Universal Physics Journal

Question 2:Why does gravity behave so forcefully during impact?

Hi Ethan:

I am enjoying your articles. Keep them coming. My question is about gravity. Most times it seems easy to handle. But at other times, the force of gravity can be brutal. Like when I was younger and fell from a ladder and hit my head on a sidewalk. I'll never forget how violent that blow felt to my head. I didn't black out, but it was some time before I felt okay. Why does gravity behave so forcefully at times like this and not at others? R.S. Austin, TX, USA

Hello R.S.:

Hope you had no lasting effects from your impact with the sidewalk. Protecting one's head from impact (sudden negative acceleration) is so important. I can't stress that enough. Pardon me if I digress for a moment to warn our readers about the latest scooter craze. The ones with the small front wheels can be a real hazard if the small front wheel drops into a depression in the street or sidewalk. The scooter may quickly stop, while providing little force to stop (negatively accelerate) any portion of the rider's body above the knees. Thus the rider's feet are taken out from under the rider as the rider falls over the scooter's steering bars. I hear that many serious head and body injuries are being caused in this manner. My friend's son broke his hip while falling from a small-wheeled scooter. He ended up needing an expensive and uncomfortable hip joint replacement, at 15 years of age!

On our city bus there is a safety ad that shows three images; one, a human brain; two, a young helmetless person riding a small-wheeled scooter; and three, a well-padded helmet. The caption under the brain reads "If you have one of these...". The caption under the scooter reads: "And you ride one of these...". The caption under the helmet reads: "...Then wear one of these."

Now let's talk about what really happens when you hit your head on the sidewalk and why wearing a well-padded helmet can make a real difference in the outcome. The major player in the forces present during impact is not the internal force of gravitation which remains almost perfectly constant during the entire event. There is a second force, this one being an external (contact) force, R.S., that becomes present as the cause when negative acceleration occurs to your head that is often a hundred or more times more forceful than Earth gravitation. It is this second force that is the cause of the damage and the reason your helmet needs thick padding on the front, back, and sides, plus a strong secure chin-strap that will keep the helmet well-placed on your head so its padding can be effective in reducing the forces experienced by your brain during impact when falling from skates, a skate board, a scooter, a bicycle, a motorcycle, a snowmobile, a horse, an ATV, or something even more dangerous, a ladder!

As your fall begins when you lose your balance on the ladder (I hope you were not standing on the ladder's insecure top step!), the Type 2 internal forces of Earth gravitation, which are the action forces that give your body downward external weight against the equal upward external weights of the ladder's and Earth's Type 2 internal action forces of gravitation toward your body (See the mutual weighing of the pavers and Earth in Article IV.) come to an end as the ladder tips in one direction caused by a sideways push from your foot or feet as your upper torso rotates free of the ladder in the opposite direction while losing all support from the ladder. Now you are experiencing the gentle, weightless acceleration of the Type 1 internal action forces of Earth gravitation supported by another Type 1 internal force, that being the force of acceleration/Reaction. These two internal forces are being generated by different means equally, oppositely, and separately within each component of your body's matter. Gravitation is the action force causing your body's acceleration and the a/R force is the reaction force from your body that is being caused by and providing support for the force (gravitation) that is acting as the cause of your acceleration. You are accelerating toward Earth at about the same rate as when you accelerate due to the Type 3 external stacking force of a race car on a race track yet when this acceleration of yours is being caused by a Type 1 internal force, you will not feel its presence. Instead, you will feel as if you are at rest and weightless and will likely think that it is the ground that is rushing up to collide with you! This is what Albert Einstein learned by talking to a construction worker who survived a fall, from the outside of a building, down 5 stories or floors to the ground . During his fall, the construction worker said he had no sensation of falling (accelerating) but that it felt instead like he was staying still in the air while watching the ground and feeling the air above it rush up to his position. Albert Einstein was most interested and somewhat confused by the worker's story.

As you rotate and accelerate toward the ground, your head takes on a motion that is quite different from the motion of the ground below. The closing speed between your head and the ground may reach 20 ft/second (6.1 meters/sec) if the distance you fall is not too great (we are talking about a step ladder here, not an extension ladder). During the moments of impact between your head and the sidewalk, understand that your head is bearing against the sidewalk with the usual force of its gravitational weight of say 10 lbs (44.48 N). We know from Newton's LAW I that it takes a force to accelerate (change the motion of) an object. Relative to the ground, you head has a motion of 20 feet per second. Newton's LAW I means it is going to take an action force from the ground to change the motion of your head so that your head's motion becomes equal to the ground's motion. LAW III tells us that this motion-changing acceleration/Action force from the ground will cause its own terminating support force in the form of an equal and opposite acceleration/Reaction force from the matter of your head, including the soft gray matter within! Wearing a safety helmet does nothing to change this fact. After the impact, the motion of your head will be equal to the motion of the ground, whether you are wearing a helmet or not. The difference the helmet makes is in the distance over which the negative acceleration of your head occurs. If the ground is soft and the safety helmet has thick padding, then due to the deformation of both the ground and the padding, the distance over which the negative acceleration of your head occurs will be significant. If the ground is concrete and you are wearing no protective head gear, then the distance over which the negative acceleration of your head occurs will be minimal. Every halving of the (de)acceleration distance results in a doubling of the accelerative force impressed externally against your head in accordance with Newton's LAW II. Wearing a helmet can easily make the difference between walking away unhurt verses ending up in a hospital with concussion, permanent brain damage, or worse!

To calculate the acceleration/Action force impressed against your head, we need to know the distance over which the force is acting and the elapsed time of that action in order to determine the rate of acceleration occurring to your head. When your helmetless head, rated at 10 lbs.mass, impacts the concrete, I estimate the distance of acceleration will be about 1/4" or 0.02 ft or 0.00635 meters which is about the thickness of the end of your smallest finger measured from nail to fingerprint, when squashed. Your head's rate of acceleration equals the change in velocity, Velocity2 minus Velocity1, divided by the elapsed time of the impact. Your velocities are positive, relative to, and generally directed downward toward Earth's center of matter. Your acceleration is negative and generally directed upward away from Earth's center. (If you are bothered by the following calculations, just note the underlined force amount at the bottom on the right and then continue on with your reading.)

US units   Force causing negative acceleration for an unprotected head impacting concrete.
Velocity1 (V1) = 20 ft/sec down.
Velocity2 (V2) = 0 ft/sec down.
Average Velocity during impact = (V1+V2) / 2 = 20 ft/sec + 0 ft/sec / 2 = 10 ft/sec down.
Distance of acceleration = 0.02 ft
Elapsed Time = Distance / Average Velocity = 0.02 ft / 10 ft/sec = 0.00,2 sec
Acceleration = (V2 - V1) / Elapsed Time = (0 ft/sec - 20 ft/sec) / 0.00,2 sec = -10,000 ft/sec^2
Absolute Force (Poundal) = Mass of object x Acceleration of object = 10 lb.m x -10,000 ft/sec^2 = -100,000 Poundal
Acceleration/Action Force (lb.f) = Absolute Force (P) / g = -100,000 P / 32.17 ft/sec^2 = -3,108 lb.force!

Now to the shockingly high upward exterior head force of this Type 3 external acceleration/Action stacking force of -3,108 lb., that is causing upward-directed acceleration for your head, you need to add the relatively insignificant upward Type 3 external 10 lb.force of Earth's gravitational weight against your head. The total -3,118 lb.f is as much force as the weight of a mid-sized automobile yet as you can plainly see, gravitation's role is not even 1 % of the forces present during this event. Of course the upward-directed acceleration/Action (abbrev. a/A) force from Earth is mutually supported by the downward-directed acceleration/Reaction (a/R) force of 3,118 lb.force from your head, including all of its thoughtful contents, with this large reaction force being slightly increased by the downward Type 3 external 10 lb. action force from your head's gravitational weight against Earth.

Before having a look at the reduced forces of acceleration present when wearing a safety helmet, I will repeat the above helmetless calculations in SI units.
SI units   Force causing negative acceleration for an unprotected head impacting concrete.

Velocity1 (V1) = 6.1 meters/sec down.
Velocity2 (V2) = 0 m/sec down.
Average Velocity during impact = (V1+V2) / 2 = 6.1 m/sec + 0 m/sec / 2 = 3.5 m/sec down.
Distance of acceleration = 0.00635 meters
Elapsed Time = Distance / Average Velocity = 0.00635 m / 3.5 m/sec = 0.00,2 sec
Acceleration = (V2 - V1) / Elapsed Time = (0 m/sec - 6.1 m/sec) / 0.00,2 sec = -3,050 m/sec^2.
Acceleration/Action Force (Newton) = Mass of object x Acceleration of object = 4.5 kg x -3,050 m/sec^2 =   -13,725 Newton

Now let us calculate the acceleration/Action and mutual supporting acceleration/Reaction forces that are present when your 10 lb.mass head, sporting a well-padded safety helmet, impacts with and is thereby accelerated by the concrete sidewalk. Because of the helmet's padding, this time your head will be accelerated over a 1 in or 0.08 ft, or 0.02,54 meter distance which is 4 times the previous distance of 1/4".

US units Force causing negative acceleration for a helmeted head impacting concrete.
Velocity1 (V1) = 20 ft/sec down.
Velocity2 (V2) = 0 ft/sec down.
Average Velocity during impact = (V1+V2) / 2 = 20 ft/sec + 0 ft/sec / 2 = 10 ft/sec down.
Distance of acceleration = 0.08 ft
Elapsed Time = Distance / Average Velocity = 0.08 ft / 10 ft/sec = 0.00,8 sec
Acceleration = (V2 - V1) / Elapsed Time = (0 ft/sec - 20 ft/sec) / 0.00,8 sec = -2,500 ft/sec^2
Absolute Force (Poundal) = Mass of object x Acceleration of object = 10 lb.m x -2,500 ft/sec^2 = 25,000 Poundal
Acceleration/Action Force (lb.f) = Absolute Force (P) / g = 25,000 P / 32.17 ft/sec^2 = -777 lb.force

After adding the -10 lb.force of Earth's gravitational toward your head, the total a/A force reaches -787 lb.force. While this equals the force of the weight of 4 large adults, which would you rather have impressed against your head, an impact force momentarily equal to the weight of 4 large adults or one that is momentarily equal to the weight of a mid-sized automobile?

While you are thinking about these facts, R.S., consider that whatever the magnitude of the external acceleration/Action contact force against your head, it will be equaled at the point of contact by the supporting internal acceleration/Reaction forces from all the components of matter contained within your head. This means that during impact, your head, including the fragile brain inside, is serving the same role as the head of a hammer!

Again I will make the same calculation in the SI standard:
SI units Force causing negative acceleration for a helmeted head impacting concrete.

Velocity1 (V1) = 6.1 meters/sec down.
Velocity2 (V2) = 0 m/sec down.
Average Velocity during impact = (V1+V2) / 2 = 6.1 m/sec + 0 m/sec/2 = 3.5 m/sec down.
Distance of acceleration = 0.02,54 m
Elapsed Time = Distance / Average Velocity = 0.02,54 m / 3.5 m/sec = 0.00,726 sec
Acceleration = (V2 - V1) / Elapsed Time = (0 m/sec - 6.1 m/sec) / 0.00,726 sec = -840.22 m/sec^2.
Acceleration/Action Force (Newton) = Mass of object x Acceleration of object = 4.5 kg x -840.22 m/sec^2 = -3,780.99 Newton

As you can see, wearing a helmet increases the distance over which the acceleration occurs which dramatically reduces the rate of acceleration for your head and the magnitude of the mutual a/A forces acting between your head and the concrete sidewalk to 1/4 their former helmetless value. Meanwhile the forces of gravitation are limited to only about 1% of the forces present during this head-impacting event. I hope by reading this answer to your fine question, R.S., many parents around the world will benefit by insisting that their children always wear safety helmets complete with an effective chin strap anytime there is a risk of impact to the head.

On a personal note, I have extensive experience in this area for I have fallen many times from riding my off-road motorcycle without serious injury by tucking my head, arms, and legs into a "ball" before impacting the ground which greatly increases the distance over which negative acceleration occurs to my rolling body. And yes, I always wear my Bell, full-coverage, Snell Approved, fiberglass helmet when riding. I hope you do the same, no matter what type of sport vehicle you ride!

Ethan Skyler

P.S. If you are going to buy a scooter, for certain make sure it comes with large-diameter wheels, and always wear a well-padded helmet, complete with a rigid chin guard, every time you ride!