The physics of a car collision

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Image 1. A crash test dummy sits inside a Toyota Corolla during the 2017 North American International Auto Show in Detroit, Michigan. Crash test dummies are used to predict the injuries that a human might sustain in a car crash. Photo by: Jim Watson/AFP/Getty Images

During a car crash, energy is transferred from the vehicle to whatever it hits, be it another vehicle or a stationary object. This transfer of energy, depending on variables that alter states of motion, can cause injuries and damage cars and property. The object that was struck will either absorb the energy thrust upon it or possibly transfer that energy back to the vehicle that struck it. Focusing on the distinction between force and energy can help explain the physics involved.

Force: Colliding With A Wall

Car crashes are clear examples of how Newton's Laws of Motion work. His first law of motion, also referred to as the law of inertia, asserts that an object in motion will stay in motion unless an external force acts upon it. Conversely, if an object is at rest, it will remain at rest until an unbalanced force acts upon it.

Consider a situation in which car A collides with a static, unbreakable wall. The situation begins with car A traveling at a velocity (v) and, upon colliding with the wall, ending with a velocity of 0. The force of this situation is defined by Newton's second law of motion, which uses the equation of force equals mass times acceleration. In this case, the acceleration is (v - 0)/t, where t is whatever time it takes car A to come to a stop.

The car exerts this force in the direction of the wall, but the wall, which is static and unbreakable, exerts an equal force back on the car, per Newton's third law of motion. This equal force is what causes cars to accordion up during collisions.

It's important to note that this is an idealized model. In the case of car A, if it slams into the wall and comes to an immediate stop, that would be a perfectly inelastic collision. Since the wall doesn't break or move at all, the full force of the car into the wall has to go somewhere. Either the wall is so massive that it accelerates, or moves an imperceptible amount, or it doesn't move at all, in which case the force of the collision acts on the car and the entire planet, the latter of which is, obviously, so massive that the effects are negligible.

Force: Colliding With A Car

In a situation where car B collides with car C, we have different force considerations. Assuming that car B and car C are complete mirrors of each other (again, this is a highly idealized situation), they would collide with each other going at precisely the same speed but in opposite directions. From conservation of momentum, we know that they must both come to rest. The mass is the same, therefore the force experienced by car B and car C is identical, and also identical to that acting on the car in case A in the previous example.

This explains the force of the collision, but there is a second part of the question: the energy within the collision.

Energy

Force is a vector quantity while kinetic energy is a scalar quantity, calculated with the formula K = 0.5mv2. In the second situation above, each car has kinetic energy K directly before the collision. At the end of the collision, both cars are at rest, and the total kinetic energy of the system is 0.

Since these are inelastic collisions, the kinetic energy is not conserved, but total energy is always conserved, so the kinetic energy "lost" in the collision has to convert into some other form, such as heat, sound, etc.

In the first example where only one car is moving, the energy released during the collision is K. In the second example, however, two are cars moving, so the total energy released during the collision is 2K. So the crash in case B is clearly more energetic than the case A crash.

From Cars To Particles

Consider the major differences between the two situations. At the quantum level of particles, energy and matter can basically swap between states. The physics of a car collision will never, no matter how energetic, emit a completely new car.

The car would experience exactly the same force in both cases. The only force that acts on the car is the sudden deceleration from v to 0 velocity in a brief period of time, due to the collision with another object.

However, when viewing the total system, the collision in the situation with two cars releases twice as much energy as the collision with a wall. It's louder, hotter and likely messier. In all likelihood, the cars have fused into each other, with pieces flying off in random directions.

This is why physicists accelerate particles in a collider to study high-energy physics. The act of colliding two beams of particles is useful because in particle collisions you don't really care about the force of the particles (which you never really measure); you care instead about the energy of the particles.

A particle accelerator speeds up particles but does so with a very real speed limitation dictated by the speed of light barrier from Einstein's theory of relativity. To squeeze some extra energy out of the collisions, instead of colliding a beam of near-light-speed particles with a stationary object, it's better to collide it with another beam of near-light-speed particles going the opposite direction.

From the particle's standpoint, they don't so much "shatter more," but when the two particles collide, more energy is released. In collisions of particles, this energy can take the form of other particles, and the more energy you pull out of the collision, the more exotic the particles are.

Quiz

1 Read the following selection from the section "From Cars To Particles."

> *To squeeze some extra energy out of the collisions, instead of colliding a beam of near-light-speed particles with a stationary object, it's better to collide it with another beam of near-light-speed particles going the opposite direction.*

Which of the following conclusions can be drawn from the selection above?

(A) Scientists proved Newton's Laws of Motion using a particle accelerator.

(B) Scientists use particle accelerators to study collisions between large objects in motion.

(C) Scientists are attempting to maximize the force output during particle collisions in a particle accelerator.

(D) Scientists are attempting to maximize the energy output during particle collisions in a particle accelerator.

2 Which of the following claims does the author support the LEAST?

(A) Force and energy are distinct concepts.

(B) Energy can change forms, but is never destroyed in a collision.

(C) Inelastic collisions are uncommon in the real world.

(D) Collisions between moving objects tend to be more energetic.

3 What role does acceleration play in force?

(A) Force is determined by multiplying mass and velocity.

(B) Force is determined by multiplying mass and acceleration.

(C) Force is determined by multiplying acceleration and velocity.

(D) Force is determined by multiplying acceleration and time.

4 How does energy change over time?

(A) Energy cannot be transferred between objects or destroyed.

(B) Energy can be converted into other forms or destroyed.

(C) Energy is either transferred between objects or destroyed.

(D) Energy can be transferred between objects or converted into other forms.