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Time Dilation

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Abstract:- Time Dilation, in simple words, is a phenomenon where time passes at varying rates depending on the frame of reference of the observer. The main cause of this phenomenon can be the relative motion between the observers or the difference in gravitational potential energy. It has also been verified experimentally in several ways like the Hafele-Keating Experiment which has demonstrated that time dilation is a real effect and not just a phenomenon in our understanding of relativity. Time dilation has several important implications for our understanding of the universe. For instance, it could also explain why the universe is expanding increasingly fast. This could also explain why light from distant stars appears to be redshifted. Time dilation has always been an intriguing topic that is still studied by physicists today.

Keywords:- *Relativity, Time dilation, Reference.*

I. INTRODUCTION

Time Dilation is one of the most talked about topics among science and research enthusiasts and has been a topic of discussion for a long time. The topic was first mentioned by the famous theoretical physicist, Albert Einstein. The topic of time dilation is the consequence of Albert Einstein's famous theory of relativity. But before going deeper into the following topic, some basic topics need to be understood.

II. THEORY OF RELATIVITY

The **Theory of Relativity** was discovered by Sir Albert Einstein. The theory is basically the study of motion. The theorem states that "space and time are relative, and all motion must be relative to a frame of reference". The theory further broadens into two categories:- First, is the **Theory of Special Relativity**, which holds true for all physical events even when gravity is absent. Secondly, is the **Theory of General Relativity** which describes the gravitational rules and their connections to other natural forces. According to Sir Albert Einstein's belief, no absolute space exists in reality and so does absolute motion. Therefore, every motion is and has to be relative to something or the other. If someone describes the "Velocity of a body is 10m/s", the following statement can be termed incoherent because it has not been mentioned by the speaker the velocity of the body is relative to what? However, the following statement can be made relevant just by mentioning to which the velocity of the body is relative, i.e. the statement can be said as "The velocity of Body A is 10m/s relative to Body B" where body A and B are two different bodies.

III. INERTIAL FRAME OF REFERENCE

Because of non-absolute motion, the **Inertial Frame of Reference** comes into play. Continuing with the above example, the velocity of a particular body can be different for people at different Inertial Frame of Reference. If a body is moving with a certain velocity, its velocity looks different for different observers in different frames of reference although the original velocity of the body is maintained throughout.

For Example:

If a body is thrown from a moving body like a car, then the velocity of the thrown body can be different at different frames of reference.

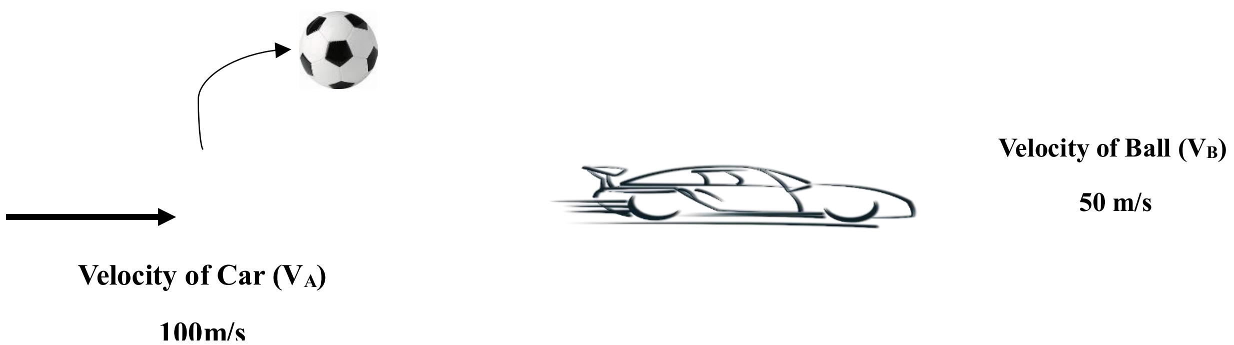

Fig. 1: Throwing Of Ball From A Moving Car

In the above case, if the velocity of the ball is calculated, it is observed to be different at different frames.

- The velocity of the Ball observed by a person sitting inside the car will be equal to the original velocity of the ball which is equal to 50 m/s.
- The velocity of the ball observed by a stationary person sitting outside will observe the velocity of the ball as the summation of the velocity of the car together with that of the ball.
- Therefore, the velocity of the ball according to this person will be equal to 150 m/s ((100+50)m/s).

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IV. RELATIVITY OF SIMULTANEITY

The concept of time dilation can be termed as a concept of the passage of time at different rates according to different observers. This phenomenon actually occurs due to the theory of Relativity of Simultaneity. This theory states that a stationary reference frame assigns a single time frame to more than one event at different points in space whereas if the reference frames are in motion relative to the first, then there will be a small (not too large rather fractional in some cases) change in the times noted for different events. This theory can also be testified by an example.

For Example:
There are two figures given below.

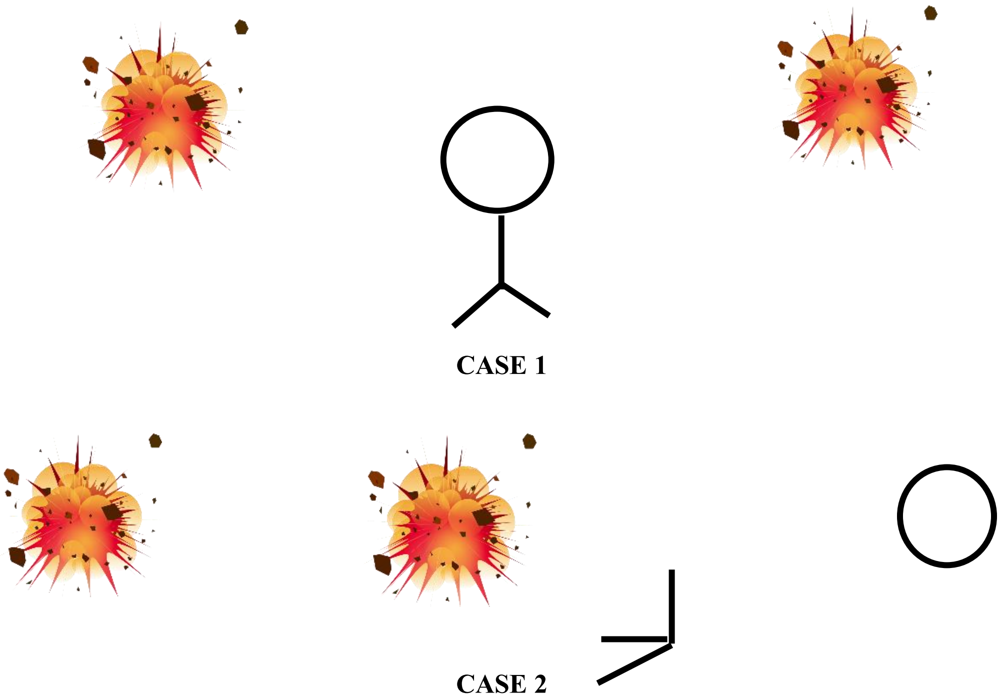

Fig. 2: Blasting Of Bombs As Observed By 2 Observers

Two bombs blast at the same time. In the first figure, the person remains stationary and sees the whole event at the same time. Therefore, the person thinks that the bombs had blasted simultaneously at the same time. However, in the second figure, the person is moving in the forward direction. Since the person sees the forward blast first, the person thinks that the occurrence of the front blast was faster than the behind one.

Therefore, Time Dilation occurs when the motion of the observer is relative to another as a result of which the time in their frame of reference flows slowly. Between the same two events taking place, a clock that is present in an accelerating body will measure shorter elapsed time as compared to an inertial or clock present in a non-accelerating body.

V. HAFELE-KEATING EXPERIMENT

- The following experiment was performed in the year 1971 by the famous physicist, Joseph C. Hafele and astronomer, Richard E. Keating. The following experiment included four caesium beam atomic clocks. The clocks were flown over commercial flights to East and West respectively. The times in the clocks were then compared with the clock situated in the U.S. Naval Observatory. When observed all three sets of time were found to be different from each other and a consistency of difference was observed in the rates of time. According to the Theory of Relativity, the rate of a clock is usually the maximum when the observer observes the body when at rest. On the other hand, according to the experiment, the motion towards the east is along the direction of the rotation of the earth and therefore greater velocity, thus resulting in a relative time loss. However, when the motion of the body is towards the west, the motion is against the direction of rotation of the earth and thus relatively lesser velocity.
- Now, let there be a person sitting in a car with a clock that is timing a pulse of light reflected between two mirrors in the car, one above another, at a distance l away from one another. There is a second observer as well who observes the car as it travels along a parallel road.

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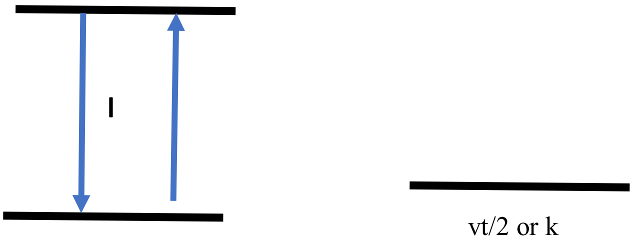

Fig. 3: Reflection Of Light Pulse Sent By A Simple Clock Made By Observer In Car

According to the observer sitting inside the car, the total distance travelled by light is **2l** whereas according to the observer on the road, the total distance is **2a** since the car is moving at a velocity v in the rightwards direction relative to the observer on the road.

$$\Delta t_0 = \frac{2l}{c}$$

The time observed by the observer on the platform will be:

$$\Delta t = \frac{2a}{c}$$

Now let's give a variable name to $\frac{vt}{2}$ as '**k**'. Applying the Pythagoras theorem in the given triangle, then 's' will be

$$a = \sqrt{l^2 + k^2}$$

According to the problem,

Substituting the value of 'a' in the equation of Δt,

$\Delta t = \frac{2a}{c} = \frac{2\sqrt{L^2+k^2}}{c}$Squaring both sides and writing value of variable **'k'** as $\frac{vt}{2}$

$$(\Delta t)^2 = (\frac{2\sqrt{L^2 + k^2}}{c})^2 = \frac{4(L^2 + k^2)}{c^2} = \frac{4(L^2 + (\frac{vt}{2})^2)}{c^2} = \frac{4L^2 + (vt)^2}{c^2}$$

Since $\frac{4L^2}{c^2}$ is equal to $(\Delta t_0)^2$, we get

$$(\Delta t)^2 = (\Delta t_0)^2 + \frac{(vt)^2}{c^2}$$

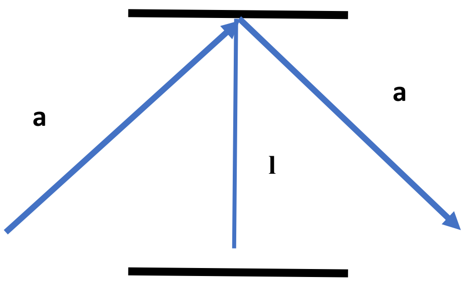

Fig. 4: Reflection Of Light Pulse Sent By A Simple Clock Made By Observer On Road

Therefore we get Δt as,

$$(\Delta t)^2 \cdot (1 - \frac{v^2}{c^2}) = (\Delta t_0)^2$$

Solving further, we get

$$(\Delta t)^2 = \frac{(\Delta t_0)^2}{\left(1 - \frac{v^2}{c^2}\right)}$$

Taking square root on both the sides,

$$\Delta t = \frac{\Delta t_0}{\sqrt{1 - \frac{v^2}{c^2}}} = \gamma \Delta t_0$$

where, value of γ is,

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

VI. WHY UNIVERSE IS INCREASING RAPIDLY FAST AND LIGHT FROM DIFFERENT STARS APPEAR TO BE REDSHIFTED?

The universe is in a state of expansion caused by a mysterious force called dark energy. This mysterious force is responsible for accelerating the structure of spacetime, leading to an increasing rate of expansion. So the distance between galaxies increases with time. To understand why the expansion of the universe is accelerating, we turn to the concept of time dilation, which is explained by the effect of time dilation according to general relativity. Within the framework of general relativity, it has been shown that time passes more slowly in regions with strong gravitational fields. This implies that time passes more slowly in the vast expanse of space separating the galaxies than in the close proximity of the galaxies themselves. As a result, the transmission of light from one galaxy to another is delayed. So, over time, the time it takes for light to travel through intergalactic space increases. The cause behind the redshift appearance of light from distant galaxies is a phenomenon called redshift, in which light from distant objects are shifted towards the red end of the spectrum. This observation supports the hypothesis that time dilation could explain the accelerated expansion of the universe. The accelerated expansion of the universe remains an important mystery in the field of physics, and scientists are using time dilation as one of the research tools to solve this mystery. By studying time dilation, the researchers hope to better understand the mechanism behind the expansion of the universe and uncover potential solutions to this fascinating mystery.

VII. CONCLUSION

Time dilation is an interesting and important phenomenon that has been experimentally verified. This has a number of implications for our understanding of the universe, including the rapid expansion of the universe.

Here are some key points mentioned in the document:

- Based on the relative mobility or position in the gravitational field of the observer, Time Dilation is the perception of time as slowing down by one observer in comparison to another.
- Time dilation has been experimentally confirmed in several ways including the Hafele-Keating.
- Time dilation has a number of implications for our understanding of the universe, including the accelerating expansion of the universe.

Time dilation is still studied by physicists today and has the potential to revolutionize our understanding of the universe and our place in it.

REFERENCES

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