UNIT 1 THEORIES OF RELATIVITY

Contents

1.0 OBJECTIVES

Relativity has profoundly changed the whole physics. By the analysis of the fundamental concepts of space and time, of mass and of force, it has given a new orientation not only to science but also to our approach to philosophical problems in general. It is the theory which says that concepts like space, time, mass, simultaneity, motion etc., are not absolute but relative; absolute to frame of reference.

1.1 INTRODUCTION

The advent of the theory of relativity and of the quantum mechanics has revolutionized the whole domain of science. They questioned some of the age old concepts such as absolute motion, absolute space, absolute mass, wave nature of particles, unlimited perfectibility of experimental results etc. They brought in certain radically new concepts and gave new insights into several baffling phenomena in nature. Towards the end of the last century it became abundantly clear to scientists that the real trouble spots in scientific inquiry were in the fathomless depths of intergalactic space at the other end. Quantum mechanics arose in an effort to answer the problems hovering in the subatomic world and relativity in the 'ultra-giant' and 'ultra-fast' world.

To show the all pervasive importance and relevance of relativity in theoretical science of today, we give a few quotations from the leading writers. Thus H. Margenau writes, "In fact the theory is now so well corroborated by experience and by assimilation into the whole of modern physics that its denial is almost unthinkable. The physicist is impressed not solely by it's for long empirical verification, but above all by the intrinsic beauty of its conception which predisposes the discriminating mind for acceptance even if there were no experimental evidenced for the theory at all. Again Hutton, "Relativity has profoundly changed the whole of physics. By the analysis of the fundamental concepts of space and time, of mass and of force, it has given a new orientation not only to science but also to our approach to philosophic problems in general."

Before Einstein, physicist were confident which they understood distance, time, and mass. They believed any skilled person could measure distance with a ruler, tell time with a clock, weigh mass with a scale, and get the True values. With his theory of special relativity, Einstein proved that this was wrong that there were no true values and he shook the very foundations of science. Einstein developed two theories of relativity: special relativity and general relativity. Special relativity, published in 1905, covers only special, simple situations, those in which there are no forces. It was followed ten years later by general relativity, which includes Einstein's theory of gravity and is the more complex theory.

1.2 THE THEORY OF RELATIVITY

In everyday language we can say that relativity is a theory which holds that concepts like motion, length, time, mass etc. not absolute. They make sense only when referred to a frame of reference. Thus an astronaut of mass say 80kgs on the surface of the earth (first frame of reference) may have a mass of 100 kgs while inside a fast moving rocket (second frame of reference). A different definition is given by Eddington, "an attitude which leads to the conclusions that we observe only relations between physical entities."

Special and General Theory of Relativity

Einstein published his theory in two papers, one in 1905 and the other in 1916. The forms the special theory and this deals with only uniform motion of bodies. The second is called the general theory and this deal with all moving bodies including those with non-uniform velocities, (i.e. accelerated bodies).

Postulates of the Special Theory of Relativity

Einstein explained the "negative result" of M. M. experiment in the form of two postulates.

Postulate I: it is impossible to determine absolute motion by any experiment whatever. So in the universe no privileged frame of reference with respect to which absolute motion can be measured exists. Hence the phenomena of nature will be the same for two observers who move with any uniform velocity whatever relative to one another. Putting it in another way we can say that uniform motion does not affect physical laws. The general laws of physics are the same in all systems moving uniformly with respect to each other in a straight line. This is called the principle of relativity, from which the theory gets its name.

Postulate II: the velocity of light is a constant absolute quantity. It is independent of the motion of the source or of the observer.

Implications and Consequences of the Postulates

It is impossible to measure the uniform motion of a body by observing events taking place within the body. According to the first postulates all natural events are unaffected by uniform motion. So by observing them from within the body moving with uniform velocity we cannot measure its velocity. Consider a train moving with constant speed. Everything inside it happens as though it is motionless.

1.3 RELATIVITY OF MOTION, LENGTH, TIME, SIMULTANEITY

We must give up the classical platform of an immobile framework of space. It is meaningless to talk of absolute rest. All motion is relative; is makes sense only when referred to a frame of reference. As an illustration consider a station master at the platform and an engine driver in a moving train. The station master will say that the engine driver is moving with respect to him.

The engine driver, on the other hand, will say that the station master is moving with respect to him and his engine.

Relativity of Length

Length is not something absolute in the sense that it has the same value everywhere. The stationary observer will notice the contraction. But the observer in the moving frame will not be able to measure any contraction because his scale also will have contracted by the same amount. Thus it follows that it is meaningless to speak of length without specifying the frame of reference, without specifying whether the length is taken with respect to a moving observer or a 'stationary' observer. (Contraction is perfectly reciprocal. Each observer notices a contraction in the system of the other. It is not a contraction of bodies, but of the measurement of bodies or of length, where 'length is not an intrinsic property of the body a conception we associate with the body')

Relativity of Time

We must give up the classical notion of 'steady, unvarying, inexorable universal time flow, streaming from the infinite past to the infinite future'. In a moving frame time slows down, two observers moving with different uniform velocities will have different values to the duration of an event. Newton assumed time was absolute and universal. He assumed time ran its own intrinsic rate, unaffected by anything else, flowing at the same rate everywhere and always. But Einstein showed that all this was wrong. Time is relative; there is no one, TRUE time. Time runs at different rates in different inertial frames; different clocks will inevitably measure different times. Let us try to see why it is true. Time is our way of measuring how rapidly things change. If nothing ever changed, time would be a meaningless concept. Every clock counts the number of 'times' something changes. In truth, it is time itself that appears to us to be slower in a moving frame; this is called 'time dilation.' Hence according to relativity there is no absolute before and after. Absolute topological time is ruled out. This means that there is no absolute past, present, future applicable to the cosmos as a whole. Also there is no absolute duration. This rule is out absolute metric time.

Space-Time and Four-Dimensional Continuum

Hermann Minkowski, realized Einstein's theory changed our understanding of the geometry of our universe. The three dimensions space can no longer be considered distinct from time; space and time must be viewed as a combined four-dimensional entity that Minkowski named space-time., In four-dimensional space-time, points are called events and four quantities are required to specify an event such as latitude, longitude, altitude, and time. Time measurements and normal three-dimensional distance measurements are relative (different from different observers), but the distance between two events in four-dimensional space-time is invariant (the same for all observers). Space is the relation of things and time is the relation or order of events. They are a relating system expressing certain general features of physical objects. Thus they describe the world in an orderly way. It is true that they are constructs of the mind, but they are not pure, empty concepts. They are concepts fit to describe the physical world. In Hans Reichenbaclis words, "these conceptual systems describe relations holding between physical objects. In addition these relations formulate physical laws of great generality, determining some fundamental features of the physical world. Space and time have as much reality as; say the relation "father" or the Newtonian forces of attraction." Thus the relations we talk of our objective relation.

In ordinary language the word ‘space’ itself is used as the name of a continuant. We can say, for example, that a part of space has become, or has contained to be, occupied. Space-time, however, is a ‘space’ in a tense less sense of this word, and because time is already in the representation it is wrong to talk of space-time as itself changing. Thus, in some expositions of relativity it is said that a certain ‘world line’ is a track along which a material body moves or a light signal is propagated. Here the body or light signal is propagated. The body or light signal, however, cannot correctly be said to move through space-time. What should be said is that the body or the light signal lines (tenselessly) along the world time. To talk of anything moving through space-time is to bring time into the story twice over and in an illegitimate manner. When we are talking about motion in terms of the space-time picture, we must do so in terms of the relative orientations of world lines. Thus, to say that two particles move with a uniform nonzero relative velocity it is expressed by saying that they lie (tenselessly) along straight world lines that are at an angle to one another. Similarly, the recent conception of the position as an electron moving backward in time is misleading because nothing can move, forward or backward, in time. What is meant is that the world lines of a position and electron, which are produced together or which annihilate one another, can be regarded as a single bent world time, and this may indeed be a fruitful way of looking at the matter.

Check Your Progress I

Note: Use the space provided for your answers.

1) What is Einstein’s theory of relativity?

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2) Give small explanation on relativity of motion and length.

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3) Write on relativity of time.

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Relativity of Simultaneity

Up to now our considerations have been referred to a particular body of reference, which we have styled as a “railway embankment." We suppose a very long train travelling along the rails with the constant velocity **v** and in the direction indicated. People travelling in this train will with a vantage view the train as a rigid reference-body (co-ordinate system); they regard all events in reference to the train. Then every event which takes place along the line also takes place at a particular point of the train. Also the definition of simultaneity can be given relative to the train in exactly the same way as with respect to the embankment. As a natural consequence, however, the following question arises: are two events (*e.g.* the two strokes of lightning A and B) which are simultaneous with reference *to the railway* embankment also simultaneous relatively to the train? We shall show directly that the answer must be in the negative.

When we say that the lightning strokes A and B are simultaneous with respect to be embankment, we mean: the rays of light emitted at the places A and B, where the lightning occurs, meet each other at the mid-point M of the length $A \rightarrow B$ of the embankment. But the events A and B also correspond to positions A and B on the train. Let M^1 be the mid-point of the distance $A \rightarrow B$ on the travelling train. Just when the flashes (as judged from the embankment) of lightning occur, this point M^1 naturally coincides with the point M but it moves towards the right in the diagram with the velocity v of the train. If an observer sitting in the position M^1 in the train did not possess this velocity, then he would remain permanently at M, and the light rays emitted by the flashes of lightning A and B would reach him simultaneously, *i.e.* they would meet just where he is situated. Now in reality (considered with reference to the railway embankment) he is hastening towards the beam of light coming from B, whilst he is riding on ahead of the beam of light coming from A. Hence the observer will see the beam of light emitted from B earlier than he will see that emitted from A. Observers who take the railway train as their reference-body must therefore come to the conclusion that the lightning flash B took place earlier than the lightning flash A. We thus arrive at the important result: "Events which are simultaneous with reference to the embankment are not simultaneous with respect to the train, and vice versa (relativity of simultaneity). Every reference-body (co-ordinate system) has its own particular time; unless we are told the reference-body to which the statement of time refers, there is no meaning in a statement of the time of an event."

Now before the advent of the theory of relativity it had always tacitly been assumed in physics that the statement of time had an absolute significance, *i.e.* that it is independent of the state of motion of the body of reference. But we have just seen that this assumption is incompatible with the most natural definition of simultaneity; if we discard this assumption, then the conflict between the laws of the propagation of light *in vacuo* and the principle of relativity disappears.

In it we concluded that the man in the carriage, who traverses the distance w per second relative to the carriage, traverses the same distance also with respect to the embankment in each second of time. But, according to the foregoing considerations, the time required by a particular occurrence with respect to the carriage must not be considered equal to the duration of the same occurrence as judged from the embankment (as reference-body). Hence it cannot be contended that the man in walking travels the distance w relative to the railway line in a time which is equal to one second as judged from the embankment. Moreover, these considerations of are based on yet a second assumption, which, in the light of a strict consideration, appears to be arbitrary, although it was always tacitly made even before the introduction of the theory of relativity.

The Limiting Velocity of Light

No body can travel faster than light. So the law of addition of velocity is such that the combined velocity does not exceed the velocity of light. If a body moves with the velocity of light, it would have contracted to nothing! This can never be reached. At the velocity of light, a clock will stop moving and so then duration will be infinite.

1. 4 MASS AND ENERGY

The fact that nobody can travel faster than light suggests that the inertia (resistance to motion) of a body increases with increasing velocity, approaching infinity as the velocity of light is reached. Now mass is nothing but inertia, a tendency opposing motion. So as velocity increases mass also increases. Mass is not absolute, but relative to the frame of reference. Mass of a body in a moving frame reference is increases and relativist correction is needed thing to move very fast. Energy of motion of a body depends on its inertial mass and the velocity. So energy can increase either with inertial mass or in velocity. But velocity cannot increase indefinitely. Its maximum value is the velocity of light. So as energy increases the inertial mass also should increase. Thus we have the famous mass-energy equation of Einstein: E=mc2 (E = Energy produced due to conversion, M= Mass that is converted, C= Velocity of light).

1.5 GENERAL THEORY OF RELATIVITY

The general theory of relativity was Einstein's crowning achievement. It revolutionized the theory of gravitation and initiated the new field of cosmology, the study of universe. Einstein pumped out the special theory of relativity in a quick five week, in contract the general theory took Einstein almost ten years from first version to final eloquent equations. "The General Theory of Relativity" was initially presented in a paper by Albert Einstein in 1915. Its primary thrust was to add the effects of gravity to "The Special Theory of Relativity," making special relativity a special case of general relativity. In the same way, ten years earlier, Einstein proposed the Theory of Special Relativity with the primary thrust of eliminating the concept of a fixed reference frame in favour of relative inertial frames in conjunction with the newly learned fact that the speed of light was a constant when measured in any inertial reference frame. This theory, in a similar way, makes the Newtonian Euclidian geometry of space a special case of special relativity. So rather than these new theories refuting the old theories, they actually verified that the previous theories were special cases of a more complicated theory that explains more of reality.

Many of us who have studied physics remember an equation that states that force equals mass times acceleration (f = ma) for a mass being accelerated by a constant force. We also remember how strange it was that an almost identical equation, force equals mass times the gravitational acceleration constant (f = mg) was used to determine the weight of a non-accelerating object in a gravitational field. This similarity (or relationship) between "a" and "g" forms the conceptual basis for general relativity. Consider yourself standing on a scale in an enclosed elevator at rest. Also consider yourself standing on a similar scale in an enclosed spaceship accelerating at one "g." Both the equation and our intuitive knowledge tell us that we cannot distinguish between the one situation and the other. We would be standing balanced on the scale with the scale reading our weight in both cases. Also consider the opposite situation where the elevator was in free fall and the spaceship was way out in space away from any star with the rockets off. In both cases, again, we cannot distinguish between being in the elevator or the spaceship. In both cases, the scale would read zero and we would be floating with no forces on our body.

Based on this conceptual foundation, additional general relativity concepts and effects have been developed. One concept is the effect of gravitational fields to cause the space-time continuum to be curved or warped by large masses. Another effect is that gravity, in addition to bending light, also can cause it to slow down. This slowing down of light results in a time dilation effect where time actually slows down. The slowing down effect of earth's gravity on time at its surface is very little. Compared with space, the earth's gravitational field slows down time by only one second per billion seconds. Experiments have verified the validity of general relativity. Some of these experiments include the precession of the perihelion of Mercury, the deflection of light, and the gravitational red shift of light.

Although the earth with its low gravitational field is at one end of the spectrum, black holes predicted by general relativity and observed in space have extremely high gravity and are at the other end of the spectrum. Black holes, in addition to bending light, slowing down light, and slowing down time, can stop light from escaping and make time stand still. For us, watching a space probe speeding toward the event horizon of a black hole, the space probe would appear to slow down and virtually stop. The fact that science can show that time can virtually stop helps our understanding of how a transcendent God, beyond time and space, can exist.

1.6 THE GRAVITATIONAL FIELD

"If we pick up a stone and then let it go, why does it fall to the ground?" The usual answer to this question is: "Because it is attracted by the earth." Modern physics formulates the answer rather differently for the following reason. As a result of the more careful study of electromagnetic phenomena, we have come to regard action at a distance as a process impossible without the intervention of some intermediary medium. If, for instance, a magnet attracts a piece of iron, we cannot be content to regard this as meaning that the magnet acts directly on the iron through the intermediate empty space, but we are constrained to imagine- after the manner of Faraday -that the magnet always calls into being something physically real in the space around it, that something being what we call a "magnetic field." In its turn this magnetic field operates on the piece of iron, so that the latter strives to move towards the magnet. We shall not discuss here the justification for this incidental conception, which is indeed a somewhat arbitrary one. We shall only mention that with its aid electromagnetic phenomena can be theoretically represented, much more satisfactorily than without it, and this applies particularly to the transmission of electromagnetic waves. The effects of gravitation also are regarded in an analogous manner.

The action of the earth on the stone takes place indirectly. The earth produces in its surrounding a gravitational field, which acts on the stone and produces its motion of fall. As we know from experience, the intensity of the action on a body demises according to a quite definite law, as we proceed farther away from the earth. From our point of view this means: The law governing the properties of the gravitational field in space must be a perfectly definite one, in order correctly to represent the diminution of gravitational action with the distance from operative bodies. It is something like this: The body (e.*g.* the earth) produces a field in its immediate neighborhood directly; the intensity and direction of the field at points farther removed from the body are thence determined by the law which governs the properties in space of the gravitational fields themselves.

In contrast to electric and magnetic fields, the gravitational field exhibits a most remarkable property, which is of fundamental importance for what follows. Bodies which are moving under the sole influence of a gravitational field receive an acceleration, which does not in the least depend either on the material or on the physical state of the body. For instance, a piece of lead and a piece of wood fall in exactly the same manner in a gravitational field (in vacuo), when they start off from rest or with the same initial velocity. This law, which holds most accurately, can be expressed in a different form in the light of the following consideration.

According to Newton's law of motion, we have

(Force) = (inertial mass) x (acceleration),

where the "inertial mass" is a characteristic constant of the accelerated body. If now gravitation is the cause of the acceleration, we then have (Force) = (gravitational mass) x (intensity of the gravitational field), where the "gravitational mass" is likewise a characteristic constant for the body. From these two relations follows:

(Acceleration= (gravitational**)** = (intensity of the gravitational field)
(Inertial)

If now, as we find from experience, the acceleration is to be independent of the nature and the condition of the body and always the same for a given gravitational field, then the ratio of the gravitational to the inertial mass must likewise be the same for all bodies. By a suitable choice of units we can thus make this ratio equal to unity. We then have the following law: The gravitational mass of a body is equal to its inertial law. It is true that this important law had hitherto been recorded in mechanics, but it had not been interpreted. A satisfactory interpretation can be obtained only if we recognize the following fact: The *same* quality of a body manifests itself according to circumstances as “inertia” or as “weight “(lit. " heaviness '). In the following section we shall show to what extent this is actually the case, and how this question is connected with the general postulate of relativity.

A New Interpretation of Gravity

Accelerated motion can be as equivalent to a gravitational field only because inertial mass is equivalent to gravitational mass. This was known already in classical physics, but no explanation was given to it. Einstein suggested that ‘the same quality of a body manifests itself according to circumstances as ‘inertia’ or as ‘weight’. Thus because of inertia bodies in ‘empty space’ is travel with uniform velocity in straight lines. Because of gravity bodies in non-empty space (gravitational field) are travel with accelerated motion in parabolic paths. Hence inertia and gravity are two aspects of a single law, ‘Every body tends to move along a geodesic’.

The New Picture of Gravity

According to Newton, gravitation is a force of attraction between two bodies. Thus the sun attracts the earth and because of this gravitational force the earth revolves round the sun. Gravitation causes the earth and other planets to describe curved paths in a straight space. According to Einstein, massive bodies distort the space-time continuum in their neighborhood. The curvature formed because of this distortion deflects the planets and they move in curved paths. Thus the paths of the planets etc., are the shortest courses in a curved space-time continuum. Gravitation is hence reduced to a geometrical property of the space-time continuum.

It is not force acting at a distance, but simply is the 'path of inertia' which the bodies follow. A massive body like the sun keeps the space in its neighborhood continually curved. It is as though the sun takes 'grooves' around it. The bodies move in these 'grooves'. Another metaphor used is that the gravitating bodies produce 'hills' or other deformities in the continuum and bodies are rolled along the 'hillside'. We quote from Barnett: " A gravitational force as much a physical reality as an electromagnetic field, and its structure is defined by the field equations of A. Einstein".

Gravitational Deflection of Light

Now light can be looked upon as a stream of minute particles called photons. Therefore they also should behave like any other material particles. So in a strong gravitational field a ray of light should undergo deflection. This is called gravitational deflection of light.

Check Your Progress III

Note: Use the space provided for your answers.

1) Give small description General Theory of Relativity.

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2) What is the Gravitational Field?

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3) Give description on the new picture of gravity.

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1.7 LET US SUM UP

Relativity dealt a death blow to the so called absolutes: absolute time, absolute space, absolute frame of reference, absolute objectivity etc. In doing so it has revolutionized the traditional notions of space, time etc. According to relativity space and time are relative. Space is the relation of things and time is the relation between the events. As Jeans says when we question nature through our experiments, we find that nature knows nothing of a space or time common to all people. When we interpret these experiments in the new light of the theory of relativity we find that space means nothing apart from our perception of objects and time means noting apart from the our experience of events. Space and time fade into subjective conceptions, just as subjective as right or left hand and 'only the four dimensional continuum is objective.'

The denial of absolute space, absolute observer and absolute frame of reference has one important impact on scientific method. This shows that since no preferential frame or absolute observer exists, we can get scientific knowledge not by referring to any special space or frame of reference, but simply by performing the experiments accurately, no matter in whatever frame of reference we are. Thus extreme dexterity and accuracy will underlie any knowledge of the laws of nature. Relativity has sparked off speculations and theories on the origin of the cosmos and its nature.

1.8 KEY WORDS

$E=mc^2$ (E = Energy produced due to conversion, M= Mass that is converted, C= Velocity of light).

In four-dimensional space-time: points are called events and four quantities are required to specify an event such as latitude, longitude, altitude, and time.

Force = inertial mass x acceleration (Acceleration= (gravitational) = (intensity of the gravitational field) (Inertial)

1.9 FURTHER READINGS AND REFERENCES

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UNIT 2 QUANTUM MECHANICS

Contents

2.0 OBJECTIVES

- To introduce the students to some of the key ideas of quantum mechanics.
- To show the weirdness of the theory.
- To indicate how successful the theory is, though most people do not understand it.

2.1 INTRODUCTION

Two of the most revolutionary theories of 20th century were Theory of Relativity and Quantum Mechanics. Theory of relativity is a deviation from Newtonian Mechanics (or common sense.). The deviations were not discovered until this Century because they are only noticeable at high speeds and under very intense gravitational fields. There is another 20th Century idea that also violates Newtonian Mechanics. This is called Quantum Mechanics (Tal 2009).
In fact, Quantum mechanics is one of the major revolutions in 20th century Physics. It is probably the closest science has come to a fundamental description of the underlying nature of reality. And yet it is totally bizarre—it flies in the face of all our intuition and common sense. It sounds more like science fiction, or a poorly written fantasy, than notions which serious scientists would entertain (Felder & Felder 1998). So one of the best scientists of last century, R. Feynman has this to say: "It is often stated that of all the theories proposed in this century, the silliest is quantum theory. Some say that the only thing that quantum theory has going for it, in fact, is that it is unquestionably correct." In this unit, we want to study the basic notions of it, its strange (or weird) character, its practical implications and we conclude with some remarks on human intuition.

2.2 THE STORY OF THE ATOM

In this section we will give a taste of the strange and fascinating world of the atom. We will keep it as descriptive and not mathematical. The Ancient Greeks proposed that matter could not be divided indefinitely. They speculated that matter was made up of units called atoms. The word comes from a Greek word meaning single item or a portion. They assumed that atoms were solid, different characteristics of substances being determined by the different shapes that atoms had. This atomic idea never really became popular (Tal 2009).
During the 16th Century, chemists worked out that behaviour of gases. If they doubled the volume of a gas, its pressure halved. If they halved its volume, its temperature doubled. It was also found that chemical reactions always took place in fixed ratios. For example one volume of oxygen always combined with two volumes of hydrogen to produce water (assuming the gases were at the same temperature and pressure). Results like these lead to the idea of atoms. The Atomic Theory was surely the best way to explain these and other phenomena. (Tal 2009)
When the idea of elements came, it was assumed that different elements had different atoms. John Dalton showed that each element had an atom that differed in weight (correctly, mass) to other atoms. So now we say that a Carbon atom has a relative mass of 12, Oxygen has one of 16. The unit is the Hydrogen atom, the lightest of all the atoms. During the middle of the 19th Century, James Maxwell explained the gas laws by applying statistics to the random motions of atoms. He showed that when you heat a gas you make its molecules go faster. These strike the surface of the container with more force, thus increasing the gas pressure. To keep the pressure the same the volume has to be increased. Atoms were now taken for granted and treated as featureless spheres (i.e. little balls). (Tal 2009)
At this point the idea that atoms were featureless spheres was overturned by several discoveries made towards the end of the 19th Century. Firstly, there were experiments in electricity and magnetism which indicated the existence of particles with less mass than the Hydrogen atom. The electron was the most famous of these. Secondly, atoms were found to be more complex that previously thought when radioactivity was discovered. Atoms were throwing out bits and changing to other atoms; atoms could take and give an electric charge.
From various observations and experiments it was eventually decided that an atom was made up of three particles (Tal 2009):

- Protons - these were charged with electricity that was positive and contained most of the mass of atoms.
- Electrons - these were very light particles (1/1800th the mass of a Hydrogen atom.) with a negative electric charge exactly equal to the charge on a proton.
- Neutrons - neutral particles with a mass similar to protons but with no charge.

In an atom, the protons and neutrons were in the central regions of the atom (called the nucleus) while the electrons revolved around at high speed. It was the outer electrons that interacted when atoms reacted chemically with other atoms. It was these electrons that were involved in electrical effects. It was the number of protons that determined how many electrons there were (they had to be the same). This number (called the Atomic Number) determined how the atom behaved, i.e. what element it was. Hydrogen atoms have 1 proton and 1 electron, Oxygen has 8 of each, Uranium has 92 of each. The electrons were held in orbit by electric attraction (positive and negative attract), much as the planets were held in orbit around the sun by the attractive force of gravity.

The above description of the atom is the Newtonian (or Classical) description. It is possible to picture it and it makes sense. Unfortunately, this description violates Maxwell's Laws of Electromagnetism. Maxwell's Laws of Electromagnetism were very powerful tools. However they could not explain how an atom could be stable. Under those laws, an electrically charged object (like an electron) that was changing direction (in orbit around the nucleus of an atom) should be radiating energy away until it spiralled into the nucleus. Clearly this does not happen. Atoms are stable. Furthermore, there were a few other observations about atoms that were not quite right (Tal 2009).

Of course, atoms did absorb and radiate energy. The problem was that this process was strictly controlled. Atoms only absorbed specific wavelengths of energy. Sodium, for example, radiated a lot of yellow light (hence its use in street lamps), Potassium radiated lilac (hence the colour of most fireworks). This was a major flaw in the physics of the turn of the century. Physics had other problems - phenomena that didn't work as predicted: the way a hot, glowing body radiated energy at a given temperature (the Black Body Problem); the way metals produced electricity when light shone on them (the Photoelectric Effect); the way atoms decayed when they were radioactive. Something was wrong with the state of Physics. What was needed was a revolution in Physics. Unlike the onset of relativity which was the brainchild of one man, this new idea would spawn from many minds – in fact the best minds of those days.

Check Your Progress I

Note: Use the space provided for your answers.

1) "Some say that the only thing that quantum theory has going for it, in fact, is that it is unquestionably correct." Give your comments.

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2) Describe the structure of an atom?

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2.3 INTRODUCING QUANTUM MECHANICS

Isaac Newton thought that light was a stream of particles; Thomas Young thought it was a wave. Most people at the turn of the century thought of light as a wave. In 1900 Max Planck found that he could explain the way hot bodies radiate energy only if he assumed that energy occurred as packets. He assumed that his equations were simply tricks with the mathematics and called these packets of energy quanta. The equations were useful but the underlying ideas were not taken seriously. In 1905, Albert Einstein published three scientific papers, any one of which was the mark of a genius. The first was Part One of his Theory of Relativity. The second proved the existence of atoms from direct observations (an effect called Brownian Motion).

The third paper is the relevant one for this essay. In this paper, he applied Planck's quantum idea of 1900 to explain the Photoelectric Effect. These quanta were now being utilised to explain two previously unexplainable phenomena. However, if quanta were real, was light a wave or a particle? It was as if in some experiments (refraction, diffraction) light was clearly a wave; in others (black body radiation, the photoelectric effect) it was a particle. This effect was strange and was known as wave-particle duality (Tal 2009).

In 1912, Louise de Broglie, suggested that if energy could behave as both particles and waves, perhaps matter could also. He nearly didn't get his PhD for that ridiculous suggestion. He produced the mathematics and predicted that under the right conditions a beam of electrons (clearly matter made of particles) might show wave properties. Surprisingly, when the experiment was performed, a beam of electrons was found to diffract just like a wave would have done. That was it. It looked like energy and matter could both exhibit wave-particle duality. It appeared that a moving particle had a wavelength. Neils Bohr decided to work out the wavelength of an electron moving around the nucleus of an atom. He found that for an electron to have a stable orbit, the orbit had to include a whole-number of the electron's wave. Orbits that include fractions of waves were impossible so the electron could not inhabit them. In other words, an electron could have a stable orbit, so that it would not lose energy and spiral in to the nucleus. If an electron absorbed or radiated energy, it would do so in discreet amounts so that it would move to another stable orbit. The analogy is a staircase. You can only stand on the steps, not in the region between steps.

So these quantum ideas explained two things. Why atoms were stable and why atoms absorbed or emitted energy in selected wavelengths. Bohr used his ideas to predict what energy could be radiated from different atoms. His theories corresponded with observation. In 1925, Erwin Schrodinger and Werner Heisenberg separately worked out the mathematics of Quantum Mechanics. Using this new theory, scientists could understand the behaviour of atoms and subatomic particles. The wave-particle duality concept it true for both matter and energy. The 'position' of a particle like an electron is given by a probability. Electrons exist in energy states. When they absorb energy, they absorb a whole number of quanta, disappear, appearing at a different energy state. Gone is the idea of little ball-like particles. The orbit of an electron is a cloud of probability around the nucleus (Tal 2009).

Another quantum effect is the famous Uncertainty Principle. This implies that there is a built-in uncertainty in the Universe. It is possible for something to be created out of nothing, given enough time. On a subatomic level it is impossible to pinpoint things down to an infinite precision. And not because of any technological failings: this is a constraint of the Universe itself. A zero energy is impossible since it would be a precise state. This is the reason that nothing can be cooled below -273 degrees C (Absolute Zero). An atom must retain at least one quantum of energy and this keeps it from cooling below Absolute Zero. This means that nothing can ever be at rest. Quantum effects are not noticeable in the macro world. They only become important as one approaches the dimensions of the atom. (Tal 2009).

Fast and Young

A tumultuous series of events occurred within the three-year period from January 1925 to January 1928 culminating in quantum revolution. We list some of them main events:

• Wolfgang Pauli proposed the exclusion principle, providing a theoretical basis for the Periodic Table.

• Werner Heisenberg, with Max Born and Pascual Jordan, discovered matrix mechanics, the first version of quantum mechanics. The historical goal of understanding electron motion within atoms was abandoned in favour of a systematic method for organizing observable spectral lines.

• Erwin Schrödinger invented wave mechanics, a second form of quantum mechanics in which the state of a system is described by a wave function, the solution to Schrödinger's equation. Matrix mechanics and wave mechanics, apparently incompatible, were shown to be equivalent.

• Electrons were shown to obey a new type of statistical law, Fermi-Dirac statistics. It was recognized that all particles obey either Fermi-Dirac statistics or Bose-Einstein statistics, and that the two classes have fundamentally different properties.

• Heisenberg enunciated the Uncertainty Principle.

• Paul A.M. Dirac developed a relativistic wave equation for the electron that explained electron spin and predicted antimatter.

• Dirac laid the foundations of quantum field theory by providing a quantum description of the electromagnetic field.

• Bohr announced the complementarity principle, a philosophical principle that helped to resolve apparent paradoxes of quantum theory, particularly wave-particle duality.

The principal players in the creation of quantum theory were very young. In 1925 Pauli was 25 years old, Heisenberg and Enrico Fermi were 24, and Dirac and Jordan were 23. Schrödinger, at age 36, was a late bloomer. Born and Bohr were older still, and it is significant that their contributions were largely interpretative. The profoundly radical nature of the intellectual achievement is revealed by Einstein's reaction. Having invented some of the key concepts that led to quantum theory, Einstein rejected it. His paper on Bose-Einstein statistics was his last contribution to quantum physics and his last significant contribution to physics. That a new generation of physicists was needed to create quantum mechanics is hardly surprising. Lord Kelvin described why in a letter to Bohr congratulating him on his 1913 paper on hydrogen. He said that there was much truth in Bohr's paper, but he would never understand it himself. Kelvin recognized that radically new physics would need to come from unfettered minds. In 1928 – just within a span of three years - the revolution was finished and the foundations of quantum mechanics were essentially complete. The main actors were very young and energetic minds in their 20s (Kleppner and Jackiw).

Controversy and Confusion

Alongside these advances, however, fierce debates were taking place on the interpretation and validity of quantum mechanics. Foremost among the protagonists were Bohr and Heisenberg, who embraced the new theory, and Einstein and Schrödinger, who were dissatisfied. To appreciate the reasons for such turmoil, one needs to understand some of the key features of quantum theory, which we summarize here. (Kleppner & Jackiw 2000)

Fundamental description: the wave function. The behavior of a system in quantum mechanics is described by Schrödinger's equation. The solutions to Schrödinger's equation are known as wave functions. The complete knowledge of a system is described by its wave function, and from the wave function one can calculate the possible values of every observable quantity. The probability of finding an electron in a given volume of space is proportional to the square of the magnitude of the wave function. Consequently, the location of the particle is "spread out" over the volume of the wave function. The momentum of a particle depends on the slope of the wave function: The greater the slope, the higher the momentum. Because the slope varies from place to place, momentum is also "spread out." The need to abandon a classical picture in which position and velocity can be determined with arbitrary accuracy, in favor of a blurred picture of probabilities, is at the heart of quantum mechanics (Kleppner & Jackiw 2000).

Waves can interfere. The heights of waves can add or subtract depending on their relative phase. Where the amplitudes are in phase, they add; where they are out of phase, they subtract. If a wave can follow several paths from source to receiver, as a light wave undergoing two-slit interference, then the illumination will generally display interference fringes. Particles obeying a wave equation will do likewise, as in electron diffraction. The analogy seems reasonable until one inquires about the nature of the wave. A wave is generally thought of as a disturbance in a medium. In quantum mechanics there is no medium, and in a sense there is no wave, as the wave function is fundamentally a statement of our knowledge of a system (Kleppner & Jackiw 2000).

Questions such as what a wave function "really is" and what is meant by "making a measurement" were intensely debated in the early years. By 1930, however, a more or less standard interpretation of quantum mechanics had been developed by Bohr and his colleagues, the so-called Copenhagen Interpretation. The key elements are the probabilistic description of matter and events, and reconciliation of the wavelike and particle-like natures of things through Bohr's principle of complementarity. Einstein never accepted quantum theory; he and Bohr debated its principles until Einstein's death in 1955. Nevertheless, the nature of quantum theory continues to attract attention because of the fascination with what is sometimes described as "quantum weirdness." (Kleppner & Jackiw 2000).

Differences from Classical Physics

Now that we have some idea of the basics of quantum mechanics, we can try to compare it with classical mechancis. The main difference of the new theory from classical physics could be summed up as follows:

1. In classical mechanics a particle can have any energy and any speed. In quantum mechanics these quantities are quantized. This means that a particle in a quantum system can only have certain values for its energy, and certain values for its speed (or momentum).
2. Newton's Laws allow one, in principle, to determine the exact location and velocity of a particle at some future time. Quantum mechanics, on the other hand, only determines the probability for a particle to be in a certain location with a certain velocity at some future time. The probabilistic nature of quantum mechanics makes it very different from classical mechanics.
3. Quantum mechanics incorporates what is known as the "Heisenberg Uncertainty Principle." This principle states that one cannot know the location AND velocity of a quantum particle to infinite accuracy. The better you know the particle's location, the more uncertain you must be about its velocity, and vice versa. In practice, the level of

uncertainty that is required is so small that it is only noticeable when you are dealing with very tiny things like atoms. This is why we cannot see the effects of the Uncertainty Principle in our daily lives.

4. Quantum mechanics permits what are called "superpositions of states". This means that a quantum particle can be in two different states at the same time. For instance, a particle can actually be located in two different places at one time. This is certainly not possible in classical mechanics.
5. Quantum mechanical systems can exhibit a number of other very interesting features, such as tunnelling and entanglement. These features also represent significant differences between classical and quantum mechanics, although they will not be as important in our discussion of quantum chaos. (Timberlake 2010)

That is a pretty brief introduction to the ideas of quantum mechanics and many important features have been skipped. But the ideas presented above should make it clear that quantum mechanics is very different from classical (Newtonian) mechanics.

Check Your Progress III
Note: Use the space provided for your answer
1) Why is it that most of the founders of quantum mechanics were very young?
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2) Give some significant differences between classical and quantum mechanics?
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2.4 WEIRDNESS OF QUANTUM MECHANICS

As already noted, the field of quantum mechanics concerns the description of phenomenon on small scales where classical physics breaks down. The biggest difference between the classical and microscopic realm, is that the quantum world cannot be perceived directly, but rather through the use of instruments. And a key assumption to quantum physics is that quantum mechanical principles must reduce to Newtonian principles at the macroscopic level (there is a continuity between Quantum and Newtonian Mechanics).

Quantum mechanics was capable of bringing order to the uncertainty of the microscopic world by treatment of the wave function with new mathematics. Key to this idea was the fact that relative probabilities of different possible states are still determined by laws. Thus, there is a difference between the role of chance in quantum mechanics and the unrestricted chaos of a lawless Universe. Every quantum particle is characterized by a wave function. In 1925 Erwin Schrodinger developed the differential equation which describes the evolution of those wave functions. By using Schrodinger equation, scientists can find the wave function which solves a particular problem in quantum mechanics. Unfortunately, it is usually impossible to find an exact solution to the equation, so certain assumptions are used in order to obtain an approximate answer for the particular problem.

However, some of its findings and principles are distinctly counter-intuitive and fiendishly difficult to explain in simple language, without resorting to complex mathematics way beyond the comfort level of most people (myself included.). This situation is not helped by the fact that the “theory” is largely a patchwork of fragments accrued over the last century or so, that some elements of it are still not well understood by the scientists themselves, and that some of the bizarre behaviour it predicts appears to fly in face of what we have come to think of as common sense.
Richard Feynman, winner of the 1965 Nobel Prize for Physics and arguably one of the greatest physicists of the post-war era, is unapologetically frank: “I think I can safely say that nobody understands quantum mechanics”. Niels Bohr, one the main pioneers of quantum theory, claimed that: “Anyone who is not shocked by quantum theory has not understood it.” (UP 2001)
Below we give two implications of quantum mechanics that makes it weird or strange.

Schrodinger's Cat

In 1935 Schrodinger, who was responsible for formulating much of the wave mechanics in quantum physics, published an essay describing the conceptual problems in quantum mechanics. A brief paragraph in this essay described the, now famous, cat paradox.
One can even set up quite ridiculous cases where quantum physics rebels against common sense. For example, consider a cat is penned up in a steel chamber, along with the following diabolical device (which must be secured against direct interference by the cat). In the device is a Geiger counter with a tiny bit of radioactive substance, so small that perhaps in the course of one hour only one of the atoms decays, but also, with equal probability, perhaps none. If the decay happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The first atomic decay would have poisoned it. The wave function for the entire system would express this by having in it the living and the dead cat mixed or smeared out in equal parts (UP 2001).
It is typical of these cases that an indeterminacy originally restricted to the atomic domain becomes transformed into macroscopic indeterminacy, which can then be resolved by direct observation. That prevents us from so naively accepting as valid a ``blurred model'' for representing reality. In itself it would not embody anything unclear or contradictory. There is a difference between a shaky or out-of-focus photograph and a snapshot of clouds and fog banks. We know that superposition of possible outcomes must exist simultaneously at a microscopic level because we can observe interference effects from these. We know (at least most of us know) that the cat in the box is dead, alive or dying and not in a smeared out state between the alternatives. When and how does the model of many microscopic possibilities resolve itself into a particular macroscopic state? When and how does the fog bank of microscopic possibilities transform itself to the blurred picture we have of a definite macroscopic state. That is the collapse of the wave function problem and Schrodinger's cat is a simple and elegant explanation of that problem (UP 2001).
Conclusion from experiment of the Schroedingers cat:

- The paradox is phrased such that a quantum event determines if a cat is killed or not
- From a quantum perspective, the whole system state is tied to the wave function of the quantum event, i.e. the cat is both dead and alive at the same time

- The paradox in some sense is not a paradox, but instead points out the tension between the microscopic and macroscopic worlds and the importance of the observer in a quantum scenario
- Quantum objects exist in superposition, many states, as shown by interference
- The observer (or measurement) collapses the wave function

Quantum Tunnelling

Quantum tunnelling refers to the phenomena of a particle's ability to penetrate energy barriers within electronic structures. The scientific terms for this are: Wave-mechanical tunnelling, Quantum-mechanical tunnelling and the Tunnel effect. Quantum tunnelling was developed from the study of radioactivity, which was discovered in 1896 by Henri Becquerel. It is the study of what happens at the quantum scale. This process cannot be directly perceived, so much of its understanding is shaped by the macroscopic world, which classical mechanics can adequately explain. Particles in that realm are understood to travel between potential barriers as a ball rolls over a hill; in our world, if the ball does not have enough energy to surmount the hill, it comes back down. Classical mechanics predicts that particles that do not have enough energy to climb the hill, it will not be able to reach the other side. In quantum mechanics, these particles can, with a very small probability, tunnel to the other side, thus crossing the barrier.

The reason for this difference comes from the treatment of matter in quantum mechanics as having properties of waves and particles. The wave function of a particle summarizes everything that can be known about a physical system. Therefore, problems in quantum mechanics centre around the analysis of the wave function for a system. Using mathematical formulations of quantum mechanics, such as the Schrödinger equation, the wave function can be solved for. This is directly related to the probability density of the particle's position, which describes the probability that the particle is at any given place. In the limit of large barriers, the probability of tunnelling decreases for taller and wider barriers. Hence, the probability of a particle on the other side is non-zero, which means that cross the high barrier sometimes. And experimentally it is also verified.

2.5 PRACTICAL VALUE OF QUANTUM MECHANICS

The equations developed by Heisenberg, Schrödinger and their colleagues give a glimpse into the nature of reality, but that's not all. They are also essential tools of modern work in key areas of practical technology--including the electronics you are using to read this text. Thousands of physicists use the equations of quantum mechanics every day to understand and improve computer components, metals, lasers, the properties of chemicals, and on and on. Many important physical effects, from fluorescent lights to the shape of a snowflake, cannot be understood at all without quantum mechanics.

Even the Uncertainty Principle isn't "merely" philosophy: it predicts real properties of electrons. Electrons jump at random from one energy state to another state which they could never reach except that their energy is momentarily uncertain. This "tunnelling" makes possible the nuclear reactions that power the sun and many other processes. Physicists have put some of these processes to practical use in microelectronics. For example, delicate superconducting instruments that use electron tunnelling to detect tiny magnetic fields are enormously helpful for safely scanning the human brain.

Quantum theory is used in a huge variety of applications in everyday life, including lasers, CDs, DVDs, solar cells, fibre-optics, digital cameras, photocopiers, bar-code readers, fluorescent lights, LED lights, computer screens, transistors, semi-conductors, super-conductors, spectroscopy, MRI scanners, lasers, super-conducting devices, etc. By some estimates, over 25% of the GDP of developed countries is directly based on quantum physics. It even explains the nuclear fusion processes taking place inside stars. Thus the effects of quantum mechanics are important in all branches of science. Quantum Mechanics is used to understand phenomena like radioactivity, chemical bonding, semi-conductors, solid-state micro-chips, electronics, sub-atomic physics, radiation from black holes, and many others (Tal 2009).

2.6 FINAL REMARKS ON HUMAN INTUITION

In spite of its weirdness, we have a theory which accounts for all of our experimental results. It correctly predicts the results of double slit experiments with photons or electrons, and it correctly predicts that in the case of normal light beams or particles. In fact, thousands of other experiments have been performed since quantum mechanics was developed, and they have continually supported its predictions to a staggering level of accuracy. This theory seems to apply to every process occurring between any kinds of matter or energy in the universe (Felder & Felder 1998).

No one really understands this theory of quantum mechanics. But Quantum mechanics can be used to successfully predict experimental results. So quantum mechanics leads to new ways of looking at existence and reality. The modern view of quantum mechanics states that Schrodinger's cat, or any macroscopic object, does not exist as super positions of existence due to de-coherence. A pristine wave function is coherent, i.e. undisturbed by observation. But Schrodinger's cat is not a pristine wave function it is constantly interacting with other objects, such as air molecules in the box, or the box itself. Thus a macroscopic object becomes de-coherent by many atomic interactions with its surrounding environment.

Decoherence explains why we do not routinely see quantum super positions in the world around us. It is not because quantum mechanics intrinsically stops working for objects larger than some magic size. Instead, macroscopic objects such as cats and cards are almost impossible to keep isolated to the extent needed to prevent de-coherence. Microscopic objects, in contrast, are more easily isolated from their surroundings so that they retain their quantum secrets and quantum behaviour (Uorgaon 2011).

It doesn't seem to make sense. But another school of thought says, why should it make sense? After all, humans evolved in a world of "normal" objects. And we developed a facility called "intuition" that helped us survive in that world by helping us predict the effects of our actions. That physical intuition was, and is, a great asset. But perhaps it shouldn't be too surprising that it becomes a liability when we try to apply it to areas that we didn't evolve for. Quantum mechanical laws generally only have measurable effects when applied to things that are too small to see, so we never evolved an understanding of them, so they seem bizarre (Felder & Felder 1998).

In fact, at roughly the same time that quantum mechanics first began to suggest that *very small* things defy our intuition, Einstein was proposing his special theory of relativity which shows that *very fast* things defy our intuition; and then his general theory of relativity, which concerns the odd behaviour of *very big* things (Felder & Felder 1998). It seems that, more and more, the only way to understand the world is to apply the math, and stop trying to "understand" what's actually going on. If you look at it like this, it seems that quantum physics is not weird and incomprehensible because it describes something completely different from everyday reality. It is weird and incomprehensible precisely because it describes the world we see around us-past, present, and future.

Check Your Progress III

Note: Use the space provided for your answers.

1) What is the significance of quantum tunnelling?

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2) Is quantum mechanics practical?

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2.7 LET US SUM UP

In this unit we have tried to understand the weird character of quantum mechanics, one of the most successful scientific theories. It radically changes the way we look at reality.

2.8 KEY WORDS

De-coherence: In quantum mechanics, quantum de-coherence is the mechanism by which quantum systems interact with their environments to exhibit probabilistically additive behaviour

Quantum tunnelling: It refers to the phenomena of a particle's ability to penetrate energy barriers within electronic structures. The scientific terms for this are Wave-mechanical tunnelling, Quantum-mechanical tunnelling and the Tunnel effect.

Quantum: A discrete quantity of energy proportional in magnitude to the frequency of the radiation it represents. It is the smallest amount of a physical quantity that can exist independently, especially a discrete quantity of electromagnetic radiation

Schrödinger’s equation: An equation describing the state and evolution of a quantum mechanical system, given boundary conditions. Different solutions to the equation are associated with different wave functions, usually associated with different energy levels. This equation is fundamental to the study of wave mechanics.

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UNIT 3 UNCERTAINTY PRINCIPLE

Contents

3.0 OBJECTIVES

- To study the basics of the uncertainty principle.
- To see some of its implications, including philosophical implications.
- To have some basic ideas of the Copenhagen interpretation of quantum mechanics.

3.1 INTRODUCTION

This unit takes up one of the fundamental principles from quantum mechanics. It also studies the confusion and challenges created by it. Finally it studies some of the implications of this theory.

3.2 SIMPLE DEFINITION OF UNCERTAINTY PRINCIPLE

"The more precisely the position is determined, the less precisely the momentum is known." This is the simplest statement of the uncertainty principle in quantum mechanics. The position and momentum of a particle cannot be simultaneously measured with arbitrarily high precision. There is a minimum for the product of the uncertainties of these two measurements. There is likewise a minimum for the product of the uncertainties of the energy and time. This is not a statement about the inaccuracy of measurement instruments, nor a reflection on the quality of experimental methods; it arises from the wave properties inherent in the quantum mechanical description of nature. Even with perfect instruments and technique, the uncertainty is inherent in the nature of things. Heisenberg formulated it in 1927 thus: “The more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa.” This is a

succinct statement of the "uncertainty relation" between the position and the momentum (mass times velocity) of a subatomic particle, such as an electron. It asserts that the position and the velocity of an object cannot both be measured exactly, at the same time, EVEN IN THEORY. The very concepts of exact position and exact velocity together, in fact, have no meaning in nature.
Because of the scientific and philosophical implications of the seemingly harmless sounding uncertainty relations, physicists speak of an uncertainty principle, which is often called more descriptively the "principle of indeterminacy."

Check Your Progress I
Note: Use the space provided for your answer
1) Give a simple definition of the principle of uncertainty, explaining the various terms?
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2) Is it possible to measure the exact location of a particle, both practically and theoretically? Why?
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3.3 BEYOND STRONG OBJECTIVITY

Classical physics was caught completely off-guard with the discovery of the uncertainty principle. Ordinary experience provides no clue of this principle. It is easy to measure both the position and the velocity of, say, an automobile, because the uncertainties implied by this principle for ordinary objects are too small to be observed. The complete rule stipulates that the product of the uncertainties in position and velocity is equal to or greater than a tiny physical quantity, or constant (about 10^{-34} joule-second, the value of the quantity h (where h is Planck's constant). Only for the exceedingly small masses of atoms and subatomic particles does the product of the uncertainties become significant (Uorgaon 2011).

Any attempt to measure precisely the velocity of a subatomic particle, such as an electron, will knock it about in an unpredictable way, so that a simultaneous measurement of its position has no validity. This result has nothing to do with inadequacies in the measuring instruments, the technique, or the observer; it arises out of the intimate connection in nature between particles and waves in the realm of subatomic dimensions. Every particle has a wave associated with it; each particle actually exhibits wavelike behavior. The particle is most likely to be found in those places where the undulations of the wave are greatest, or most intense. The more intense the undulations of the associated wave become, however, the more ill defined becomes the wavelength, which in turn determines the momentum of the particle. So a strictly localized wave has an indeterminate wavelength; its associated particle, while having a definite position, has no certain velocity. A particle wave having a well-defined wavelength, on the other hand, is spread out; the associated particle, while having a rather precise velocity, may be almost anywhere. A

$$\Delta\chi\Delta\rho \geq \frac{\hbar}{2}$$

momentum precisely, but then its position is unknown. Notice that this is not the measurement problem in another form, the combination of position, energy (momentum) and time are actually undefined for a quantum particle until a measurement is made (then the wave function collapses).

Also notice that the uncertainty principle is unimportant to macroscopic objects since Planck's constant, h, is so small (10^{-34}). For example, the uncertainty in position of a thrown baseball is 10^{-30} millimeters (Uorgaon 2011).

The depth of the uncertainty principle is realized when we ask the question; is our knowledge of reality unlimited? The answer is no, because the uncertainty principle states that there is a built-in uncertainty, indeterminacy, unpredictability to Nature. The field of quantum mechanics concerns the description of phenomenon on small scales where classical physics breaks down. The biggest difference between the classical and microscopic realm, is that the quantum world can be not be perceived directly, but rather through the use of instruments. And a key assumption to an quantum physics is that quantum mechanical principles must reduce to Newtonian principles at the macroscopic level (there is a continuity between quantum and Newtonian mechanics).

Quantum mechanics was capable of bringing order to the uncertainty of the microscopic world by treatment of the wave function with new mathematics. Key to this idea was the fact that relative probabilities of different possible states are still determined by laws. Thus, there is a difference between the role of chance in quantum mechanics and the unrestricted chaos of a lawless Universe. Every quantum particle is characterized by a wave function. In 1925 Erwin Schrodinger developed the differential equation which describes the evolution of those wave functions. By using Schrodinger equation, scientists can find the wave function which solves a particular problem in quantum mechanics. Unfortunately, it is usually impossible to find an exact solution to the equation, so certain assumptions are used in order to obtain an approximate answer for the particular problem (Uorgaon 2011).

The difference between quantum mechanics and Newtonian mechanics is the role of probability and statistics. While the uncertainty principle means that quantum objects have to be described by probability fields, this doesn't mean that the microscopic world fails to conform to deterministic laws. In fact it does. And measurement is an act by which the measurer and the measured interact to produce a result, although this is not simply the determination of a pre-existing property. The quantum description of reality is objective (weak form) in the sense that everyone armed with a quantum physics education can do the same experiments and come to the same conclusions. Strong objectivity, as in classical physics, requires that the picture of the world yielded by the sum total of all experimental results to be not just a picture or model, but identical with the objective world, something that exists outside of us and prior to any measurement we might have of it. Quantum physics does not have this characteristic due to its built-in indeterminacy.

For centuries, scientists have gotten used to the idea that something like strong objectivity is the foundation of knowledge. So much so that we have come to believe that it is an essential part of the scientific method and that without this most solid kind of objectivity science would be pointless and arbitrary. However, the Copenhagen interpretation of quantum physics (see below) denies that there is any such thing as a true and unambiguous reality at the bottom of everything. Reality is what you measure it to be, and no more. No matter how uncomfortable science is with this viewpoint, quantum physics is extremely accurate and is the foundation of modern physics (perhaps then an objective view of reality is not essential to the conduct of physics). And concepts, such as cause and effect, survive only as a consequence of the collective behavior of large quantum systems (Uorgaon 2011).

3.4 THE HISTORICAL ORIGIN OF UNCERTAINTY PRINCIPLE

The origins of uncertainty involve almost as much personality as they do physics. Heisenberg's route to uncertainty lies in a debate that began in early 1926 between Heisenberg and his closest colleagues on the one hand, who espoused the "matrix mechanics" form of quantum mechanics, and Erwin Schrödinger and his colleagues on the other, who espoused the new "wave mechanics." (Cassidy 2011)

Most physicists were slow to accept "matrix mechanics" because of its abstract nature and its unfamiliar mathematics. They gladly welcomed Schrödinger's alternative wave mechanics when it appeared in early 1926, since it entailed more familiar concepts and equations, and it seemed to do away with quantum jumps and discontinuities. French physicist Louis de Broglie had suggested that not only light but also matter might behave like a wave. Drawing on this idea, to which Einstein had lent his support, Schrödinger attributed the quantum energies of the electron orbits in the old quantum theory of the atom to the vibration frequencies of electron "matter waves" around the atom's nucleus. Just as a piano string has a fixed tone, so an electron-wave would have a fixed quantum of energy. This led to much easier calculations and more familiar visualizations of atomic events than did Heisenberg's matrix mechanics, where the energy was found in an abstruse calculation.

In May 1926 Schrödinger published a proof that matrix and wave mechanics gave equivalent results: mathematically they were the same theory. He also argued for the superiority of wave mechanics over matrix mechanics. This provoked an angry reaction, especially from Heisenberg, who insisted on the existence of discontinuous quantum jumps rather than a theory based on continuous waves. Heisenberg had just begun his job as Niels Bohr's assistant in Copenhagen when Schrödinger came to town in October 1926 to debate the alternative theories with Bohr. The intense debates in Copenhagen proved inconclusive. They showed only that neither interpretation of atomic events could be considered satisfactory. Both sides began searching for a satisfactory physical interpretation of the quantum mechanics equations in line with their own preferences (Cassidy 2011).

Studying the papers of fellow scientists, Dirac and Jordan, while in frequent correspondence with Wolfgang Pauli, Heisenberg discovered a problem in the way one could measure basic physical variables appearing in the equations. His analysis showed that uncertainties, or imprecisions, always turned up if one tried to measure the position and the momentum of a particle at the same time. (Similar uncertainties occurred when measuring the energy and the time variables of the particle simultaneously.) These uncertainties or imprecisions in the measurements were not the fault of the experimenter, said Heisenberg, they were inherent in quantum mechanics. Heisenberg presented his discovery and its consequences in a 14-page letter to Pauli in February 1927. The letter evolved into a published paper in which Heisenberg presented to the world for the first time what became known as the uncertainty principle (Cassidy, 2011).

3.5 SOME IMPLICATIONS OF UNCERTAINTY

Heisenberg realized that the uncertainty relations had profound implications. First, if we accept Heisenberg's argument that every concept has a meaning only in terms of the experiments used to measure it, we must agree that things that cannot be measured really have no meaning in physics. Thus, for instance, the path of a particle has no meaning beyond the precision with which it is observed. But a basic assumption of physics since Newton has been that a "real world" exists independently of us, regardless of whether or not we observe it. (This assumption did not go unchallenged, however, by some philosophers.) Heisenberg now argued that such concepts as orbits of electrons do not exist in nature unless and until we observe them (Jammer 1974). There were also far-reaching implications for the concept of causality and the determinacy of past and future events. These are discussed on the page about the origins of uncertainty. Because the uncertainty relations are more than just mathematical relations, but have profound scientific and philosophical implications, physicists sometimes speak of the "uncertainty principle."

In the sharp formulation of the law of causality, Heisenberg in 1927 asserted: "If we know the present exactly, we can calculate the future -it is not the conclusion that is wrong but the premise." This implies that we can never know the present reality exactly. Heisenberg also drew profound implications for the concept of causality, or the determinacy of future events. Schrödinger had earlier attempted to offer an interpretation of his formalism in which the electron waves represent the density of charge of the electron in the orbit around the nucleus. Max Born, however, showed that the "wave function" of Schrödinger's equation does not represent the density of charge or matter. It describes only the probability of finding the electron at a certain point. In other words, quantum mechanics cannot give exact results, but only the probabilities for the occurrence of a variety of possible results. (Cassidy, 2011a)

Heisenberg took this one step further: he challenged the notion of simple causality in nature, that every determinate cause in nature is followed by the resulting effect. Translated into "classical physics," this had meant that the future motion of a particle could be exactly predicted, or "determined," from a knowledge of its present position and momentum and all of the forces acting upon it. The uncertainty principle denies this, Heisenberg declared, because one cannot know the precise position and momentum of a particle at a given instant, so its future cannot be determined. One cannot calculate the precise future motion of a particle, but only a range of possibilities for the future motion of the particle. (However, the probabilities of each motion, and the distribution of many particles following these motions, could be calculated exactly from Schrödinger's wave equation.)

Although Einstein and others objected to Heisenberg's and Bohr's views, even Einstein had to admit that they are indeed a logical consequence of quantum mechanics. For Einstein, this showed that quantum mechanics is "incomplete." Research has continued to the present on these and proposed alternative interpretations of quantum mechanics. One should note that Heisenberg's uncertainty principle does not say "everything is uncertain." Rather, it tells us very exactly where the limits of uncertainty lie when we make measurements of sub-atomic events. Heisenberg's uncertainty principle constituted an essential component of the broader interpretation of quantum mechanics known as the Copenhagen Interpretation (Cassidy, 2011).

Check Your Progress II

Note: Use the space provided for your answers.

1) How does Heisenberg relate the principle of uncertainty to the principle of causality?
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2) Where lies the basic difference between classical and quantum mechanics?
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3.6 TRIUMPH OF COPENHAGEN INTERPRETATION

The Copenhagen interpretation is a commonly taught interpretation of quantum mechanics. Classical physics draws a distinction between particles and energy, holding that only the latter exhibit waveform characteristics, whereas quantum mechanics is based on the fact that matter has both wave and particle aspects and postulates that the state of every subatomic particle can be described by a wave-function—a mathematical representation used to calculate the probability that the particle, if measured, will be in a given location or state of motion (Cassidy, 2011).

The Copenhagen interpretation of quantum mechancis is an attempt to explain the results of the experiments and their mathematical formulations, as formulated by Bohr, Werner Heisenberg and others in the years 1924–27. They theorised a new world of energy quanta, entities which fit neither the classical idea of particles nor the classical idea of waves. They thereby stepped beyond the world of empirical experiments and pragmatic predictions of such phenomena as the frequencies of light emitted under various conditions. According to their interpretation, the act of measurement causes the calculated set of probabilities to "collapse" to the value defined by the measurement. This feature of the mathematics is known as wave-function collapse. The Copenhagen interpretation is, in form, a composite of those statements which can be legitimately made in natural language to complement the statements and predictions made in the language of instrument readings and mathematical operations (Cassidy, 2011). Essentially, it attempts to answer the question, "What do these amazing experimental results really mean?" The concept that quantum mechanics does not yield an objective description of microscopic reality but deals only with probabilities, and that measurement plays an ineradicable role, is the most significant characteristic of the Copenhagen interpretation.

Because it consists of the views developed by a number of scientists and philosophers during the second quarter of the 20th Century, there is no definitive statement of the Copenhagen Interpretation. Thus, various ideas have been associated with it; Some of its key notions are as follows (CI 2011):

1. A system is completely described by a wave function ψ, representing an observer's subjective knowledge of the system. (Heisenberg)
2. The description of nature is essentially probabilistic, with the probability of an event related to the square of the amplitude of the wave function related to it. (The Born rule, after Max Born)
3. It is not possible to know the value of all the properties of the system at the same time; those properties that are not known with precision must be described by probabilities. (Heisenberg's uncertainty principle)
4. Matter exhibits a wave-particle duality. An experiment can show the particle-like properties of matter, or the wave-like properties; in some experiments both of these complementary viewpoints must be invoked to explain the results, according to the complementarity principle of Niels Bohr.
5. Measuring devices are essentially classical devices, and measure only classical properties such as position and momentum.
6. The quantum mechanical description of large systems will closely approximate the classical description. (The correspondence principle of Bohr and Heisenberg.)

We regard quantum mechanics as a complete theory for which the fundamental physical and mathematical hypotheses are no longer susceptible of modification. (Heisenberg and Max Born, paper delivered to Solvay Congress of 1927)

3.7 DIFFICULTIES AND CHALLENGES

Not everyone agreed with the new interpretation, or with Born and Heisenberg's statement about future work. Einstein and Schrödinger were among the most notable dissenters. Until the ends of their lives they never fully accepted the Copenhagen doctrine. Einstein was dissatisfied with the reliance upon probabilities. But even more fundamentally, he believed that nature exists independently of the experimenter, and the motions of particles are precisely determined. It is the job of the physicist to uncover the laws of nature that govern these motions, which, in the end, will not require statistical theories. The fact that quantum mechanics did seem consistent only with statistical results and could not fully describe every motion was for Einstein an indication that quantum mechanics was still incomplete. Alternative interpretations have since been proposed and are now under serious consideration. The objections of Einstein and others notwithstanding, Bohr, Heisenberg and their colleagues managed to ensure the acceptance of their interpretation by the majority of physicists at that time. They did this both by presenting the new interpretation on lecture trips around the world and by demonstrating that it worked. The successes of the theory naturally attracted many of the best students to institutes such as Heisenberg's, some coming from as far away as America, India, and Japan. These bright students, nurtured by the Copenhagen doctrine and educated into the new quantum mechanics, formed a new and dominant generation of physicists. Those in Germany and Central Europe carried the new ideas with them as they dispersed around the world during the 1930s and 1940s in the wake of Hitler's rise to power in Germany (Cassidy 2011).

Albert Einstein was not happy with the uncertainty principle, and he challenged Niels Bohr and Werner Heisenberg with a famous thought experiment we fill a box with a radioactive material which randomly emits radiation. The box has a shutter, which is opened and immediately thereafter shut by a clock at a precise time, thereby allowing some radiation to escape. So the time is already known with precision. We still want to measure the conjugate variable energy precisely. Einstein proposed doing this by weighing the box before and after. The equivalence between mass and energy from special relativity will allow you to determine precisely how much energy was left in the box. Bohr countered as follows: should energy leave, then the now lighter box will rise slightly on the scale. That changes the position of the clock. Thus the clock deviates from our stationary reference frame, and again by special relativity, its measurement of time will be different from ours, leading to some unavoidable margin of error. In fact, a detailed analysis shows that the imprecision is correctly given by Heisenberg's relation.

Within the widely but not universally accepted Copenhagen interpretation of quantum mechanics, the uncertainty principle is taken to mean that on an elementary level, the physical universe does not exist in a deterministic form—but rather as a collection of probabilities, or potentials (Cassidy 2011). For example, the pattern (probability distribution) produced by millions of photons passing through a diffraction slit can be calculated using quantum mechanics, but the exact path of each photon cannot be predicted by any known method. The Copenhagen interpretation holds that it cannot be predicted by any method.

It is this interpretation that Einstein was questioning when he said "I cannot believe that God would choose to play dice with the universe." Bohr, who was one of the authors of the Copenhagen interpretation responded, "Einstein, don't tell God what to do." Einstein was convinced that this interpretation was in error. His reasoning was that all previously known probability distributions arose from deterministic events. The distribution of a flipped coin or a rolled dice can be described with a probability distribution (50% heads, 50% tails). But this does *not* mean that their physical motions are unpredictable. Ordinary mechanics can be used to calculate exactly how each coin will land, if the forces acting on it are known. And the heads/tails distribution will still line up with the probability distribution (given random initial forces). Einstein did not believe that the theory of quantum mechanics was complete. But Heisenberg and Max Born asserted at the famous Solvay Congress of 1927: “We regard quantum mechanics as a complete theory for which the fundamental physical and mathematical hypotheses are no longer susceptible of modification.” That is the basic difference between them.

3.8 PHILOSOPHICAL IMPLICATIONS OF UNCERTAINTY PRINCIPLE

The Uncertainty Principle is often presented as a manifestation of the fact that the act of measurement inevitably perturbs the state that is being measured. Thus, the smaller the particle being observed, the shorter the wavelength of light needed to observe it, and hence the larger the energy of this light and the larger the perturbation it administers to the particle in the process of measurement. This interpretation, while helpful for visualization, has its limitations. It implies that the particle being observed does have a precise position and a precise momentum which we are unable to ascertain because of the clumsiness of the measurement process. However, more correctly, we should view the Uncertainty Principle as telling us that the concepts of position and momentum cannot coexist without some ambiguity. There is no precise state of momentum and position independent of the act of measurement, as naïve realist philosophers had assumed. In large, everyday situations this quantum mechanical uncertainty is insignificant for all practical purposes. In the sub-atomic world it is routinely confirmed by experiment and plays a fundamental role in the stability of matter. Note that if we take the limit in which the quantum aspect of the world is neglected (so Planck's constant, *h,* is set to zero), then the Heisenberg Uncertainty would disappear and we would expect to be able to measure the position and momentum of any object with perfect precision using perfect instruments (of course in practice this is never possible) (Barrow 2006).

The Uncertainty Principle has had a major effect upon the philosophy of science and belief in determinism. It means that it is impossible to determine the present state of the world (or any small part of it) with perfect precision. Even though we may be in possession of the mathematical laws that predict the future from the present with complete accuracy we would not be able to use them to predict the future. The Uncertainty Principle introduces an irreducible indeterminacy, or graininess, in the state of the world below a particular level of observational scrutiny. It is believed that this inevitable level of graininess in the state of matter in the universe during the first moments of its history led to the production of irregularities that eventually evolved into galaxies (Barrow 2006). Experiments are underway in space to test the detailed predictions about the variations left over in the temperature of the universe that such a theory makes. Of the other pairs of physical quantities that Heisenberg showed cannot be measured simultaneously with arbitrarily high precision, the most frequently discussed pair is energy and time. Strictly, this pair is not a true indeterminate pair like position and momentum because time is not an observable in the way that energy, position, and momentum are in quantum mechanics. By using a time defined externally to the system being observed (rather than intrinsically by it), it would be possible to beat the requirement that the product of the uncertainty in energy times the uncertainty in time be always greater than Planck's constant divided by 4 π (Barrow 2006).

The physicist Niels Bohr (1885–1962) called quantities, like position and momentum, whose simultaneous measurement accuracy was limited by an uncertainty principle *complementary pairs.* The limitation on simultaneous knowledge of their values is called *complementarity.* Bohr believed that the principle of complementarity had far wider applicability than as a rigorous deduction in quantum mechanics. This approach has also been adopted in some contemporary religious apologetics, notably by Donald Mackay and Charles Coulson. There has also been an interest in using quantum uncertainty, and the breakdown of rigid determinism that it ensures, to defend the concept of free will and to provide a channel for divine action in the world in the face of unbreakable laws of nature. The Uncertainty Principle also changes our conception of the vacuum. Quantum uncertainty does not allow us to say that a volume of space is empty or contains nothing. Such a statement has no operational meaning. The quantum vacuum is therefore defined differently, as the lowest energy state available to the system locally. This may not characterize the vacuum uniquely and usually a physical system will have more than one possible vacuum state. Under external changes it may be possible to change from one to another. It is therefore important to distinguish between the non-scientific term, "nothing" and the quantum mechanical conception of "nothing" when discussing creation out of nothing in modern cosmology (Barrow 2006).

Check Your Progress III

Note: Use the space provided for your answers.

1) Why did Einstein object to some of the elements of quantum mechanics?

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2) What are some of the philosophical implications of uncertainty principle?
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3.9 LET US SUM UP

In this unit we tried to see the uncertainty principle, its difficulties and implications. It has changed the way we normally looked at the nature of particle, velocity, etc., and so opened a totally new way of understanding reality.

3.10 KEYWORDS

Decoherence: quantum decoherence (is how quantum systems interact with their environments to exhibit probabilistically additive behavior. Quantum decoherence gives the appearance of wave function collapse (the reduction of the physical possibilities into a single possibility as seen by an observer) and justifies the framework and intuition of classical physics as an acceptable approximation (See also the previous unit keywords).

Matrix mechanics: Matrix mechanics is a formulation of quantum mechanics created by Werner Heisenberg, Max Born, and Pascual Jordan in 1925. Here physical quantities are represented by matrices and matrix algebra is used to predict the outcome of physical measurements.

Momentum: he quantity of motion of a moving body, measured as a product of its mass and velocity.

Wave function collapse: The reduction of the physical possibilities in quantum mechancis into a single possibility as seen by an observer.

Wave mechanics: A method of analysis of the behavior of atomic phenomena with particles represented by wave equations. It is based on Schrodinger's equation; atomic events are explained as interactions between particle waves

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UNIT 4 THE ORIGIN AND THE END OF THE UNIVERSE

Contents

4.0 OBJECTIVES

- To familiarise ourselves with some general theories on the origin and end of the physical universe.
- To know that scientific theories on the universe keep on evolving and changing.
- To be familiar with the commonly accepted theory on the origin and end of the universe (Big Bang and Big Crunch)

4.1 INTRODUCTION

According to Stephen Hawking (1988) the problem of the origin of the universe, is a bit like the old question: Which came first, the chicken, or the egg. In other words, Who created the universe? Or perhaps, the universe, or the agency that created it, existed forever, and didn't need to be created. Up to recently, scientists have tended to shy away from such questions, feeling that they belonged to metaphysics or religion, rather than to science. However, in the last few years, it has emerged that the Laws of Science may hold even at the beginning of the universe and also may explain the end of the universe.

The debate about whether, and how, the universe began, has been going on throughout recorded history. Basically, there were two schools of thought. Many early traditions, and the Jewish, Christian and Islamic religions, held that the universe was created in the fairly recent past. For instance, Bishop Usher calculated a date of four thousand and four BC, for the creation of the universe, by adding up the ages of people in the Old Testament. One fact that was used to support the idea of a recent origin, was that the Human race is obviously evolving in culture and technology. We remember who first performed that deed, or developed this technique. Thus, the argument runs, we cannot have been around all that long. Otherwise, we would have already progressed more than we have. In fact, the biblical date for the creation, is not that far off the date of the end of the last Ice Age, which is when modern humans seem first to have appeared.

The universe of 100 years ago was simple: eternal, unchanging, consisting of a single galaxy, containing a few million visible stars. The picture today is more complete and much richer. The cosmos began 13.7 billion years ago with the big bang. A fraction of a second after the beginning, the universe was a hot, formless soup of the most elementary particles, quarks and leptons. As it expanded and cooled, layer on layer of structure developed: neutrons and protons, atomic nuclei, atoms, stars, galaxies, clusters of galaxies, and finally superclusters. The observable part of the universe is now inhabited by 100 billion galaxies, each containing 100 billion stars and probably a similar number of planets. Galaxies themselves are held together by the gravity of the mysterious dark matter. The universe continues to expand and indeed does so at an accelerating pace, driven by dark energy, an even more mysterious form of energy whose gravitational force repels rather than attracts. In this context, this unit attempts to give some of the common theories on the origin and end of the universe from scientific perspectives. The religious perspectives are not considered here.

4.2 THE ORIGIN OF THE UNIVERSE

Some of the common scientific theories explaining the beginning of the universe

Steady State Theory

Steady State Theory proposes that matter is being continuously created, at the rate of a few hundred atoms per year. This would allow the density of the universe to remain constant as it expands. It holds that the universe looks, on the whole, the same at all times and places. The Austrian-British astronomer Hermann Bondi and the Austrian-American astronomer Thomas Gold formulated the theory in 1948. The British astronomer Fred Hoyle soon published a different version of the theory based on his mathematical understanding of the problem. Most astronomers believe that astronomical observations contradict the predictions of the steady-state theory and uphold the big bang theory. The infinite duration of time was the most appealing feature of the steady state theory. Even the notion of creation was used to advantage: the failure to detect a large flux of gamma rays led to the proposal that creation preferentially took place only in dense galactic nuclei and quasars. This proposal initially met with some enthusiasm, because it appeared to solve two problems: continuous creation was revived, and an ample energy source was provided for the most energetic objects in the universe.

However, three shortcomings eventually led to the demise of steady state cosmology. First, astronomers have discovered a large increase in the number of faint radio sources as the limiting flux level is systematically decreased. The number that they estimate is well above that expected for a uniform source distribution in Euclidean space, which suggests that strong evolutionary effects are occurring at great distances. The notion of an excess number of distant faint sources did not find universal acceptance. For several years, Hoyle was able to argue that an equally plausible hypothesis was a deficit of nearby bright sources. Now, however, it seems clear with measured redshifts that the highly red shifted sources, most notably the radio galaxies and the quasars, reveal strong evolutionary effects. Equal volumes of space contain progressively more quasars and powerful radio galaxies at greater distances. Looking at evidence, explanations, rationalizations, and arguments for naturalistic origins of the universe leads to a simple conclusion. Once all of the cards are on the table, recent discoveries have given life to interpretations that are long on theory and short on proof. To put it another way, all scientists have really proven about the origin of the universe is that they don’t really know how it happened, and they may be looking at it the wrong way.

Check Your Progress I

Note: Use the space provided for your answer

1) Give an approximate size of our universe?

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2) Give a brief description of the steady-state theory.

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Big Bang Theory

The Big Bang theory is an effort to explain what happened at the very beginning of our universe. Discoveries in astronomy and physics have shown beyond a reasonable doubt that our universe did in fact have a beginning. According to the standard theory, our universe sprang into existence as "singularity" around 13.7 billion years ago. Our universe is thought to have begun as an infinitesimally small, infinitely hot, infinitely dense, something - a singularity. We don't know where it came from not why did it appear. After its initial appearance, it apparently inflated (the "Big Bang"), expanded and cooled, going from very, very small and very, very hot, to the size and temperature of our current universe. It continues to expand and cool to this day and we are inside of it: incredible creatures living on a unique planet, circling a beautiful star clustered together with several hundred billion other stars in a galaxy soaring through the cosmos.

Evidence for the Theory

First of all, we are reasonably certain that the universe had a beginning. Second, galaxies appear to be moving away from us at speeds proportional to their distance. This is called "Hubble's Law," named after Edwin Hubble (1889-1953) who discovered this phenomenon in 1929. This observation supports the expansion of the universe and suggests that the universe was once compacted. Third, if the universe was initially very, very hot as the Big Bang suggests, we should be able to find some remnant of this heat. In 1965, Radio astronomers Arno Penzias and Robert Wilson discovered a 2.725 degree Kelvin (-454.765 degree Fahrenheit, -270.425 degree Celsius) Cosmic Microwave Background radiation (CMB) which pervades the observable universe. This is thought to be the remnant which scientists were looking for. Penzias and Wilson shared in the 1978 Nobel Prize for Physics for their discovery. Finally, the abundance of the "light elements" Hydrogen and Helium found in the observable universe are thought to support the Big Bang model of origins.

Big Bang Theory - What About God?

Any discussion of the Big Bang theory would be incomplete without asking the question, what about God? This is because cosmogony (the study of the origin of the universe) is an area where science and theology meet. Creation was a supernatural event. That is, it took place outside of the natural realm. This fact begs the question: is there anything else which exists outside of the natural realm? Specifically, is there a master Architect out there? We know that this universe had a beginning. Was God the "First Cause"?

Check Your Progress II

Note: Use the space provided for your answer

1) Give a brief description of Big Bang?

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2) What are some of the evidences for Big Bang Theory.

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4.3 THE END OF THE UNIVERSE

Theories explaining the end of the universe are the following.

Heat Death

German physicist Hermann von Helmholtz made a prediction in the year 1856 that the universe is dying. This prediction was based on the law of thermodynamics. A more thoroughgoing analysis enables this law to be generalized to all closed systems: the entropy never falls. If the universe as a whole can be considered as a closed system, on the basis that there is nothing 'outside' it, then the second law of thermodynamics makes an important prediction: the total entropy of the universe never decreases. In fact it goes on rising remorselessly. When heat flows from hot to cold, the entropy rises, but eventually the cold body will warm up and the hot body will cool down so that they reach the same temperature. When the state is achieved, there will be no further heat transfer. The system inside the container will have reached a uniform temperature – a stable state of maximum entropy referred to as thermodynamic equilibrium. No further change is expected, as long as the system remains isolated. All physical activity in the universe tends toward a final state of thermodynamic equilibrium, or maximum entropy, following which nothing of value is likely to happen for all eternity. This one-way slide toward equilibrium became known to the early thermodynamicists as the 'heat death' of the universe.

Big Freeze

Observations suggest that the expansion of the universe will continue forever. If so, the universe will cool as it expands, eventually becoming too cold to sustain life. For this reason, this future scenario is popularly called the Big Freeze. The future of an expanding universe is bleak. If a cosmological constant accelerates the expansion of the universe, the space between clusters of galaxies will grow at an increasing rate. Redshift will have stretched ancient, incoming photons (even gamma rays) to undetectably long wavelengths and low energies. Stars are expected to form normally for 1×1012 to 1×1014 years, but eventually the supply of gas needed for star formation will be exhausted. Once the last star has exhausted its fuel, stars will cease to shine. According to theories that predict proton decay, the stellar remnants left behind would disappear, leaving behind only black holes which themselves eventually disappear as they emit Hawking radiation. Ultimately, if the universe reaches a state in which the temperature approaches a uniform value, no further work will be possible, resulting in a final heat death of the universe.

The Big Rip

A new and somewhat sinister theory about the long-term future of the universe is emerging. It has been called the “Big Rip”, and it forecasts that our bodies will be literally torn apart. Its leading proponent Robert Caldwell of Dartmouth University calls it a “pretty fantastic possibility”, but he and his colleagues cannot see how it can be avoided if the present acceleration of the cosmos continues. The idea is like this: the universe, driven by that mysterious force called “dark energy”, or repulsive gravity, is flying apart. The furthest galaxies are moving ever further from us. But the rate of expansion is itself accelerating. The accelerating acceleration continues unchecked. Eventually the increased acceleration comes every 100 yards, and at last every foot. Finally everything explodes. “The expansion becomes so fast that it literally rips apart all bound objects,” says Caldwell.

There is no need for immediate panic, since this dreadful sequence of events will not become noticeable for another 20 billion years. At this point all galaxies beyond our own, traveling much faster than light, will have flown so far away from us that they become invisible. (This is not a violation of Einstein's special relativity. The galaxies are not flying through space. In the expanding universe, space itself expands.) Our Milky Way galaxy alone can be seen. Then the Milky Way begins to fly apart, and at this point there are only 60 million years left. Long before this, of course, other events will have destroyed our Sun and planets. But imagine some part of humanity inhabiting the planets of another stellar system. When there are only three months left, these planets and their parent Sun explode. “There's about 30 minutes left before atoms and their nuclei break apart,” says Caldwell, “but it's not quality time. We're not sure what happens after that. On the face of it, it would look like time ends.” Repulsive dark energy, although we know next to nothing about its cause, comprises 73 per cent of all the energy in the cosmos. It exists everywhere in the vacuum of space.

Check Your Progress III

Note: Use the space provided for your answers.

1) What is heat death theory?

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2) Give your comments on the Big Rip theory.

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Big Bounce

The Big Bounce is a theorized scientific model related to the formation of the known universe. It derives from the cyclic model or oscillatory universe interpretation of the Big Bang where the first cosmological event was the result of the collapse of a previous universe. According to some oscillatory universe theorists, the Big Bang was simply the beginning of a period of expansion that followed a period of contraction. In this view, one could talk of a Big Crunch followed by a

Big Bang, or more simply, a Big Bounce. This suggests that we might be living in the first of all universes, but are equally likely to be living in the 2 billionth universe (or any of an infinite other sequential universes).

Multiverse: No Complete End

The multiverse (or meta-universe, metaverse) is the hypothetical set of multiple possible universes (including the historical universe we consistently experience) that together comprise everything that exists: the entirety of space, time, matter, and energy as well as the physical laws and constants that describe them. The term was coined in 1895 by the American philosopher and psychologist William James. The various universes within the multiverse are sometimes called parallel universes. The structure of the multiverse, the nature of each universe within it and the relationship between the various constituent universes, depend on the specific multiverse hypothesis considered. Multiverses have been hypothesized in cosmology, physics, astronomy, religion, philosophy, transpersonal psychology and fiction, particularly in science fiction and fantasy. In these contexts, parallel universes are also called "alternative universes", "quantum universes", "interpenetrating dimensions", "parallel dimensions", "parallel worlds", "alternative realities", and "alternative timelines", among others.

Cyclic Theories

In several theories there is a series of infinite, self-sustaining cycles (for example: an eternity of Big Bang-Big crunches). A multiverse of a somewhat different kind has been envisaged within the multi-dimensional extension of string theory known as M-theory, also known as Membrane Theory. In M-theory our universe and others are created by collisions between p-branes in a space with 11 and 26 dimensions (the number of dimensions depends on the chirality of the observer); each universe takes the form of a D-brane. Objects in each universe are essentially confined to the D-brane of their universe, but may be able to interact with other universes via gravity, a force which is not restricted to D-branes. This is unlike the universes in the "quantum multiverse", but both concepts can operate at the same time.

The concept of other universes has been proposed to explain why our universe seems to be fine-tuned for conscious life as we experience it. If there were a large number (possibly infinite) of different physical laws (or fundamental constants) in as many universes, some of these would have laws that were suitable for stars, planets and life to exist. The weak anthropic principle could then be applied to conclude that we would only consciously exist in those universes which were finely-tuned for our conscious existence. Thus, while the probability might be extremely small that there is life in most of the universes, this scarcity of life-supporting universes does not imply intelligent design as the only explanation of our existence.

Critics claim that many of these theories lack empirical testability, and without hard physical evidence are unfalsifiable; outside the methodology of scientific investigation to confirm or disprove. Reasons why such claims lack empirical evidence or testability according to most Multiverse theories is that other universes are in a different spacetime framework, so in principle they cannot be observed.

The logical foundation of modern science is hypothetico-deductive logic which permits a theory to propose unobservable entities if these help explain observable outcomes, either by theory based predictions (of future observations) or retroductionism (of already known observations).

False vacuum

In quantum field theory, a false vacuum is a metastable sector of space that appears to be a perturbative vacuum, but is unstable due to instant on effects that may tunnel to a lower energy state. This tunneling can be caused by quantum fluctuations or the creation of high-energy particles. Simply put, the false vacuum is a local minimum, but not the lowest energy state, even though it may remain stable for some time. This is analogous to metastability for first-order phase transitions. The possibility that we are living in a false vacuum has been considered. If a bubble of lower energy vacuum were nucleated, it would approach at nearly the speed of light and destroy the Earth instantaneously, without any forewarning. Thus, this vacuum metastability event is a theoretical doomsday event. This was used in a science-fiction story in 1988 by Geoffrey A. Landis, in 2000 by Stephen Baxter, and in 2002 by Greg Egan. According to the many-worlds interpretation of quantum mechanics, the universe will not end this way. Instead, each time a quantum event happens that causes the universe to decay from a false vacuum to a true vacuum state, the universe splits into several new worlds. In some of the new worlds the universe decays; in some others the universe continues as before.

The big crunch

In physical cosmology, the Big Crunch is one possible scenario for the ultimate fate of the universe, in which the metric expansion of space eventually reverses and the universe recollapses, ultimately ending as a black hole singularity. If the universe is finite in extent and the cosmological principle (not to be confused with the cosmological constant) does not apply, and the expansion speed does not exceed the escape velocity, then the mutual gravitational attraction of all its matter will eventually cause it to contract. Because entropy continues to increase in the contracting phase, the contraction would appear very different from the time reversal of the expansion. While the early universe was highly uniform, a contracting universe would become increasingly clumped. Eventually all matter would collapse into black holes, which would then coalesce producing a unified black hole or Big Crunch singularity.

The Hubble Constant measures the current state of expansion in the universe, and the strength of the gravitational force depends on the density and pressure of the matter and in the universe, or in other words, the critical density of the universe. If the density of the universe is greater than the critical density, then the strength of the gravitational force will stop the universe from expanding and the universe will collapse back on itself. Conversely, if the density of the universe is less than the critical density, the universe will continue to expand and the gravitational pull will not be enough to stop the universe from expanding. This scenario would result in the 'Big Freeze', where the universe cools as it expands and reaches a state of entropy. Some theorize that the universe could collapse to the state where it began and then initiate another Big Bang, so in this way the universe would last forever, but would pass through phases of expansion (Big Bang) and contraction (Big Crunch).

Recent experimental evidence (namely the observation of distant supernova as standard candles, and the well-resolved mapping of the cosmic microwave background) have led to speculation that the expansion of the universe is not being slowed down by gravity but rather accelerating. However, since the nature of the dark energy that drives the acceleration is unknown, it is still possible (though not observationally supported as of today) that it might eventually reverse sign and cause a collapse.

Check Your Progress IV

Note: Use the space provided for your answers.

1) Give an evaluation of the cyclic theory of the universe?

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2) What is a false vacuum?

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4.4 LET US SUM UP

In this unit after having seen some of the theories on the origin of the universe, we have focussed on the end of the universe. The whole unit has been dealing with the different scientific theories and not the religious theories of the origin and destiny of our universe.

4.5 KEY WORDS

Singularities are zones which defy our current understanding of physics. They are thought to exist at the core of "black holes." Black holes are areas of intense gravitational pressure. The pressure is thought to be so intense that finite matter is actually squished into infinite density (a mathematical concept which truly boggles the mind). These zones of infinite density are called "singularities."

Big Crunch: In physical cosmology, the Big Crunch is one possible scenario for the ultimate fate of the universe, in which the metric expansion of space eventually reverses and the universe recollapses, ultimately ending as a black hole singularity.

Big Rip: The Big Rip is a cosmological hypothesis first published in 2003, about the ultimate fate of the universe, in which the matter of the universe, from stars and galaxies to atoms and subatomic particles, are progressively torn apart by the expansion of the universe at a certain time in the future.

The Big Bounce is a theorized scientific model related to the formation of the known Universe. It derives from the cyclic model or oscillatory universe interpretation of the Big Bang where the first cosmological event was the result of the collapse of a previous universe

Big Freeze: Recent observations suggest that the expansion of the universe will continue forever. If so, the universe will cool as it expands, eventually becoming too cold to sustain life. For this reason, this future scenario is popularly called the Big Freeze.

Heat Death and Cold Death: In a simple definition, heat death will occur when all energy (heat) is supposedly evenly distributed throughout the universe, so that there is no place for it to go. In thermodynamics, energy is continuously being transferred through objects in the form of work or heat. The heat-death of the universe is when the universe has reached a state of maximum entropy. This happens when all available energy (such as from a hot source) has moved to places of less energy (such as a colder source). Once this has happened, no more work can be extracted from the universe. Since heat ceases to flow, no more work can be acquired from heat transfer. This same kind of equilibrium state will also happen with all other forms of energy (mechanical, electrical, etc.). Since no more work can be extracted from the universe at that point, it is effectively dead, especially for the purposes of humankind. This concept is quite different from what is commonly referred to as cold death. Cold death is when the universe continues to expand forever. Because of this expansion, the universe continues to cool down. Eventually, the universe will be too cold to support any life; it will end in a whimper. The opposite of cold death, is NOT "heat death" but actually the Big Crunch. The big crunch occurs when the universe has enough matter density to contract back on itself, eventually shrinking to a point. This shrinking will cause the temperature to rise, resulting in a very hot end of the universe.

4.6 FURTHER READINGS AND REFERENCES

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