

Apparent weight: person on scale in elevator

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Apparent Weight: Person on Scale in Elevator A person with mass, m , who is located at or near the surface of the Earth will always have some weight $W = mg$. When a person stands on a scale, the reading (the number of pounds or newtons) on the scale is actually the Normal Force that the scale exerts back towards the person to support the person's weight. (Note that the person and the scale are stationary relative to each other, in other words they are always in contact with each other, so they always have equal and opposite action and reaction forces acting between them.) Things get complicated, though, when the scale and the person experience acceleration. This will change the contact force (the Normal Force) between the person and the scale. Let's look at several cases. We will assume that Up is the positive direction and Down is the negative direction.

Case 1: No acceleration of elevator If the acceleration of the elevator is zero, then there are two possible scenarios; the elevator can be at rest (stationary, zero velocity) or moving with a constant speed (no acceleration if velocity does not change). In this case, the action and reaction force pair between the person and the scale is just the weight. The person pushes down on the scale with a force of $-W = -mg$ (negative direction) and the scale pushes back up against the man with a Normal Force of $F_N = +W = +mg$. Because the reading on the scale is the magnitude of the normal force, the scale will read the true weight when the elevator is NOT accelerating.

Case 2: going up & speeding up (acceleration a is positive (up)) In this case, the elevator and the person are starting from rest at a lower floor. The elevator accelerates upward. The inertia of the person would prefer to stay stationary, so the elevator floor and scale must push up on the person to accelerate him upward along with the

elevator. (The person doesn't sink into the floor when the elevator accelerates up. The elevator and the scale and the person all move together.) The scale therefore has to push upward with extra force on the person to accelerate the person's mass upward. This results in a greater contact force between the scale and the person. Therefore the Normal Force is larger, so the reading on the scale is a number that is GREATER than the true weight. Let's consider Newton's 2nd Law ($\Sigma F = ma$) acting on the person. The overall acceleration of the person is upward (with the elevator). So ma is positive (upward). The only external forces acting on the person are the force of gravity acting down ($-W = -mg$) and the supporting Normal Force F_N that the scale applies upward on the person. So $\Sigma F = ma = -mg + F_N$. We want to know F_N because that is the number that we read off the scale. $F_N = mg + ma$, which is GREATER than the true weight. Case 3: going up & slowing down (acceleration a is negative (down)) In this case, the elevator and the person are initially moving upward at a constant speed and slowing down to rest at a higher floor. The acceleration of the elevator is downward (opposite to the upward motion, which causes a reduction of the velocity). The inertia of the person would prefer to keep moving upward at a constant speed, so the elevator floor and scale effectively drop out a little bit from underneath the person as the elevator slows down. The person doesn't float upward, because again the elevator and the person move together, but the contact force between the person and the scale is reduced. The scale therefore has to push upward with less force on the person to support the person's weight. Therefore the Normal Force is smaller, so the reading on the scale is a number that is LESS than the true weight. Let's consider Newton's 2nd Law

$\Sigma F = ma$) acting on the person. The overall acceleration of the person is downward (with the elevator). So ma is negative (downward). The only external forces acting on the person are the force of gravity acting down ($-W = -mg$) and the supporting Normal Force F_N that the scale applies upward on the person. So $\Sigma F = -ma = -mg + F_N$. We want to know F_N because that is the number that we read off the scale. $F_N = mg - ma$, which is LESS than the true weight. Case 4: going down & slowing down (acceleration a is positive (up)) In this case, the elevator and the person are initially moving downward at a constant speed and then slow to rest at a lower floor. The elevator accelerates upward (opposite direction to negative/downward velocity to reduce velocity magnitude). The inertia of the person would prefer to keep moving downward at the constant speed, so the elevator floor and scale must push up on the person to accelerate him upward, slowing him down. (The person doesn't sink into the floor here either. Elevator and scale and person move together.) The scale therefore has to push upward with extra force on the person to accelerate the person's mass upward. This results in a greater contact force between the scale and the person. Therefore the Normal Force is larger, so the reading on the scale is a number that is GREATER than the true weight. Let's consider Newton's 2nd Law ($\Sigma F = ma$) acting on the person. The overall acceleration of the person is upward (with the elevator). So ma is positive (upward). The only external forces acting on the person are the force of gravity acting down ($-W = -mg$) and the supporting Normal Force F_N that the scale applies upward on the person. So $\Sigma F = ma = -mg + F_N$. (Note that this is the same equation as we got in case 2.) We want to know F_N because that is the number that we read off the scale. $F_N =$

$mg+ma$, which is GREATER than the true weight. Case 5: going down & speeding up (acceleration a is negative (down)) In this case, the elevator and the person are initially at rest at a higher floor. The elevator then speeds up in the downward direction towards a lower floor. The elevator acceleration of the elevator is negative/downward (increasing the velocity magnitude in the downward direction). The inertia of the person would prefer to stay at rest, so the elevator floor and scale effectively drop out a little bit from underneath the person as the elevator accelerates down. The person doesn't float upward here also, because again the elevator and the person move together, but the contact force between the person and the scale is reduced. The scale therefore has to push upward with less force on the person to support the person's weight. Therefore the Normal Force is smaller, so the reading on the scale is a number that is LESS than the true weight. Let's consider Newton's 2nd Law ($\Sigma F = ma$) acting on the person. The overall acceleration of the person is downward (with the elevator). So ma is negative (downward). The only external forces acting on the person are the force of gravity acting down ($-W = -mg$) and the supporting Normal Force F_N that the scale applies upward on the person. So $\Sigma F = -ma = -mg + F_N$. (Note that this is the same equation that we got for Case 3.) We want to know F_N because that is the number that we read off the scale. $F_N = mg - ma$, which is LESS than the true weight. Case 6: freefall ($a = -g$) If the elevator cable were to break, the whole elevator-scale-person system would all begin to accelerate downward due to the force of gravity. All objects in freefall accelerate downward with the same magnitude (acceleration due to gravity, g). The scale and the person are freefalling together, so there is NO contact

force (Normal Force) between the scale and the person. (When they are both falling together, there is no way that the scale can support any of the person's weight.) Note that this is a special case of downward acceleration, which we discussed in Case 3 and Case 5. Just as in Cases 3 and 5, the apparent weight (which is zero when $a=-g$) is less than the true weight. A pictorial summary of apparent weight: