Motion in a Lift (Elevator)

You step into a lift on the ground floor of a tall building. As the lift starts moving upward, you feel slightly heavier as your legs feel the extra pressure. When the lift reaches the top floor and begins to stop, you feel momentarily lighter, almost as if you are floating. Yet your mass has not changed at all.

This sensation is one of the most direct experiences of Newton's laws in daily life. The lift is a connected-body system: you (the passenger) and the lift cabin move together with the same acceleration. The normal reaction from the lift floor (what you feel as your "weight") changes depending on whether the lift accelerates upward, downward, or moves at constant velocity.

Understanding lift motion is not just strengthening your grasp of tension, weight, acceleration, and equilibrium. It also governs elevator design, astronaut training (simulating weightlessness), amusement park rides, and even the sensation pilots experience during takeoff and landing.

Note on classification: While motion in a lift differs from traditional connected body problems (where we analyse forces between two separate masses connected by strings), we include it here because: (1) the person and lift move together with the same acceleration, similar to connected systems, (2) the analysis uses the same Newton's second law approach we have developed in this section, and (3) it demonstrates practical applications of forces in accelerating systems. Strictly speaking, this is an example of motion in an accelerating reference frame, where we analyse forces on a single body (the person) rather than interactions between connected bodies.

The physical setup:

Consider a person of mass **m** standing on a weighing scale inside a lift (elevator).

The weighing scale reads the **normal reaction R** between the person and the lift floor. It is sometimes called **apparent weight**. So:

$$\textbf{Apparent weight} = \textbf{Normal reaction } (\mathbf{R})$$

This may differ from the actual weight depending on the lift's motion.

Forces acting on the person:

- Weight: $W = mg$ (downward, always constant)
- Normal reaction, R from the lift floor (upward, not constant)

The **resultant force** on the person determines the acceleration according to Newton's second law.

With this setup in mind, we can now examine how the lift's motion affects the normal reaction and therefore the apparent weight by considering the different possible cases of motion.

Case 1: Lift at rest or moving with constant velocity

When the lift is stationary or moving at constant velocity (either upward or downward), the acceleration, $\mathbf{a} = \mathbf{0}$. This is equilibrium in vertical motion.

Applying Newton's second law: $R - mg = 0$ or $\mathbf{R} = \mathbf{mg}$

Conclusion: *The normal reaction equals the actual weight. The person feels their normal weight.*

Case 2: Lift accelerating upward

When the lift accelerates upward with acceleration a, the person must also accelerate upward (they move together with the lift).

In this case, the resultant force on a person must be upward to produce upward acceleration.

Applying Newton's second law:

$$R - mg = ma \text{ or } R = mg + ma$$

Therefore: $\mathbf{R} = \mathbf{m}(\mathbf{g} + \mathbf{a})$

Conclusion: *The normal reaction,* $\boldsymbol{R > mg}$. *The person feels* ***heavier*** *than usual.*

Physical interpretation: *The lift floor must push upward with extra force to accelerate the person upward. This extra push is what makes you feel heavier when a lift starts moving upward.*

Case 3: Lift accelerating downward

When the lift accelerates downward with acceleration a, the person also accelerates downward.

In this case, the resultant force on a person must be downward to produce downward acceleration.

Applying Newton's second law:

$$\mathrm{mg - R = ma \text{ or } R = mg - ma}$$

Therefore: $\mathbf{R = m(g - a)}$

Conclusion: *The normal reaction,* $R < mg$. *The person feels lighter than usual.*

Physical interpretation: *The lift floor does not need to push as hard because gravity is helping to accelerate the person downward. This reduced push makes you feel lighter when a lift slows down while moving upward, or speeds up while moving downward.*

Case 4: Free fall (cable breaks)

If the lift cable breaks and the lift falls freely under gravity alone, the acceleration equals the acceleration due to gravity: $\mathbf{a = g}$ (downward).

Applying Newton's second law:

$$\mathrm{mg - R = ma}$$

From which (as shown earlier):

$$\mathrm{R = m(g - a)}$$

Substituting $\mathrm{a = g}$

$$\mathrm{R = m(g - g) = 0}$$

Conclusion: *The normal reaction,* $\boldsymbol{R = 0}$. *The person experiences* ***weightlessness****.*

Physical interpretation: *Both the person and the lift fall together at the same rate. The lift floor no longer pushes against the person's feet (they do not "press" against each other).* This is exactly how astronauts experience weightlessness in orbit. Fortunately, real lifts have strong safety systems (including emergency brakes and shock absorbers) preventing true free fall.

Summary Table: Apparent Weight in Different Lift Conditions

Lift Motion	**Acceleration**	**Normal reaction**	**Apparent Weight R**	**Sensation**
At rest	$a = 0$	$R = mg$	Normal	Normal weight
Constant velocity (up or down)	$a = 0$	$R = mg$	Normal	Normal weight
Accelerating upward	a (upward)	$R = m(g + a)$	Increased	Feel heavier
Decelerating upward	a(downward)	$R = m(g - a)$	Decreased	Feel lighter
Accelerating downward	a(downward)	$R = m(g - a)$	Decreased	Feel lighter
Decelerating downward	a (upward)	$R = m(g + a)$	Increased	Feel heavier
Free fall	a=g(downward)	$R = 0$	Zero	Weightless

A crucial distinction to remember:

- Accelerating upward means either starting to move upward **or slowing down while moving downward.**
- Accelerating downward means either starting to move downward **or slowing down while moving upward**.

Always focus on the direction of acceleration, not the direction of motion.

With the ideas now simmering nicely, let us serve them properly through a few worked examples and enjoy the flavour of physics in action.

BINDER Example 31

A person of mass 70kg stands on a weighing scale inside a lift. Take $g = 9.8\ m/s^2$. Determine the scale reading (in kg):

(a) When the lift is at rest.
(b) When the lift accelerates upward at $3m/s^2$?
(c) When the lift accelerates downward at $2.5m/s^2$?

Solution

(a) When at rest, acceleration $a = 0$.

$$R = mg = 70kg \times 9.8m/s^2 = 686N$$

Scale reading in kilograms:

$$\text{Reading} = \frac{R}{g} = \frac{686N}{9.8m/s^2} = 70kg$$

The scale reads 70kg.

(b) When lift is accelerating upward:

$$R = m(g + a) = 70kg(9.8 + 3)m/s^2 = 896N$$

Scale reading in kilograms:

$$\text{Reading} = \frac{896N}{9.8m/s^2} = 91.4kg$$

The scale reads 91.4kg.

(c) When lift is accelerating downward:

$$R = m(g - a) = 70kg(9.8 + 2.5)m/s^2 = 511N$$

Scale reading in kilograms:

$$\text{Reading} = \frac{511N}{9.8m/s^2} = 52.1kg$$

The scale reads 52.1kg.

Making Sense of the Answer: *The actual weight (686N) never changes, that is determined by mass and gravity. What changes is the normal reaction (what you feel), which depends on acceleration. When accelerating upward, the floor must push harder (896N) to accelerate you. When accelerating downward, the floor pushes less (511N) because gravity does some of the work.*

Thinking Like a Physicist: *The percentage change in apparent weight depends on the ratio a/g. For $a = 3m/s^2$, the change is $\frac{896N-686N}{686N} = \frac{3m/s^2}{9.8m/s^2} \approx 31\%$. Similarly for $a = 2.5m/s^2$, it is 26%. Fast elevators in skyscrapers typically limit acceleration to about $2m/s^2$ for passenger comfort since larger accelerations would be uncomfortable and potentially dangerous.*

REAL Example 32

Kipute and Kipanga visit their aunt who lives on the 20th floor of a tall building in Dar es Salaam. As they ride the elevator up, Kipanga places his school bag (mass 8kg) on a weighing scale on the elevator floor.

Kipanga: *"Look, Kipute! When the lift started moving, the scale showed 10kg for a moment. But my bag is only 8 kg!"*

Kipute: *"That's because the lift was accelerating upward. The scale had to push harder against the bag to make it accelerate. What does it show now?"*

Kipanga: *"Now it shows exactly 8kg. We must be moving at constant velocity."*

Kipute: *"Correct! And watch what happens when we approach the 20th floor..."*

(The lift begins to slow down)

Kipanga: *"Wow! Now it shows only 6kg! Did my bag lose weight?"*

Kipute: (laughing) *"No, silly! The lift is decelerating, it's slowing down while moving upward, which means it's accelerating downward. So the scale pushes less against the bag."*

Question:

(a) Calculate the upward acceleration of the lift when the scale read 10kg.
(b) Calculate the downward acceleration when the scale read 6kg.
(c) If the lift cable were to break, what would the scale read?

Take $g = 9.8\ m/s^2$.

Solution

(a) The scale reading represents the normal reaction R.

$$R = 10kg \times 9.8m/s^2 = 98N$$

For upward acceleration:

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

Substituting:

$$98N = 8kg(9.8m/s^2 + a);\ a = 2.45\ m/s^2$$

The lift was accelerating upward at $2.45\ m/s^2$.

(b) When scale reads 6 kg:

$$R = 6kg \times 9.8m/s^2 = 58.8N$$

For downward acceleration (deceleration while moving up):

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

$$58.8N = 8kg(9.8m/s^2 - a); a = 2.45\ m/s^2$$

The lift was accelerating downward at $2.45\ m/s^2$.

(c) In free fall: $a = g$.

$$R = m(g - g) = 0$$

The scale would read 0kg.

Making Sense of the Answer: *Interestingly, the magnitude of acceleration is the same ($2.45m/s^2$) whether speeding up or slowing down. This is typical of well-designed elevator that maintains constant acceleration/deceleration rates for smooth rides. The scale reading changed by $\pm 2kg$ (from 8 to 10, or 8 to 6), which represents a $\pm 25\%$ change. This corresponds to $a/g = 2.45/9.8 = 0.25$ or 25%.*

Thinking Like a Physicist: *Elevator designers must balance several competing factors: velocity (to move people quickly), acceleration (affects comfort and safety), and cable strength (must support apparent weight during upward acceleration, which exceeds actual weight). Modern high-speed elevators use sophisticated control systems to minimize jerky motion and thus they gradually increase acceleration at the start and gradually decrease it before stopping.*

HOT Example 33

A person of mass 60kg stands in a lift and holds a 5kg bag suspended by a light string.

(a) Calculate the tension in the string when the lift moves upward with constant velocity of $2m/s$.
(b) Calculate the tension in the string when the lift accelerates upward at $2.5\ m/s^2$.
(c) Calculate the tension in the string when the lift accelerates downward at $3m/s^2$.
(d) The person feels they can comfortably hold a tension of up to 70N. What is the maximum acceleration the lift can have without the person dropping the bag?
(e) Calculate the total force that the lift floor exerts on the person for case (b). Explain why this differs from the person's weight.

Take $g = 9.8\ m/s^2$.

Solution

(a) Forces acting on the bag:
- Tension: T (upward)
- Weight: $W = mg$ (downward)

Applying Newton's second law:

$$T - mg = ma$$

But at constant velocity, acceleration $a = 0$.

$$T - mg = 0 \text{ or } T = mg = 5kg \times 9.8m/s^2 = 49N$$

The tension is 49N.

(b) If the lift accelerating upward at $2.5\ m/s^2$, the bag must also accelerate upward at $2.5\ m/s^2$.

Again using:

$$T - mg = ma \text{ or } T = mg + ma = m(g + a) = 5kg(9.8 + 2.5)m/s^2 = 61.5N$$

The tension is 61.5N.

(c) If the lift is accelerating downward:

$$mg - T = ma \text{ or } T = mg - ma = m(g - a) = 5kg(9.8 - 3)m/s^2 = 34N$$

The tension is 34N.

(d) When the lift accelerates downward, the tension decreases; when it accelerates upward, the tension increases. Therefore, for the tension to rise to the limiting value of 70N, the lift must be accelerating upward.

For upward acceleration:

$$T - mg = ma \text{ or } T = mg + ma$$

From which:

$$a = \frac{T - mg}{m}$$

It follows that:

$$a_{max} = \frac{T_{lim} - mg}{m} = \frac{70N - 5kg \times 9.8m/s^2}{5kg} = 4.2m/s^2$$

Hence, the maximum acceleration is $4.2m/s^2$ **upward**.

Understand that: *Above this acceleration, the required tension would exceed 70N and the person would drop the bag.*

(e) Forces acting on a person (holding a bag):

- Normal reaction: R (upward)
- Tension: T (downward)
- Weight of the person: mg

Applying Newton's second law (for upward acceleration):

$$R - T - mg = ma \text{ or } R = ma + T + mg$$

Substituting:

$$R = 60kg \times 2.5\ m/s^2 + 61.5N + 60kg \times 9.8m/s^2 = 799.5N$$

The total force that the lift floor exerts on the person is 799.5N.

Alternative solution

Treating both a person and a bag as one object: $m_t = (60 + 5)kg = 65kg$

Applying Newton's second law:

$$R - m_t g = m_t a \text{ or } T = m_t g + m_t a = m_t(g + a) = 65kg(9.8 + 2.5)m/s^2 = 799.5N$$

The total force is 799.5N.

Explanation:

This differs from the person's actual weight (588 N) because the person is accelerating upward, which requires an additional upward force. In addition, the bag being held must also be accelerated upward. Consequently, the floor must provide enough force to accelerate the entire system (person plus bag).

Making Sense of the Answer: *Constant velocity means zero acceleration, so the tension equals the bag's weight (49N). Upward acceleration increases the required tension, while downward acceleration reduces it. The floor* *force on the person is larger than their weight because it must both accelerate the person upward and counter the downward pull from the bag.*

Thinking Like a Physicist: *Only acceleration changes forces, not velocity. Decide the direction of acceleration first, then apply Newton's second law. Remember: upward acceleration increases apparent weight and tension; downward acceleration decreases them.*

That brings our subtopic-by-subtopic worked examples to a satisfying close. The plates are cleared! Now let us enjoy the full buffet, where all the ideas of this topic come together in miscellaneous worked examples.