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Article

Extending Einstein's elevator thought experiment to multiple spatial dimensions at the Luxor Hotel & Casino

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SUMMARY

In 1907, Albert Einstein wrote one of his most important works, involving a comparison of the physical phenomenon that would be observed in an imaginary elevator in a gravitational field and an imaginary elevator that is accelerating in a zero-gravity environment (1). This thought experiment had far-reaching implications regarding gravitational and inertial mass (1), the bending of spacetime (2,3), and the curving of light by gravity (4,5). Now, a century later, we expand on Einstein's principles and conduct the experiment in an actual elevator traveling at an angle in the pyramid-shaped Luxor Hotel and Casino in Las Vegas. This raises the research question, "Can the angle of the accelerating inclined elevator be measured from inside the elevator with no view of the outside world?" To answer this question, we designed a series of experiments based on the decomposition of motion vectors and Einstein's Equivalency Principle. The experiment yielded data that accurately measured the angle of inclination and reasonable conclusions were drawn that the angle of inclination could in fact be measured with no view of the outside world.

INTRODUCTION

In discussing the methodology of examining the motion status (e.g., acceleration, moving at a constant speed, or at rest) of an object on Earth, we need to review Einstein's famous 1907 thought experiment where Einstein's Equivalency Principle was proposed. Einstein thought of two identical elevators, except that one was stationary in the Earth's gravitational field and the other was accelerating upwards through deep space (i.e., in the absence of a gravitational field) at 9.8 m/s^2. Einstein declared that the physics inside each elevator would be identical, assuming that there was one observer standing exactly at the same position in each elevator. For example, if one dropped a ball inside each elevator from the same height at the same time, the behavior of the balls would be identical to the observers, respectively. In other words, the balls would fall at the same rate and hit the floor at the same time. The two frames of reference are equivalent and the person inside the elevator is unable to tell if they are in the stationary elevator on Earth's gravitational field or if they are accelerating (1).

To better understand Einstein's Equivalency Principle, we intended to conduct an actual elevator experiment arising from this equivalency, "Would the observer inside the elevator be able to qualitatively detect and quantitively measure the acceleration while inside the elevator, with no view of the outside world?" Given that it was not possible to conduct this experiment in zero-gravity, we designed an experiment to be conducted on a real elevator accelerating in the Earth's gravitational field. In fact, the experiment would require measuring the acceleration in more than one dimension if the acceleration of the elevator does not align with the same direction of gravity. Such an elevator exists here in Las Vegas, Nevada. Inside the Luxor Hotel and Casino, which is a pyramid-shaped building, the elevators are inclined at a specific angle. Thus, the question becomes, "Would it be possible to measure the magnitude and direction of the elevator's acceleration with no view of the world outside the elevator?"

Einstein's elevator thought experiment and the resulting theory of relativity became central themes in modern physics. Any work that enriches our understanding of this theory serves to advance our overall understanding of space and time. Our calculations for the inclination of the elevator were in close agreement with the actual value of 39 degrees. (**Figure 1**).

Figure 1: Luxor Discovery Fact: an inclination angle of 39-degree.

RESULTS

In order to determine if the acceleration of an inclined elevator could be measured from the inside, we conducted our experiment on an inclined elevator such that the acceleration direction follows along with the movement of the elevator. According to Newton's second law and the decomposition of the movement, the observed acceleration can be expressed as a combination of two orthogonal accelerations: vertical and horizontal (**Figure 2**). The lengths of the vectors represent the magnitude of the accelerations, respectively, and the angle between the combination acceleration and horizon indicates the incline angle (**Figure 3**).

The weight of the observer was measured using a common bathroom scale (**Figure 4**) and the vertical acceleration was calculated. Since the weight at rest (W_{rest}) is measured (262 lb. or 1166 N) and the gravity on Earth is constant (a_{rest} = g = 9.8 m/s^2), the mass of the observer can be computed as 119 kg (Eq. (1)). When the elevator accelerated upwards, the acceleration in the vertical direction caused the weight to increase, but the mass remains intact. The weight at acceleration (W_{acc}) was recorded as 273 lbs (1216 N) and the gravity under acceleration (aacc) can be computed as in Eq. (2). The experiment was duplicated 5 times to ensure data integrity.

$$W_{rest} = m * a_{rest} \quad 1166 \text{ N} = m * 9.8 \text{ m/s}^2 \quad m = 119 \text{ kg} \qquad \text{Eq. (1)}$$

$$W_{acc} = m * a_{acc} \quad 1216 \text{ N} = 119 \text{ kg} * a_{acc} \quad a_{acc} = 10.2 \text{ m/s}^2 \qquad \text{Eq. (2)}$$

The difference between two "gravities" under each scenario is the vertical acceleration provided by the elevator (av), which can be calculated by Eq. (3).

$$W_{acc} - W_{rest} = m * a_v \quad a_v = 0.4 \text{ m/s}^2 \qquad \text{Eq. (3)}$$

The vertical acceleration was again measured using the common bathroom scale with the second observer. The weight was measured as 110 lbs (490 N) and mass to be 50 kg at rest and the weight becomes 114.5 lbs (510 N) during acceleration. The experiment with the second observer was also duplicated for 5 times to ensure data integrity, and we achieve the same vertical acceleration (0.4 m/s^2) of the elevator.

The next step was to compute the horizontal acceleration of the elevator. To achieve this goal, a key ring was tied to one end of a string and the other end was attached to a protractor (**Figure 5**). As the elevator accelerated horizontally, the key ring swept through an arc and was hung at a particular angle (i.e. 3) against the vertical direction, which was measured on the protractor. The tangent of the angle was multiplied by the previously measured vertical "gravity", which is 10.2 m/s^2, and the horizontal acceleration was computed as Eq. (4):

$$a_h = \tan(3^o) * a_{acc} = 0.052 * 10.2 \text{ m/s}^2 = 0.53 \text{ m/s}^2 \qquad \text{Eq. (4)}$$

The two components of vertical and horizontal acceleration were then resolved into a single vector as Eq. (5), which approximates to the actual value for inclination stated in hotel (i.e. 39, **Figure 1**).

$$\text{angle of inclination} = \tan^{-1}(a_v / a_h) = \tan^{-1}(0.40/0.53) \approx 37° \qquad \text{Eq. (5)}$$

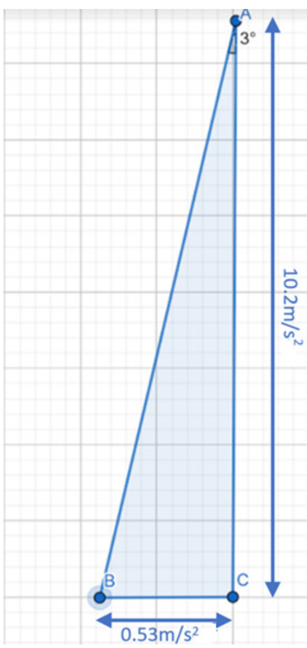

Figure 2: Calculating the horizontal acceleration.

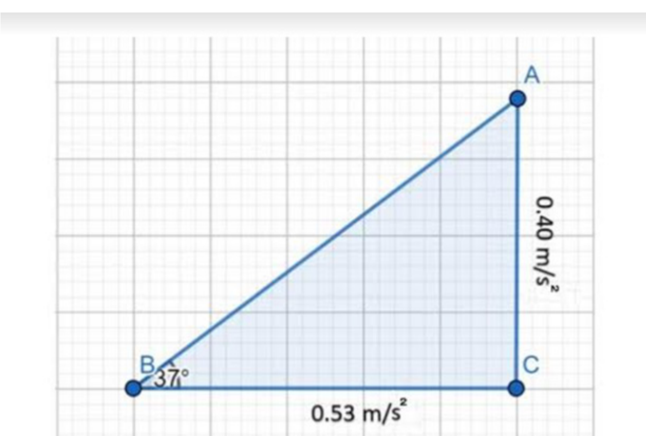

Figure 3: Calculating the angle of inclination.

Figure 4: Measuring the change in weight due to the vertical acceleration.

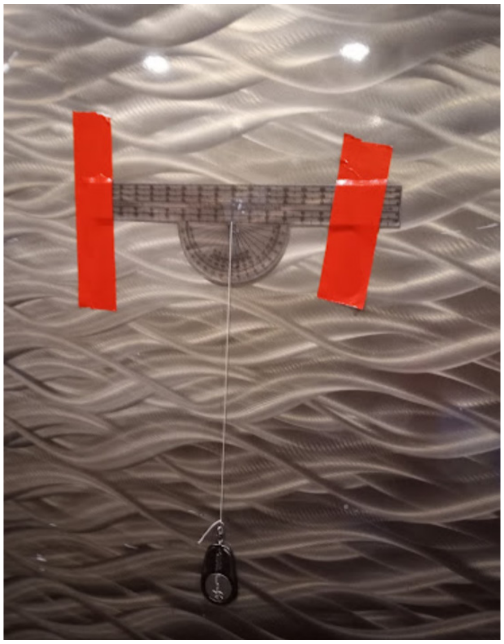

Figure 5: Measuring the deviation angle between the vertical line and the direction of the total acceleration (with gravity).

DISCUSSION

To summarize, the conducted experiment and outcomes supported our original hypothesis and verified that both acceleration and inclination of the elevator can be measured from the inside, with no view of the outside world. The experiment was reproducible with observers of different masses, producing the same conclusion.

It should be noted that a possible source of error was in measuring the horizontal acceleration with a protractor. The first attempt of the experiment involved a hand-held protractor to measure the angle, while in the second attempt, the protractor was fastened to the wall of the elevator with duct tape. The second configuration was not subject to the natural unsteadiness of the human hand, and for this reason we had greater confidence that the data were accurate. In both trials, an angle was measured at 3 degrees, in between the perpendicular line and the string with key ring (**Figure 5**). The significant figures could be reported at best to an estimated tenth of a degree. If the floor of the elevator was not perfectly horizontal, it would significantly change the interpretation of the data. Therefore, a carpenter's level was used, together with the protractor, to verify that angle between vertical and perpendicular line and the string with key ring.

In the future, we would like to repeat the experiment with digital accelerometers, which could provide higher accuracy and maximumly eliminate sources of experimental error. Two accelerometers could be employed to simultaneously measure horizontal and vertical acceleration.

Einstein's elevator thought experiment set the stage for one of the most major advances in physics. It led to the development of the Theory of Relativity which ultimately changed our understanding of gravity, acceleration, and space-time (7). These new ideas ultimately led to the development of nuclear power and the weapons that ended WWII. The Luxor experiment was conducted in an elevator that did not move or accelerate in a direction parallel to gravity. This experiment makes significant additions to Einstein's 1907 work. It someday could serve as the basis of a model for space-time curving in response to multiple gravitational sources, such as one would find when light traveled past a binary star.

MATERIALS AND METHODS

Preparation

The experiment began by traveling to the Luxor Hotel and Casino in Las Vegas, NV. and renting a room. This allowed access to the inclined elevators used by guests. We walked to the guest elevators and selected an elevator to use for data collection. A carpenter's level was used to verify the floor was horizontal and not angled. We fastened a protractor with a weight and string to the wall located perpendicular to the door using duct tape, A bathroom scale was placed on the floor of the elevator and two observers would record their weights at rest and accelerating. Data collection begins at Floor 5.

Data Collection

With the elevator stopped at Floor 5 one observer would step on the bathroom scale and record their weight at rest. The other observer would send the elevator to Floor 21. The first observer would record the maximum weight displayed on the digital scale during acceleration (**Figure 4**). The other observer would record the maximum angle formed by the string and protractor during acceleration. (**Figure 5**).

A trip would be considered successful if the elevator traveled from Floor 5 to Floor 21 with no stops in between. Five pairs of vertical and horizontal accelerations were calculated for each observer.

Method of Analysis

Each trial generated a horizontal and a vertical component. Each of these components were resolved into a single vector. The directions of these vectors were compared to the known inclination of the elevator, which was 39 degrees. There was excellent agreement.

Perhaps no other physicist has made a greater contribution to the field than Albert Einstein. Any experiment which clarifies or extend his work is of great importance. Einstein's elevator and the theory of relativity had major significance in expanding the understanding of space, time and gravity (7). Perhaps one day the Luxor Experiment done by the students at Nasri Academy will be the basis of a model for the curvature of space time as light passes two or more gravitational lenses.

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