Unreasonable Results A 75.0-kg Man Stands On A Bathroom Scale In An Elevator That Accelerates From Rest

Unreasonable Results A 75.0-kg Man Stands On A Bathroom Scale In An Elevator That Accelerates From Rest

Introduction

Imagine a scenario where a man weighing 75.0 kilograms stands on a bathroom scale inside an elevator that initially rests at rest. When the elevator begins to accelerate upwards or downwards, the reading on the scale may seem counterintuitive, leading to what some might consider "unreasonable" results. These apparent anomalies are rooted in the fundamental principles of physics, particularly Newton's laws of motion and the concept of apparent weight. Understanding the physics behind these readings requires a detailed analysis of the forces involved, the nature of acceleration, and how the scale measures weight under dynamic conditions.

Understanding the Basic Concepts

What Is Apparent Weight?

- Definition: Apparent weight is the normal force exerted by the scale on the person standing on it.
- Difference from True Weight: True weight is the gravitational force (mass times acceleration due to gravity), which for this man is:

$$
W = m \times g = 75.0\, \text{kg} \times 9.81\, \text{m/s}^2 \approx 735.75\, \text{N}
$$

- In a Static Situation: When the elevator is at rest or moving at constant velocity, the apparent weight equals the true weight, and the scale reads approximately 75.0 kg.

Forces in Play in an Accelerating Elevator

- Gravity (Weight): Acts downward with force $W = m \times g$.

- Normal Force (N): The upward force exerted by the scale; this is what the scale displays.
- Elevator Acceleration (a): Can be upward or downward, affecting the normal force and thus the apparent weight.

Analyzing the Forces and Scale Reading

The Basic Equation of Motion

Applying Newton's second law in the vertical direction:

$$
\sum F = m a
$$

where $\sum F$ is the net force acting on the man.

- When the elevator accelerates upward:

$$
N - W = m a
$$

- When the elevator accelerates downward:

$$
W - N = m a
$$

Rearranged, the normal force N (the scale reading) is:

$$
N = m (g + a) \quad \text{(for upward acceleration)}
$$

$$
N = m (g - a) \quad \text{(for downward acceleration)}
$$

Note: The sign of a determines whether the acceleration is upward or downward.

Interpreting the Scale Reading

- Upward Acceleration: The scale reading increases, sometimes exceeding the true weight, leading to a sense of "heaviness".
- Downward Acceleration: The scale reading decreases, sometimes falling below the true weight, leading to a "lighter" feeling or even zero reading during free fall.

Scenarios and "Unreasonable" Results

Case 1: Elevator Accelerates Upward with a Large Magnitude

Suppose the elevator accelerates upward at a significant rate, say $a = 5\, \text{m/s}^2$.

- The normal force:
$$
N = 75.0\, \text{kg} \times (9.81 + 5) = 75.0 \times 14.81 \approx 1110.75\, \text{N}
$$
- Corresponding scale reading in kg:
$$
\text{Scale reading} = \frac{N}{g} \approx \frac{1110.75}{9.81} \approx 113.2\, \text{kg}
$$

Unreasonable Result: The scale displays a weight of about 113 kg, which seems impossible given the man's actual mass of 75 kg. This indicates that the elevator's acceleration greatly affects the apparent weight, leading to "overweight" readings that may seem physically unreasonable.

Case 2: Elevator Accelerates Downward at a Large Rate

Suppose the elevator accelerates downward at $a = 9.81\, \text{m/s}^2$, equivalent to free fall.

- The normal force:
$$
N = 75.0\, \text{kg} \times (9.81 - 9.81) = 0\, \text{N}
$$
- The scale reads zero, implying weightlessness.

Unreasonable Result: If the acceleration exceeds g, say $a = 12\, \text{m/s}^2$, the normal force becomes negative:
$$
N = 75.0 \times (9.81 - 12) = - 75 \times 2.19 = -164.25\, \text{N}
$$
which physically means the normal force can't be negative; the man is in free fall, and the scale cannot exert an upward force. The scale would show zero or no reading, but the negative value is "unreasonable" physically.

Understanding the Limits and Physical Reality

What Happens During Free Fall?

- When the elevator accelerates downward at \(g\), the man experiences weightlessness.
- The scale does not register any normal force, effectively reading zero.
- The man feels as if floating, despite the true weight still being present.

Why Do These Results Seem Unreasonable?

- Perception vs. Physics: The readings can surpass the actual weight or be zero, which conflicts with everyday intuition.
- Physical Constraints: The normal force cannot be negative; the scale cannot pull the person upward.
- Real-world Limitations: Elevators cannot accelerate beyond certain limits; thus, extremely high accelerations are physically impossible in typical scenarios.

Practical Implications and Real-Life Examples

Designing Elevator Safety Systems

- Elevators are engineered with acceleration limits to prevent "unreasonable" or unsafe experiences.
- Sudden or excessive accelerations can cause discomfort, but safety mechanisms prevent extreme accelerations that produce impossible scale readings.

Experiencing Apparent Weight Changes

- Passengers often notice increased weight during upward acceleration and decreased weight during downward acceleration.
- These effects are predictable and consistent with physics, but the magnitude of the change is bounded by the elevator's engineering constraints.

Educational Demonstrations

- Physics instructors often use elevator models to demonstrate principles of acceleration and apparent weight.
- These demonstrations help students understand why "unreasonable" readings are actually physically plausible within certain bounds.

Conclusion

The "unreasonable" results observed when a 75.0-kg man stands on a bathroom scale in an accelerating elevator are rooted in the fundamental physics of forces and acceleration. When the elevator accelerates upward, the man appears heavier, with the scale reading exceeding his actual weight; when accelerating downward, especially near free fall, the reading drops to zero or near-zero, creating the illusion of weightlessness. These phenomena are entirely consistent with Newton's laws but can seem counterintuitive because they challenge everyday perceptions of weight. Recognizing the limits of acceleration and the physical constraints of elevators clarifies why these results, while seemingly unreasonable at first glance, are physically plausible. Ultimately, understanding the relationship between force, acceleration, and apparent weight provides critical insights into the dynamics of objects in accelerated frames of reference, illustrating the fascinating interplay between physics and everyday experiences.

Frequently Asked Questions

Why does the scale show a different reading when the elevator accelerates upward?

Because the elevator's upward acceleration increases the effective weight reading on the scale, making the man appear heavier than his actual mass.

What is the apparent weight of the man when the elevator accelerates upward at $2.0\ m/s^2$?

The apparent weight is given by: $W = m(g + a) = 75.0\ kg \times (9.8\ m/s^2 + 2.0\ m/s^2) = 75.0 \times 11.8 = 885\ N$.

How does the scale reading change if the elevator accelerates downward instead of upward?

If the elevator accelerates downward, the scale reading decreases, and the apparent weight becomes $W = m(g - a)$. It can be less than the actual weight and even zero if the acceleration equals gravity.

What would the scale read if the elevator is in free fall?

In free fall, the man experiences weightlessness, so the scale would read zero regardless of his actual weight.

Can the scale show a reading greater than the man's actual weight? Why?

Yes, when the elevator accelerates upward, the scale reading can exceed his actual weight because the acceleration adds to gravity, increasing the normal force exerted on the scale.

What is the significance of the scale's reading in terms of the man's apparent weight?

The scale's reading indicates the man's apparent weight, which can vary depending on the elevator's acceleration, differing from his true weight due to inertial effects.

How does understanding these results help in real-world applications?

It helps in designing elevators, safety systems, and understanding forces in accelerating frames, ensuring accurate weight measurements and safety protocols.

What physics principles explain the change in scale reading during elevator acceleration?

Newton's second law and the concept of normal force explain the change; the normal force (scale reading) adjusts based on the acceleration of the frame relative to gravity.

Additional Resources

Unreasonable Results: A 75.0-kg Man Stands On A Bathroom Scale In An Elevator That Accelerates From Rest

Understanding the physics behind everyday phenomena often reveals surprising insights, especially when it involves seemingly simple scenarios such as standing on a bathroom scale in an accelerating elevator. The question of what a bathroom scale reads when an elevator accelerates involves fundamental principles of Newtonian mechanics, yet it can lead to results that appear counterintuitive or "unreasonable" at first glance. This article aims to delve deeply into this problem, exploring the physics involved, analyzing the factors at play, and clarifying why the readings can sometimes seem perplexing.

The Basic Setup and Premise

Imagine a man with a mass of 75.0 kg standing on a bathroom scale inside an elevator. The elevator initially rests at rest, and then it begins to accelerate upward or downward. The primary goal is to determine the reading on the bathroom scale during different states of acceleration.

Key assumptions:
- The man’s mass, m = 75.0 kg.
- Acceleration due to gravity, $g \approx 9.80 \text{ m/s}^2$.
- The man's weight in static conditions: $W = m \times g = 75.0 \times 9.80 = 735 \text{ N}$.

The core physics involves analyzing the forces acting on the man and how these influence the scale reading, which is effectively the normal force exerted by the scale on the man.

Fundamental Principles in Play

The physics governing the scenario hinges on Newton's second law:

$$\sum \mathbf{F} = m \mathbf{a}$$

Where:
- $\mathbf{F}$ is the net force acting on the object (the man).
- m is the mass.
- $\mathbf{a}$ is the acceleration of the object.

In the context of the elevator:
- When the elevator accelerates upward, the man experiences an increased effective weight.
- When it accelerates downward, the effective weight decreases.
- When at rest or moving at constant velocity, the scale reads the man's true weight.

Analyzing the Forces: Normal Force and Apparent Weight

The scale reading corresponds to the normal force N exerted on the man, which is what the scale measures.

- At rest or constant velocity: $N = mg$
- During acceleration: $N = m (g + a)$ when accelerating upward, or $N = m (g - a)$ when accelerating downward.

Important point: The sign and magnitude of a determine whether the reading is higher or lower than the actual weight.

Upward Acceleration

Suppose the elevator accelerates upward with acceleration a. The forces acting on the man are:

- Downward: gravity, mg.
- Upward: normal force, N.

Applying Newton's second law:

$$N - mg = m a$$

Rearranged to find the normal force:

$$N = m (g + a)$$

The scale reading (which measures the normal force N) is therefore:

$$\boxed{
\text{Scale reading} = N = m (g + a)
}$$

This implies:
- When $a > 0$, the scale reading exceeds the man's actual weight.
- For example, if $a = 2 \text{ m/s}^2$:

$$N = 75.0 \times (9.80 + 2.0) = 75.0 \times 11.80 = 885 \text{ N}$$

which corresponds to approximately 90.4 kg in "apparent mass," a clear increase over the static weight.

Downward Acceleration

If the elevator accelerates downward with acceleration a:

$$N - mg = - m a$$

So,

$$ N = m (g - a) $$

This results in a reduced normal force:

- For $a = 2 \text{ m/s}^2$:

$$ N = 75.0 \times (9.80 - 2.0) = 75.0 \times 7.80 = 585 \text{ N} $$

which corresponds to about 59.7 kg in apparent weight.

Understanding "Unreasonable" or Counterintuitive Results

While the physics formulas are straightforward, certain results can seem "unreasonable" or perplexing at first glance. For example, what if the scale reads a value greater than the man's actual weight during upward acceleration, or less than zero during certain scenarios?

Key questions include:
- Can the scale read zero or even a negative value?
- How do these results relate to physical reality?
- What assumptions lead to these outcomes?

Can the Scale Read Zero or Negative?

Zero reading:
This occurs when the normal force N becomes zero:

$$ N = m (g + a) = 0 \Rightarrow a = -g $$

This corresponds to a free-fall scenario:

- If the elevator accelerates downward at 9.80 m/s^2, equal to gravity, the man experiences weightlessness.
- The scale reads zero because there is no normal force exerted on the man; he appears to float.

Negative reading:
In classical physics, the normal force cannot be negative; it can only be zero or positive. A negative normal force would imply the surface pulls

upward on the man, which is not physically plausible in this context.

However, in certain computational models or theoretical analyses, a negative normal force can be interpreted as a sign that the man would be "pushed" away from the scale if such an interaction could occur. Practically, this suggests the man would lose contact with the scale, experiencing weightlessness or even slight lift-off.

Conclusion:
- The scale cannot physically read a negative value; the minimum is zero.
- Negative normal force indicates loss of contact, leading to weightlessness.

Real-World Scenarios and Limitations

Physiological considerations:
The human body can tolerate temporary changes in apparent weight, but extreme accelerations (beyond a few g's) can be dangerous or uncomfortable. The scale's readings during rapid accelerations are more of a physics demonstration than a real-world safety concern.

Mechanical constraints:
In a real elevator, acceleration is limited to prevent discomfort or mechanical damage. The maximum accelerations typically are well below those needed to produce extreme readings or zero-normal-force scenarios.

Scale limitations:
Standard bathroom scales may not accurately measure rapid changes or forces beyond their design limits, and their readings can lag or oscillate during acceleration.

Implications for Understanding Force and Motion

This problem exemplifies how force measurements depend on acceleration, not just weight. The concept of "apparent weight" is crucial in understanding various phenomena:

- Elevator rides: The sensation of being heavier or lighter.
- Amusement park rides: Accelerations producing strong normal forces.
- Space travel: Weightlessness in orbit where free-fall mimics zero normal force.

Summary of Key Points

- The scale measures the normal force exerted by the man.
- During upward acceleration: the scale reads $m(g + a)$.
- During downward acceleration: the scale reads $m(g - a)$.
- At free fall ($a = g$), the scale reads zero, and the man experiences weightlessness.
- Theoretically, a negative normal force would imply loss of contact; in practice, it results in zero normal force and no scale reading.
- "Unreasonable" results often arise from misinterpretations or neglecting physical constraints.

Conclusion

The seemingly "unreasonable" results in the problem of a 75.0-kg man standing on a bathroom scale in an accelerating elevator are, in fact, well-understood consequences of Newtonian physics. They highlight how our perception of weight is not absolute but depends on acceleration. The key lies in recognizing that the normal force—and thus the scale reading—is directly influenced by the elevator's acceleration relative to gravity.

In everyday life, these principles underpin our understanding of sensations of heaviness and lightness, and in engineering, they inform safety standards and design considerations. While extreme accelerations may produce results that seem counterintuitive—such as zero or very low readings—they are consistent with physical laws, provided we account for the physical constraints of contact and forces.

This analysis underscores the importance of carefully applying Newton's laws and understanding the context in which measurements are made. The "unreasonable" results are, in fact, quite reasonable once the underlying physics is properly understood, illustrating the elegance and consistency of classical mechanics.

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