5,578K and in the core it reaches a staggering 15.7 million K.

These extreme conditions keep the processes of nuclear fusion of hydrogen into helium running - the result is the release of an enormous amount of energy.

G*ravity is the force which drives our universe*!

Newton's Weighty Problem

In Newton's world gravity was an accelerating force; the problem was by our every day experience we accelerate objects using contact forces, pushes or pulls; the strange thing about the gravitational force it *acts over a distance* with apparently nothing in between the gravitating masses.

Newton's Reservations about Gravity

It is important to understand that while Newton was able to formulate his law of gravity in his monumental work, he was deeply uncomfortable with the notion of 'action at a distance' which his equations implied. He never, in his words, 'assigned the cause of this power.' In all other cases, he used the phenomenon of motion to explain the origin of various forces acting on bodies, but in the case of gravity, he was unable to experimentally identify the motion that produces the force of gravity. Moreover, *he refused to even offer a hypothesis as to the cause of this force* on grounds that to do so was contrary to sound science. He lamented the fact that 'philosophers have hitherto attempted the search of nature in vain' for the source of the gravitational force, as he was convinced 'by many reasons' that there were 'causes hitherto unknown' that were fundamental to all the 'phenomena of nature.'

This fundamental phenomenon (the cause of gravity) is still under investigation and, although hypotheses abound, the definitive answer is yet to be determined.

Before we go on to theorize a possible cause and mechanism for gravity, let us discuss Einstein's view on gravity:

Albert Einstein's Gravity

Some two hundred years after Isaac Newton formulated his ideas of gravity Albert Einstein came on the scene. He was a German-born theoretical physicist who is still widely considered to have been one of

the greatest physicists of all time. While best known for the theory of relativity (and specifically mass-energy equivalence, $E=mc^2$), he was awarded the 1921 Nobel Prize in Physics 'for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect.' In popular culture, the name 'Einstein' has become synonymous with genius. In 1999 Einstein was named Time magazine's 'Person of the Century.' Einstein's many contributions included his special theory of relativity, where he concludes *all observers will always measure the speed of light to be the same no matter what their state of uniform linear motion is* and his general theory of relativity which extended the principle of relativity to include his *geometrical theory of gravitation*.

General relativity is currently the most successful gravitational theory, being almost universally accepted and well confirmed by observations. The first success of general relativity was in explaining the anomalous perihelion precession of Mercury. Then in 1919, Sir Arthur Eddington announced that observations of stars near the eclipsed Sun confirmed general relativity's prediction that massive objects bend light. Since then, many other observations and experiments have confirmed many of the predictions of general relativity, including gravitational time dilation, the gravitational red-shift of light, signal delay, and gravitational radiation. In addition, numerous observations are interpreted as confirming the weirdest prediction of general relativity, the existence of black holes. In Einstein's view gravity was not a force as formulated by Newton, but acceleration. His general theory dictates that:

> *A mass in empty space-time geometrically distorts the space-time around it resulting in an acceleration of all masses in the space-time gravitational field.*

In this theory, space-time is treated as 4-dimensional, the three dimensions of space and one of time, which is curved by the presence of mass, energy and momentum within it, the motion of objects being influenced solely by the geometry of space-time. I usually demonstrate the warping of space-time to my students by stretching a thin sheet of rubber over a wooden frame and placing different mass marbles in the centre. The bigger, more massive marbles cause more distortion. When a large marble is placed in the centre to represent a planet, a small marble at the edge of the sheet will promptly accelerate towards the large mass. If you're really skilled you can get the small marble to orbit the large one.

One of the defining features of general relativity is the idea that gravitational 'force' is replaced by geometry. In general relativity, phenomena that in classical mechanics are ascribed to the action of the force of gravity (such as free-fall, orbital motion, and spacecraft trajectories) are taken in general relativity to represent inertial motion in a curved space-time. So what people standing on the surface of the Earth perceive as the 'force of gravity' is a result of their undergoing a continuous physical acceleration. Their experience of weight is caused by the mechanical resistance of their accelerated motion by the surface on which they are standing. It is the curvature of space-time paths that objects in inertial motion follow i.e. 'deviate' or 'change direction' over time.

This deviation appears to us as acceleration towards massive objects, which Newton characterized as being gravity. In general relativity however, this acceleration or free fall is actually inertial motion. Objects in a gravitational field appear to fall at the same rate due to their being in inertial motion while the observer is the one being accelerated. This identification of free fall and inertia is known as the: Equivalence principle. The relationship between the presence of mass, energy, momentum and the curvature of space-time is given by the Einstein field equations.

The symbolic form:

$$G\mu\nu = 8\pi T\mu\nu$$

This elegant symbolic formulation of Einstein's general theory of relativity cannot be used for actual calculations, but it clearly shows the principle that 'matter tells space-time how to curve, and curved space tells matter how to move' (John Wheeler, Princeton University and the University of Texas at Austin) . The left side of the equation contains all the information about how space is curved, and the right side contains all the information about the location and motion of the matter. General relativity is beautiful and simple (to a physicist), but mathematically it's very complicated and subtle.

The actual shapes of space-time are described by solutions of the Einstein field equations.

Summary

1. Mass, energy, and momentum curves space-time (creates a gravitational field)

2. Objects in free-fall follow the contours (paths) of curved space-time

3. This motion of change in direction over time appears to us as acceleration towards a massive object - what we call gravity

4. All objects in curved space-time accelerate at the same rate.

Newton and Einstein Views of Gravity

Newton's laws of motion work very well for anything moving at much less than the speed of light. His law of gravity works very well for any place of weak gravity such as in the solar system. Spacecraft sent to the distant planets in the solar system arrive at their intended destinations (barring mechanical problems) within a few minutes of the expected time even after travelling for billions of kilometres over several years. Scientists use Newton's laws to guide the spacecraft to its destination, but when things are moving very fast (at a significant fraction of the speed of light) we need Einstein's formulations on light and inertial motion and that space and time can be radically changed in a very strong gravitational field. In Einstein's universe, gravity is not really a force, but acceleration. While it is true that Einstein's hypotheses are successful in explaining the effects of gravitational forces more precisely than Newton's in certain cases, *he too never assigned the cause of gravity or its mechanism* in his theories.

Einstein's equations tell us that:

Matter tells space how to curve, and space tells matter how to move.

But this new idea, completely foreign to the world of Newton, does not enable Einstein to assign the *cause of this power* of a mass to curve space-time any more than the Law of Universal Gravitation enabled Newton to assign its cause. Let us look at Newton's own words on the cause of gravity:

'I wish we could derive the rest of the phenomena of nature by the same kind of reasoning from mechanical principles; for I am induced by many reasons to suspect that they may all depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are either mutually impelled towards each other, and cohere in regular figures, or are repelled and recede from each other; which forces being unknown, philosophers have hitherto attempted the search of nature in vain. If science is eventually able to discover the cause of the gravitational force.'

In a way his wish came true, Einstein described the motion of objects and gravity more accurately, but did not assign a cause to gravity or its mechanism, yes mass warps space-time which we see as acceleration, but why exactly does a mass warp space time and what physical meaning does this pertain to? If a gravitational field is distorted space and distorted time, what exact physical change occurs?

We cannot simply accept that there is a distortion of the dimensions of space-time, without knowing exactly the fundamental physical structure of such dimensions and the mechanism by which a matter particle changes this physical structure. Our understanding of space-time distortion cannot be left as a pure mathematical description, it needs substance.

We need an actual physical cause of gravity other than it is just mass and it is with an understanding of *why a mass creates a gravitational field* that we ourselves may one day be able to create or modify such a field. We have already discussed the fact that in Einstein's mass-energy equivalence that mass and energy are interchangeable, that matter is condensed electromagnetic energy which can be released as electromagnetic radiation and it is here in the nature of matter itself that we may find nature's mechanism for a mass to generate a warped space-time i.e. the cause of a gravitational field.

Some Important Gravitational Effects of Space-Time Curvature

The following important effects can be used to detect the presence of a gravitational field *and* more importantly can be used to test a theoretical model for the actual mechanism of gravity:

1. Gravitational red-shifting of light

The wavelength of light increases (become 'redder') as it moves from a strong gravitational field to a weaker one. If you were to shine a blue beam of light upwards from the surface of a planet, where the gravitational field is strongest, as it moves upwards to where the gravitational field becomes increasingly weaker, the light would change colour - become redder. This is because the wavelength gets longer:

Question: why is the wavelength shorter in a gravitational field?

Answer: According to Einstein's General Relativity theory: In a gravitational field the dimensions of space-time are squashed along the vertical lines of the radial gravitational field.

This gravitational red shift *needs* a *physical explanation* and one that is based on solid classical and modern quantum physics. We cannot simply accept that the dimension of *empty space* is squashed, what exactly is squashed? How can you squeeze empty space? Part of the answer to this must be that empty space is not empty at all!

Space must have substance!

And since a ray of light leaving a gravitating mass increases in wavelength (gets redder), then:

A strong gravitational field must be 'optically' denser than a weak gravitational field.

This brings us immediately back to the notion of 'action at a distance,' such as gravity acting over empty space, a concept that Newton was uncomfortable with. The notion that geometrical space may indeed have substance Einstein himself acknowledged later on in his life. Here is a quote from his address delivered on May 5th, 1920, in the University of Leyden:

'Recapitulating, we may say that according to the general theory of relativity space is endowed with physical qualities; in this sense, therefore, there exists an ether. According to the general theory of relativity space without ether is unthinkable; for in such space there not only would be no propagation of light, but also no possibility of existence for standards of space and time (measuring-rods and clocks), nor therefore any space-time intervals in the physical sense. But this ether may not be thought of as endowed with the quality characteristic of ponderable media, as consisting of parts which may be tracked through time. The idea of motion may not be applied to it.'

2. Time Dilation

A gravitational field distorts the time dimensions of space-time. Clocks run slower in a strong gravitational field compared an observer in a weak gravitational field. The clock at the top of a mountain will run faster than a clock at sea level. Clocks in satellites in orbit around the Earth have to compensate for the time difference with clocks running on the Earth's surface. Similarly, there must be a *physical*

reason for this time dilation and part of the answer lies in what we have already reasoned:

Gravitational fields slow down the speed of light

And since light governs time:

Gravitational fields must slow down time

Linking this back to what we said before: that empty space must have substance, it is this substance of empty space that is responsible for Einstein's gravitational General Theory effects on space-time.

3. The Shapiro Delay

The Shapiro time delay effect, or gravitational time delay effect, is one of the four classic solar system tests of General relativity. Radar signals passing near a massive object take slightly longer to travel to a target and longer to return (as measured by the observer) than it would if the mass of the object were not present. Signals (including light) will take longer than expected to move through a gravitational field. Dr. Shapiro was the first to make use of a previously forgotten facet of Einstein's relativity theory - that the speed of light is reduced when it passes through a gravitational field. The stronger the gravitational field the slower the speed of light.

This is similar to the reduction of the speed of light discussed earlier (refraction) when light travels through a more optically dense medium.

It seems therefore, that a gravitational field acts exactly like a transparent medium which affects the speed of light and hence time.

For example: due to the presence of the Sun's gravitational field, a radar signal travelling from the Earth to Venus and back, would have a delay of about 200 microseconds. The standard explanation for time delay in the Shapiro effect is given below:

The speed of light in meters per given interval of 'proper time' is a constant, however the travel time of *any* electromagnetic wave, or signal, moving at 299,792,458 meters per 'second' can be affected by the gravitational time dilation in regions of space-time through which it travels. This is because the coordinate time and proper time diverge as the gravitational field strength increases. The time delay (Δt) is directly

proportional to the mass (M) of the object which distorts the space-time. This is what Einstein said about the Shapiro delay:

'In the second place our result shows that, according to the general theory of relativity, the law of the constancy of the velocity of light in vacuum, which constitutes one of the two fundamental assumptions in the special theory of relativity and to which we have already frequently referred, cannot claim any unlimited validity. A curvature of rays of light can only take place when the velocity of propagation of light varies with position. Now we might think that as a consequence of this, the special theory of relativity and with it the whole theory of relativity would be laid in the dust. But in reality this is not the case. We can only conclude that the special theory of relativity cannot claim an unlimited domain of validity ; its results hold only so long as we are able to disregard the influences of gravitational fields on the phenomena (e.g. of light).' - Albert Einstein (The General Theory of Relativity: Chapter 22 - A Few Inferences from the General Principle of Relativity.)

Following on from our previous deductions it seems that so far these physical effects of geometric warped space-time in Einstein's General Relativity can be explained by known classical effects in physics:

a. *A space-time behaves like a transparent medium with optical mass-energy density and it is this energy density of the fabric of space-time which limits the speed of light to a constant (c).*

b. This 'optical' medium of space is more energy dense near the surface of a gravitating mass and less dense away from the mass.

c. There must be an energy density curvature of this optical medium around a gravitating mass which decreases as an inverse square law away from the mass – thus following exactly Newton's inverse square law for gravity and Einstein's curvature of space time.

Summary

It is this changing density of the medium of space which is responsible for changes in the speed of light in a vacuum, and since the speed of light governs time, this explains the time dilation in a gravitational field and thus the Shapiro Effect. The changing density of the medium of space also explains the wavelength changes in

gravitational red shift by simple refraction through optically different density media.

4. Bending of light

When light passes through a gravitational field it follows a curved path. This we can now see as the process of refraction through the substance of empty space, around the planet where gravity is strongest, the optical medium of space must be more dense causing a light ray to be bent (refracted) inwards in a curved path – just like the process of refraction in mirage formation where light is curved upwards: as the light passes through less dense (hot air) near the ground through to more dense (cold air) high above the ground it curves from less dense in towards more dense air. This refractive curvature of light is caused by its reduction in speed through the medium.

5. Gravitons

According to quantum mechanics, gravitational radiation must be composed of quanta (particles of mass-energy) called gravitons. General relativity predicts that these will be spin -2 particles. They have not yet been observed.

6. Acceleration

In a gravitational field all objects fall (accelerate) at the same rate, their acceleration is independent of mass. The time period of swing of a pendulum in a gravitational field is independent of the mass, this is a good test for gravity, and any change in the gravitational field strength can alter the time period of a pendulum. In a stronger gravitational field the pendulum will oscillate faster.

In essence we understand the properties of a gravitational field and can predict using Einstein's general theory and his equations its effects very accurately, but thus far we have no explanation as to why a mass distorts space-time or in the light of the above conclusions we can more correctly say: why a mass distorts (changes) the optical energy density of space-time. We must now take a quantum leap into the world of sub-atomic particles, for if we can understand the true nature of matter we may understand why it generates the curvature of space-time.

CHAPTER 4

The Fundamental Nature of Matter

Its threefold nature

After the Big Bang the early universe was filled with massive clouds of hot hydrogen gas and during expansion local areas of hydrogen became cooler and denser and under the attractive force of gravity, between the hydrogen atoms, the clouds collapsed to form stars. This seems like a good place to start our exploration of why a matter particle affects the optical energy density of space, thus warping the space-time matrix; even the smallest part of an element, an atom, has gravity, so it makes sense to start with the simplest, the hydrogen atom.

Atomic Structure - The Hydrogen Atom

The simplest type of atom is hydrogen which consists of a single positively charged proton in its central nucleus with a single negatively charged electron in orbit around it. This wonderful basic unit of matter is intriguing, somehow this simple hydrogen atom produces its own gravitational field, because it has mass – it curves space-time, but what is its mechanism? Let us examine the hydrogen atom in more detail:

Mass of a hydrogen atom: 1.673×10^{-27} kg

The diameter of the hydrogen atom is about: 1.06×10^{-10}m

The size of the nucleus is about: 10^{-15} m

The nucleus is 100,000 times smaller than the size of the whole atom and contains most of the mass of the atom in a very small space, it is extremely dense.

Question: what is the density of a hydrogen nucleus and how does it compare to the density of steel?

Answer: Density = Mass/Volume

Density of nucleus = mass of proton/volume of proton

$$\text{Density} = \text{Mass}/(4/3\pi r^3)$$

$$= 1.673 \times 10^{-27}\text{kg}((4/3\pi \times (0.0503 \times 10^{-15}\text{m})^3)$$

$$\text{Density of hydrogen nucleus} = 9.86 \times 10^{21}\text{kg/m}^3$$

The density of steel is: 7.850×10^3 kg/m^3

Therefore the nucleus of a hydrogen atom is a thousand billion times denser than steel.

The electron is only 1/1800 times the mass of the proton. It was once thought that the electron orbits the nucleus much like a planet orbits the sun, as a mass particle. This was a simplistic view of the structure of the atom

Bohr Quantum Model of Atom and Electron Orbital Energies

It was known that hydrogen atoms emit specific wavelengths (colours) of light after being excited. In 1913, Neils Bohr, focusing on the particle properties of electrons, constructed a quantum model to explain this. He proposed that electrons orbited the nucleus at specific radii, also called energy levels. Electrons required specific (quantized) amounts of energy to move from one energy level to another, and emitted characteristic amounts of energy when returning to the ground-state energy levels. His model predicted that electrons were more tightly bound when they were closer to the nucleus and that atoms emitted energy when electrons dropped energy levels, moving towards the nucleus. In other words, when an electron is given extra energy (excited) it jumps from its lowest energy state (ground state or lowest orbital) to a higher energy level. This extra energy can come from the atom absorbing a photon (packet) of electromagnetic energy of a specific wavelength (frequency/energy). The electron stays in this high energy state for a fraction of a second and then drops back to a lower energy state/orbital - as it does so it emits the extra energy as a photon of light.

Each energy jump corresponds to a specific amount of energy (quantum) E. Each quantum of energy is emitted as a photon of light at a specific wavelength (colour). These specific emissions are seen as line spectra in a spectrometer.

The energy of a photon of light can be calculated using Planck's equation:

$$\text{Energy Quantum of photon} = \text{Plank's constant (h)} \times \text{frequency of photon (f)}$$

$$E = h f$$

Where $h = 6.626 \times 10^{-34}$ Js

Question: how much energy is needed to jump free an electron from the hydrogen nucleus?

Answer: the measured value (ionization energy) is equal to 13.6 electron volts.

Question: how much is 13.6 electron volts equal to in joules and what wavelength of light carries this amount of energy in a photon?

Answer:

$$1eV = 1.6 \times 10\text{-}19J$$

$$\text{Therefore } 13.6 \text{ eV} = 13.6 \text{ eV} \times 1.6 \times 10\text{-}19 \text{ J/eV}$$

$$= 2.176 \times 10\text{-}18 \text{ J}$$

This is equivalent to a photon of wavelength:

$$\text{Since } E = hf \text{ and } c = f\lambda$$

$$\text{Then } E = hc/\lambda$$

$$\text{Therefore wavelength } \lambda = hc/E$$

$$= (6.626 \times 10^{-34} \text{ Js} \times 3 \times 10^{8} \text{ m/s}) / 2.176 \times 10^{-18} \text{ J}$$

$$= 9.135 \times 10^{-8} \text{ m}$$

$\lambda = 91.35$ nano-metres (ultra-violet)

This is the highest energy transition the hydrogen electron can make. If an electron in the ground unexcited state absorbs a photon of this wavelength (U.V.) it will free itself from the electrostatic grip of the nucleus. With a lot of assumptions and adjustments, the Bohr Model fits hydrogen pretty well, but failed for all other atoms. It was soon recognized that it was fundamentally wrong, and a new approach was needed. Today we understand that the electron 'orbits' the nucleus as an oscillating standing wave of electromagnetic mass-energy.

The Wave Mechanical Model

In the mid-1920s, Erwin Schrodinger, building on the dual nature of matter, began focusing on the standing wave-like properties of the

electron. So what is a standing wave? A good example of a standing wave is a guitar string. When a string is plucked it oscillates as a standing wave - we see the string oscillating up and down with maximum movement (amplitude) in the middle (antinode) of the string and minimum movement at the ends (node). The term standing wave is a little misleading, in fact if you could video the string and play it back in slow motion you would see two waves going up and down the string and being reflected at both fixed ends of the string. When these two waves meet in the middle they add their energy to each other, this is why you see maximum amplitude in the middle. The reason it is called a standing wave, is because it is moving between fixed points - staying in one place. The natural frequency at which the string oscillates is called the fundamental frequency and is equal to half a wavelength and is the lowest energy at which it can oscillate. The fundamental frequency (f_0) gives the fundamental wavelength (λ_0). Standing waves can oscillate at higher frequencies (harmonics):

By visualizing electrons as standing waves (like guitar strings) instead of 'orbiting' particles, the distinct energy levels observed by experiments could be explained. In the circumference of a circular electron standing wave only certain numbers of whole wavelengths are allowed (energy levels). Other ones result in destructive interference and are not 'allowed.' Using this idea, Schrodinger developed a mathematical model based on wave mathematics to describe the position of electrons in an atom.

For the hydrogen atom:

Electron wave resonance n = 1

First orbital where the wavelength equals the circumference of the circular standing wave:

$$\lambda_1 = 2\pi r_1$$

Electron wave resonance n = 2

Second orbital where the wavelength equals the circumference of the circular standing wave:

$$2\lambda_2 = 2\pi r_2$$

Electron wave resonance n = 3

Third orbital where the wavelength equals the circumference of the circular standing wave:

$$3\lambda_3 = 2\pi r_3$$

For a given atom, Schrodinger's Equation has many solutions, and these different solutions (energy levels) are called orbitals. These orbitals do not describe actual orbits like Bohr's model, but, instead, solutions to a mathematical equation. The standing wave model diagram is a visualization of why, if electrons have wave-like properties like wavelength, only certain orbitals are allowed. It is not meant to say that electrons move in wavy orbits around the nucleus - they oscillate around the nucleus as a standing wave of electromagnetic energy. This idea that the electron particle (with mass) can behave like a wave is called wave-particle duality.

Wave-Particle Duality Nature of Matter and Light

We have already said that a photon (packet) of light, an electromagnetic wave, has a specific amount (quantum) of energy - in this way it can be thought of as a particle. But particles such as electrons can also behave as waves. De Broglie showed that electrons can be diffracted - spread out like a wave when passed through small gaps. Diffraction is one of the properties of waves. He derived an equation to calculate the wavelength (De Broglie Wavelength, λ_b) of a moving particle using Planck's constant (h) and the object's momentum (mv, mass x velocity):

De Broglie Wavelength

= Planck's constant (h) /momentum (mv)

$$\lambda_b = h/mv$$

So particles (electrons) can behave as waves and waves (photons) can behave as particles. This wave-particle duality for waves and the particle-wave duality for particles reveals to us the true nature of matter and energy, matter particles behaves as waves and waves behave as matter particles, this makes sense since we have already shown the electromagnetic nature of mass-energy, remembering this energy is

electromagnetic light. This reinforces the concept that matter is condensed stationary waves of electromagnetic mass-energy.

Therefore, since matter (mass) is a standing wave of electromagnetic energy

and light electromagnetic energy is a free moving wave.

It is not difficult to see how matter can be transformed

into energy (light) and vice versa.

This is Einstein's mass-energy equivalence, now $E = mc^2$ makes sense.

Students of physics sometimes ask, 'why c squared?' The simple answer is that the left hand side of the equation is units of energy, so the right hand side of the equation must reduce to units of energy and for this to happen we have to have speed squared. In terms of the fundamental physical reason, it may be something to do with the fact that the energy of a wave is proportional to the amplitude of a wave squared or the fact that the wave has both, electric field energy and magnetic field energy.

Summary for Wave-Particle Duality

Plank's equation describes light as a quantum (particle) of energy:

$$E = hf$$

The left hand side of the equation (E) a quantum (packet) of energy shows that a photon is a particle; the right hand side which includes wave frequency reminds us that it is also a wave – a photon of electromagnetic light is a wave packet.

De Broglie's equation describes particles as waves:

$$\lambda_b = h/mv$$

The momentum (mv) on right hand side of the equation reminds us that it is really a particle and the left side with wavelength shows us that a particle is also a wave.

Question: what is the De Broglie wavelength for an electron?

Answer: assuming the velocity for an electron in oscillatory orbit around the nucleus is the *speed of light* (c):

$$\lambda_b = h/mv$$

$$= 6.626 \times 10^{-34}\text{Js} / (9.11 \times 10^{-31}\text{kg} \times 3 \times 10^{8}\text{m/s})$$

$$\lambda_b = 2.424 \times 10^{-12}\text{m}$$

A size, which puts it exactly in the right place in orbit in the atom: bigger than the size of the nucleus (10^{-14}m) and smaller than the diameter of the atom (10^{-10}m). The electron fits as a standing wave. If we assume the electron is in a circular orbit where the wavelength equals the circumference then the radius of the orbit:

$$\text{Radius} = \text{circumference}/2\pi$$

$$= 2.424 \times 10^{-12}\text{m}/2\pi$$

$$r = 3.859 \times 10^{-13}\text{m}$$

Therefore, a diameter equal to 7.72×10^{-13}m. This fits well for our model of the atom. We have seen already that mass and energy are interchangeable and that matter is really a standing wave of electromagnetic light energy, atoms can absorb electromagnetic wave energy as a photon which increases the orbital energy of the electron. In this case the matter particle absorbing the photon as increased its mass by:

$$\text{Since } \Delta E = mc^2$$

$$m = \Delta E/c^2$$

$$\text{And since } \Delta E = h\Delta f$$

Then this mass increase due to photon absorption is:

$$m = h\Delta f/c^2$$

This is energy-mass conversion, free electromagnetic wave energy travelling at the speed of light, becoming a standing wave of electromagnetic energy. Similarly the electron drops back down from a high energy state to a lower one and emits a photon packet of electromagnetic wave energy, a standing electromagnetic wave to a free one travelling at c. So by $E = mc^2$ we see that mass energy conversions are:

Light Energy to Matter: Is equivalent to: free electromagnetic wave travelling at c becoming a condensed standing electromagnetic wave.

Matter to light energy is the converse of this: this is a mass (standing electromagnetic wave energy) to free energy (electromagnetic wave

packet of energy). This demonstrates that mass-energy conversions are really conversion of the mode of propagation of 'light' waves from 'free wave' to 'standing wave' and vice versa.

EXERCISE

Deriving an Equation which describes Mass-Energy Conversions

Continuing on the theme of mass-energy equivalence and wave-particle duality I recall that one afternoon while teaching three physics students about quantum mechanics and the wave-particle duality nature of light and matter, an interesting thing happened. I had just put the two equations on the board to summarize the particle nature of light and the wave nature of matter:

$$\text{Plank: } E = hf \quad (1)$$

$$\text{De Broglie: } \lambda_b = h/mv \quad (2)$$

When one of my students asked if there was an equation which linked the two? My excited reply was: 'Let's see, shall we?' We noticed that Planck's constant was in both equations, so the equations could be rearranged in terms of (h) and then equated:

$$\text{Plank: } h = E/f \quad (3) \qquad \text{De Broglie: } h = \lambda_b \times m \times v \quad (4)$$

$$\text{Since } h = h$$

$$E/f = \lambda_b \times m \times v \quad (5)$$

To equate particle and wave we need the velocity (v) to equal the speed of light (c) so:

$$\text{Let } v = c \quad (6)$$

Substituting v with c in equation (5) we get:

$$E/f = \lambda_b \times m \times c \quad (7)$$

Now from the wave speed equation we know that:

$$v = f \times \lambda \quad (8)$$

For light v = c the speed of light, so:

$$c = f \times \lambda \quad (9)$$

Rearranging equation (9) gives:

$$\lambda = c / f \quad (10)$$

Now we substituted equation (10) back into equation (7):

$$E/f = c/f \times m \times c$$

Seeing this derived equation I was very excited about where this exercise had led to and asked my students if they realised what this equation means, one of them did.

We cancelled the f on both sides and were left with:

$$E = c \times m \times c$$

Giving:

$$\mathbf{E = m c^2}$$

Einstein's mass-energy equivalence! Highly excited we thought back to where we started: Einstein's equation of mass-energy equivalence ($E = mc^2$) links the two equations which define particles (mass) as waves (energy) and waves (energy) as particles (mass) - it all makes sense!

The Fundamental Equation

There is something fundamental about Einstein's mass energy equation $E = mc^2$, what exactly does it mean that the electromagnetic light energy (E) is equivalent to the mass times the speed of light squared. Why squared? Why does light in matter have mass? Light in itself has no mass only energy? A photon of light has no *rest mass* (as do particles) but it does have mass-energy! If we are to understand gravity and its mechanism we need to delve deeper into the very nature of matter, let's start with the equation by looking at the terms in $E = mc^2$.

Fundamental electromagnetic energy (E) of the wave by Planck's equation ($E = hf$) is directly proportional to the frequency (f) of the wave, if we double the frequency of the wave we double its mass-energy.

Fundamental mass (m) we say is a measure of how much matter there is – the standing electromagnetic energy waves (matter particles).

Fundamental speed of light (c) is the wave speed of both the free wave (light) and the standing wave i.e. matter, light always travels at the

same speed, whether it's a free wave through the vacuum of space or oscillating at the speed of light in matter.

There are two important fundamental constants which give us the speed of light:

1. The constant of magnetic fields:

u_0 The permeability of free-space =

$4\pi \times 10^{-7}$ Wb A^{-1} m^{-1}

This constant determines the strength of a magnetic field in a particular medium, in this case the space vacuum. For example the magnetic field strength around a current carrying conductor:

Magnetic field strength $B = u_0(N/L)I$

Where:

N is the number of turns of wire around the electromagnet

I is the current in amperes

L is the length of the magnetic circuit

2. The constant for electric fields:

ε_0 The permittivity of free-space

$= 8.8542 \times 10^{-12}$ Fm^{-1}

This constant determines the strength of an electric field in a medium. For example the electric field strength around a point charge:

Electric field strength per unit charge:

$$E = Q/(4\pi \varepsilon_0 r^2)$$

Where:

Q is the charge of the particle creating the electric field in Coulombs (C)

r is the distance from the particle with charge in metres (m)

What is interesting about these constants (of the space vacuum) is that they determine the speed of light (c)!

$$c^2 = 1/u_0\varepsilon_0$$

Let's take another, very revealing, look at matter: By Einstein's equation $E = mc^2$

$$\text{Mass (m)} = E/c^2$$

Mass is energy per light speed squared!

Substituting the electric and magnetic constants we have:

$$\text{Mass} = Eu_0\varepsilon_0$$

This makes sense since matter is made out of electric and magnetic light wave energy; it shows us the electric and magnetic nature of matter. Now let us substitute the E using Planck's equation E = hf and we get:

$$\mathbf{Mass = hfu_0\varepsilon_0}$$

Considering the mass of a particle such as the electron:

$$\mathbf{m_e = hfu_0\varepsilon_0}$$

This is a highly revealing equation about matter! It tells us that not only that matter electromagnetic in nature (the constants $u_0\varepsilon_0$), but that matter is a wave of frequency (f). But the most startling thing in this equation, and the most revealing about the nature of matter, is it that it contains Planck's constant (h).

Mass which creates a gravitational field is

electromagnetic in nature.

Summary

1. Electromagnetic waves have an oscillating electric and magnetic field which propagates (travels) at the speed of light.

2. Matter and light energy (electromagnetic waves) are interchangeable by $E = mc^2$.

3. Newton: Gravity is the force of attraction between massive particles.

4. Gravity is acceleration due to a mass curvature of space-time.

5. Mass (matter) is made up of standing waves of electromagnetic energy.

6. An electron around an atom is a standing wave of electromagnetic energy.

7. The mass particles can be defined by the fundamental mass equation:

$$\mathbf{m_p = hfu_0\varepsilon_0}$$

CHAPTER 5
The Trouble with Matter

Having delved into the structure of matter and seen mass as a standing wave of electromagnetic light energy we now explore the quantum world of sub-atomic particles. This journey will lead us to some interesting conclusions about the very nature of matter and mass energy equivalence.

The Fundamental Structure of Matter

We understand that the atom is made up of electrons in 'orbit' as stationary electromagnetic waves around a central positively charged nucleus and that this nucleus is extremely small compared to the size of the atom and extremely dense. Here the positively charged protons balance out the negatively charged electrons making the atom (and matter) electrically neutral. The nucleus itself contains particles called nucleons. There are two types of nucleons:

Protons and Neutrons

The proton is positively charged (+1) i.e. we say it has positive unit charge, but the neutron has no net charge (0). Originally it was thought that the electron, proton and neutron were fundamental i.e. the smallest parts of matter, but in modern physics we now know that the proton and neutron are made up of other 'particles.' Collisions of these 'fundamental' particles in high energy particle accelerators have shown us that the proton and neutron have sub-structure – lumpiness! Their mass and charge are not evenly distributed into a perfect sphere.

Deep inelastic scattering experiments, where particles are smashed into each other at near light speeds provided the evidence that protons and neutrons were made up of smaller more fundamental 'particles.' Deep inelastic scattering is the process used to probe the insides of heavy particles (hadrons, such as protons and neutrons), using electrons, and closely related muons and neutrinos (leptons, light particles). The results of these experiments provided the first

convincing evidence of the reality of quarks, which had previously been thought to be a purely mathematical phenomenon.

Analysis of the results of these experiments led to the following conclusions:

a. The hadrons (heavy particles) do have internal structure.

b. In baryons (protons and neutrons), there are three points of deflection i.e. baryons consist of three quarks.

c. In mesons, there are two points of deflection (i.e. mesons consist of a quark and an anti-quark.

Quarks appear to be point charges, as electrons appear to be, with fractional charges.

There are six types of quarks known: up, down, strange, charm, truth, and beauty. Each type of quark carries a specific fractional charge:

Up +2/3

Down -1/3

Charm +2/3

Strange -1/3

Top +2/3

Bottom -1/3

All of these quarks have spin ½. The proton is composed of two up quarks (u) and one down quark (d) bound together by the strong nuclear force and the neutron is composed of one up quark and two down quarks. By adding the charges of individual quarks together, we can show the charges of the nucleons they compose.

Quarks can compose particles other than protons or neutrons. However, these particles are very exotic and rare. They also usually have very short lives; they often decay after less than a second.

A proton is composed of uud (up-up-down) quarks and a neutron is made up of udd (up-down-down) quarks:

Proton charge = charges of its components added = (+2/3) + (+2/3) + (-1/3) = +1

Neutron charge = charges of its components added = (+2/3) + (-1/3) + (-1/3) = 0

Single quarks have never been observed and it is believed that quarks must exist in pairs or triplets. Quarks are thought to be fundamental particles (like electrons), which means that nothing smaller composes them. This is not proven, however and physicists believe it is possible that quarks are also composed of smaller particles. This I consider unlikely as I will explain later. Besides quarks which make up ordinary matter, there are anti-quarks (with opposite charge and 'spin') which make up anti-matter.

Antimatter

You may have watched the American TV series, *Star Trek*. The characters talk about anti-matter as the source of power for the ship. In the core of the *Warp Drive* of the Star Ship Enterprise, they mix matter and anti-matter together to provide the enormous amount of energy needed to drive the mighty warp engines. These warp engines drive the space ship at light speeds and greater by warping space and time around the ship – they ride an artificially generated gravitational wave!

So why does the mixing of matter and anti-matter provide energy? Well, it turns out that anti-matter isn't just science fiction. Anti-matter is actually science fact. But, what is it? Simply put, anti-matter is the opposite of normal matter. For every 'normal' particle of matter there is an opposite, anti-particle. There are anti-electrons, which are just like electrons but instead of a negative charge, they carry a positive charge. They are called positrons. There are anti-quarks with opposite charge to normal quarks. There are anti-protons and anti-neutrons, which are composed of anti-quarks that are just like real quarks, but have opposite properties. Anti-protons are negatively charged instead of being positively charged:

An anti-proton (-1 charge) is made up of two anti-up quarks and one anti-down quark: $(-2/3) + (-2/3) + (+1/3) = -1$

An anti-neutron (0 charge) is made up of two anti-down quarks and one anti-up quark: $(-1/3) + (-1/3) + (+2/3) = 0$

Anti-neutrons are neutral, just like normal neutrons, but have the opposite spin of a regular neutron. The anti-electrons called positrons have a positive charge. But these antimatter particles are short lived - they are soon annihilated by normal matter.

Matter Verses Antimatter

Whenever anti-matter comes in contact with matter,

both masses convert directly into electromagnetic energy, gamma rays, in a violent explosion.

Anti-particles do not last long on earth because they almost instantly annihilate themselves on meeting matter particles. However, their presence has been recorded in specially designed machines whose purpose is to create anti-matter, among other things. Antimatter-matter annihilation is the only way known for atoms to completely convert to energy – a pure mass-energy conversion. It could be a possible energy source in the future. If a 1/2 kilogram of anti-matter could be created and stored, it could be combined with a 1/2 kilogram of regular matter to release the amount of mass-energy equivalent to 1 kilogram.

Question: how much energy would be released if ½ kg of matter annihilated ½ kg of anti-matter?

Answer:

$$E = m\ c^2$$

$$= 1\text{kg x ((300,000,000m/s) squared))}$$

$$\text{Energy released} = 90{,}000{,}000{,}000{,}000{,}000 \text{ Joules of energy}$$

This is an enormous amount of energy from 1 kg of matter/anti-matter fuel! *This amount of energy could run a 1000 Watt electric motor for 5.7 million years!* However, no one knows how to make that much antimatter and if we could, how could it be stored, certainly not in a container made of normal matter. In Star Trek and the *Starship Enterprise* – the anti-matter is contained by magnetic containment so that is does not touch the matter container walls.

Matter verses anti-matter - Annihilation

When a particle and anti-particle come together they annihilate each other and release their mass-energy as two electromagnetic gamma ray photons. For example, this happens if an electron and an anti-electron meet or a proton and anti-proton. What is interesting about this mass to energy conversion is that:

From these two mass particles, which as we have seen are standing waves of electromagnetic energy, come two electromagnetic gamma light rays travelling at the speed of light.

Matter is made into light!

So annihilation is when a particle collides with an anti-particle where the electromagnetic energy is released as two gamma waves. It is these two high frequency gamma waves which is the released energy. Let us do some maths.

Question: what is the frequency and wavelength of the emitted gamma rays when an electron and anti-electron (positron) collide?

Answer: since both the electron and anti-electron have the same mass (but opposite charge) and produce 2 gamma ray photons, we calculate the mass-energy transformation for one particle:

Mass of electron (m_e) = 9.11×10^{-31} kg

By Einstein's mass-energy equivalence equation in annihilation this will produce an amount of energy (E):

$$E = mc^2$$

$$= 9.11 \times 10^{-31} \text{ kg} \times (3.0 \times 10^8 \text{ m/s})^2$$

The energy of the gamma photon

$= 8.199 \times 10^{-14}$ Joules of energy

(This is equivalent to 0.51MeV)

Now using Planck's equation (E = hf) we can calculate the frequency of a photon with this amount of electromagnetic energy:

$$E = hf$$

Therefore: $f = E/h$

$$= 8.199 \times 10^{-14} \text{ J} / 6.63 \times 10^{-34} \text{ Js}$$

Frequency of the gamma photon = 1.237×10^{20} Hertz (waves per second)

This frequency shows that it is in the gamma radiation part of the electromagnetic spectrum. Now let us calculate the wavelength (λ) of this photon using the wave speed formula $v = f\lambda$:

Where c is the speed of light

$$c = f\lambda$$

Therefore:

$$\lambda = c/f$$

$$= (3 \times 10^8 m/s)/(1.2367 \times 1020Hz)$$

Wavelength of the gamma photon = 2.426×10^{-12} m!

Question: do you see something familiar about the wavelength of the gamma wave that has come from the annihilation of the electron?

Answer: It is the same wavelength as the standing wave electron around an atom, the De Broglie wavelength.

Matter from Light - Pair Production

Now there is a phenomenon in nature which is the exact opposite of mass to energy annihilation: Pair Production. Pair production can occur when two gamma wave photons of sufficient energy (frequency) meet to produce two particles, one of matter the other of anti-matter, such as an electron and positron. If the gamma rays have sufficient energy they can create heavier particles such as a proton and anti proton.

This is energy into mass conversion

Light is made into matter!

The photon need only have a total energy of twice the electron mass (i.e. 1.02 MeV) for this to occur, if it is much more energetic, heavier particles may also be produced. Gamma-ray photons with energy greater than 1.02 MeV may interact with a nucleus to form an electron-positron pair. This amount of energy is just sufficient to provide the rest masses of the electron and positron (0.51 MeV each). Excess energy will be carried away equally by these two particles which produce ionization as they travel in the material. The positron is eventually captured by an electron and annihilation of the two particles occurs. This results in the release of two photons each of 0.51 MeV known as annihilation radiation. These two photons then lose energy by Compton scattering or the photoelectric effect.

Pair Production - matter out of electromagnetic light energy!

Pair production and annihilation are the most striking examples of mass-energy equivalence ($E = mc^2$)

Annihilation: Matter into light

Pair Production: Light into matter

In essence, matter, the standing wave, becomes light, the free wave and light, the free wave becomes matter the standing wave. This reinforces the true of the nature of matter:

Matter is made of light!

Summary

1. Electrons and quarks are fundamental particles of matter.

2. Matter and antimatter particles can annihilate each other releasing energy as gamma ray photons where:

Mass to Energy

Mass to Photon energy

$mc^2 = hf$

Standing electromagnetic wave to free electromagnetic wave

3. Gamma ray photons can collide and create matter and antimatter pairs:

Energy to Mass

Photon energy to Mass

$hf = mc^2$

Free electromagnetic wave to standing electromagnetic wave

4. Matter is a standing wave of electromagnetic energy and light is a free wave of electromagnetic energy – the two are interchangeable by $E = mc^2$.

5. Matter is made of light.

END OF PREVIEW