Newton’s Third Law

Professor:

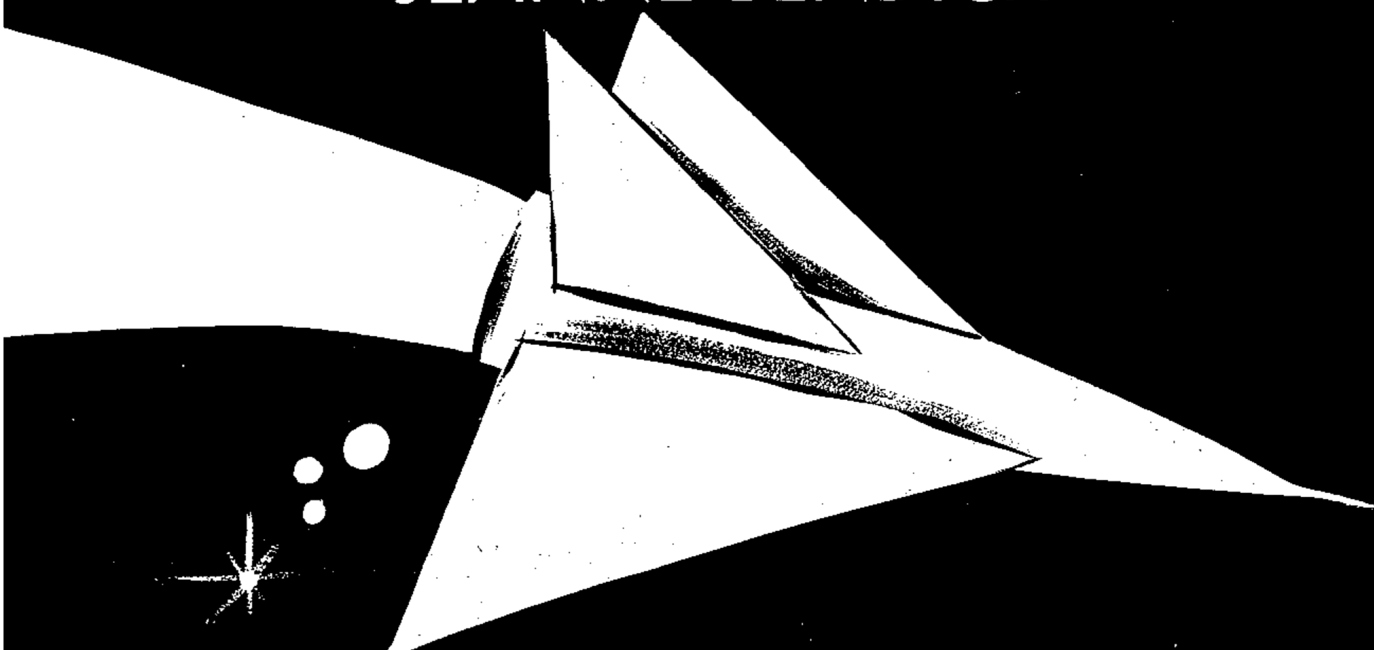
So I am studying for the MCAT and I have to admit that most of the questions I am getting right I can directly attribute to you forcing me to scrutinize certain concepts instead of memorizing countless equations. I guess what I really want to say is thank you.

(signed, a former student)

p.s. You are not allowed to show the contents of this email to future students because the ones who would benefit from it are going to have to learn the hard way, as I did, that you may actually know what you are doing. Thanks again.

THE FIRST BOOK OF SPACE TRAVEL

written and illustrated by
JEANNE BENDICK



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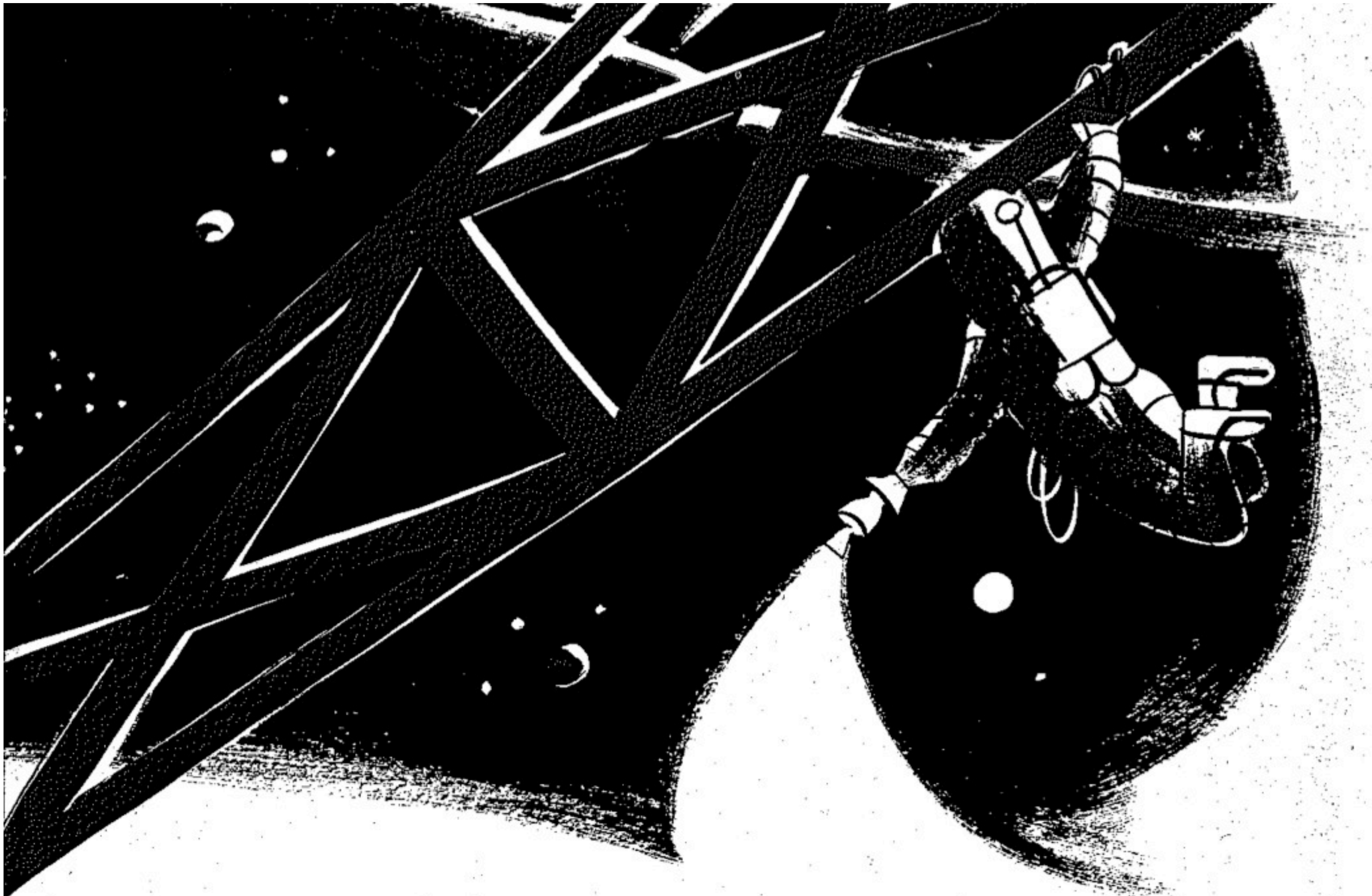

You push yourself where you are needed with your gas jet. One squirt sends you sailing wherever you want to go. Some of the other spacemen are in one-man, low-powered rockets with lifting and pushing equipment attached. Alone, you can push huge pieces of metal around easily. Remember, no weight.

A skydiver of mass 80 kg (including gear) leaps from her jump plane and plummets toward the ground. She will eventually reach terminal velocity, the constant speed that is the highest value air resistance will permit. During the period between jumping and reaching terminal speed, what is the value of the force that she and her gear exerts on the Earth itself?

1. zero
2. about 800 N
3. less than 800 N because she's falling at less than the free-flight acceleration
4. more that 800 N because of the extra force of air resistance

A skydiver of mass 80 kg (including gear) leaps from her jump plane and plummets toward the ground. Because of air resistance pushing upward, her acceleration is smaller than the familiar value for acceleration in free fall. What is the value of the force that she and her gear exerts on the Earth itself?

1. zero
2. about 800 N
3. less than 800 N because she's falling at less than the free-flight acceleration
4. more that 800 N because of the extra force of air resistance

A skydiver leaps joyfully from the safety of her jump plane and plummets toward the ground. After a short time, she reaches terminal velocity. The word “terminal” means that she is falling at a constant speed and that it is the highest value that air resistance will permit. (It does not mean that her parachute will fail to open.)

The only two forces acting on her are gravity (downward) and air resistance (upward). Which force is larger when she is moving at terminal velocity?

1. Gravity
2. Air resistance
3. They must be of equal magnitude

ANS: **3**—They must be of equal magnitude.

At terminal velocity there is no acceleration and therefore no net force. There are only two actual physical forces acting on the skydiver: gravity (downward) and air resistance (upward). These forces add as vectors to give the zero net force, so they cancel each other. Therefore, the two forces are equal in magnitude and opposite in direction.

You stand on a scale in your bathroom; it reads 150 lb. In which of the following situations will your scale read less than 150 lb with you standing on it?

1. in an elevator that is accelerating upward
2. in an elevator that is accelerating downward
3. in an elevator that is moving up at constant velocity
4. in an elevator that is moving down at constant velocity
5. two of the above

ANS: **2**—The scale will read less when the elevator accelerates downward.

No matter the motion of the elevator, there are only two forces acting on you: the downward force of gravity ($mg = 150\,\text{lb}$), and the upward normal force exerted by the scale on you. This force of the scale on you is what the scale reports. The vector sum of the two forces is your net force, ma.

At constant velocity $a = 0$, so the magnitude of the scale force would be equal to the gravitational force on you. Therefore, the scale would read $150\,\text{lb}$. If the acceleration were upward, there would be an upward net force, so the scale force would be greater than $150\,\text{lb}$. On the other hand, if the acceleration were downward, there would be a downward net force, so the scale force would be less than $150\,\text{lb}$. In the extreme case of the elevator freely falling, the downward acceleration would be a_g and the net force would be $150\,\text{lb}$ downward. In this case, the scale would read zero—it would exert no upward force on you.

Superman holds a 1999 Ford Explorer over his head. Identify the force exerted on the ground:

1. Superman's "weight" ($m_S g$)
2. the car's "weight" ($m_C g$)
3. a downward normal force at Superman's feet
4. all of the above
5. just 1 & 2

ANS: **3**—The only force on the ground is a downward normal force at Superman’s feed.

The only interaction involving the ground in this problem is the normal pushing force between the ground and Superman’s feet.

The “weight” of the car is a force on the car. It’s the downward force of gravity that Earth exerts on the car. Similarly, Superman’s weight is a force on Superman, the downward force of gravity that Earth exerts on Superman. If you draw a free-body diagram you will find that because Superman has no acceleration, the downward force of Superman’s feet on the ground is equal in magnitude (and direction, in this case) to the combined weight of Superman and the car. However, you need to understand that *equality* is not the same as *identity*.

Consider a car at rest. We can conclude that the downward gravitational pull of Earth on the car and the upward contact force of Earth on it are equal and opposite because

1. the two forces form an interaction pair.
2. the net force on the car is zero.
3. neither of the above

ANS: **2**—The net force on the car is zero.

These two forces cannot be an interaction pair because they act on the *same object*. Because the car is at rest, it has zero acceleration. Therefore, the net force on the car must be zero. This means that the two forces must be equal and opposite. The distinction is subtle, but important. You may think that the two forces are equal and opposite because of Newton’s third law, but it’s really because of Newton’s second law and the fact that the car is not accelerating.

Two teams of rugby players push horizontally on each other. One team eventually succeeds in pushing the other team backwards. Which team pushes harder on the other?

1. The team that moves forward
2. The losers that moves backwards
3. Neither

ANS: **3**—Neither team pushes harder than the other.

According to Newton's second law, the forces that each team exerts on the other are part of an interaction pair, and always equal in magnitude.

Two teams of rugby players push horizontally on each other. One team eventually succeeds in pushing the other team backwards. Which is the best explanation for their success?

1. The winners push on the losers harder than the losers push back.
2. The winners have a greater frictional interaction with the ground than the losers have.
3. The winners must have a higher mass than the losers.
4. The losers are a bunch of pencil-necked geeks

ANS: **2**—The winners have a greater frictional interaction with the ground than the losers have.

To see this, let’s call the teams “A” (on the left) and “B” (on the right). Team A exerts a force on team B directed to the right. There is also a force of static friction that the ground exerts on team B directed to the left. If these two forces are equal, team B will not accelerate. Similarly, there are two forces on team A. The force of team B on team A that is directed to the left, and a static friction force exerted by the ground on team A exerted to the right. The pushing forces between A and B form an interaction pair. A pushes just as much to the right on team B as B pushes on A.

How, then, can team A push team B backward (both teams accelerating to the right)? This occurs when the net force on both of them is to the right. The friction force the ground exerts on A is greater than the pushing force B exerts on A, so A accelerates to the right. Similarly, the force of A pushing on B is greater than the force of the ground on B, so B accelerates to the right. Therefore, the friction force of the ground pushing to the right on A is greater than the friction force of the ground pushing to the left on B.

Warmup Question

You jump off a diving board and fall toward the pool below. While you are in free fall, estimate the magnitude of the force you exert on the Earth. Explain your logic.

ANS: The force that earth exerts on you is your weight. In my case, that's around 1000 N. From Newton's third law, the force you exert on Earth is equal in magnitude to the force Earth exerts on you. Therefore, I would exert an upward force of 1000 N on Earth. This is a field (non-contact) force. We usually don't consider the force we exert on Earth as we fall, even though it is our weight, because when this force acts on a very massive Earth, the resulting acceleration of the planet will be exceedingly small.

Warmup Question

I once witnessed a car at a stoplight get rear-ended by a large bus. The collision caused the car to shoot quickly forward, while the bus continued to roll forward at a slightly slower speed. Which of the statements below is true?

1. The bus exerted a larger force on the car than the car exerted on the bus.
2. The car exerted a larger force on the bus than the bus exerted on the car.
3. The car and bus exerted equal forces on each other.
4. The bus exerted a force on the car, but the car did not exert a force on the bus.

ANS: **3**—The car and bus exerted equal forces on each other.

This is a simple application of Newton’s third law. The force the bus exerts on the car and the force the car exerts on the bus form an interaction pair and therefore are equal in magnitude, opposite in direction.

The common error here is to think that the greater acceleration of the car means that there is a greater force on it. However, you need to take the mass of the car and bus into account. Even though the forces on each vehicle are equal, the great mass of the bus means that it will have very small acceleration, while the small mass of the car means it will have a much greater acceleration.