5 Newton's Third Law of Motion—Action and Reaction

Fig. 5-1 When you push on the wall, the wall pushes on you.

If you lean over too far, you'll fall over. But if you lean over with your hand outstretched and make contact with a wall, you can do so without falling. When you push against the wall, the wall pushes back on you. That's why you are supported. Ask your friends why you don't topple over. How many will answer, "Because the wall is pushing on you and holding you in place"? Probably not very many people (unless they're physics types) realize that walls can push on us every bit as much as we push on them.*

5.1 Interactions Produce Forces

Fig. 5-2 The interaction that drives the nail is the same as the one that brings the hammer to a halt.

In the simplest sense, a force is a push or a pull. Looking closer, however, we find that a force is not a thing in itself, but is due to an interaction between one thing and another. For example, a hammer hits a nail and drives it into a board. One object interacts with another. Which exerts the force and which receives the force? Newton thought about questions like this, and the more he thought, the more he came to the conclusion that neither object has to be identified as the "exerter" or "receiver." He reasoned that nature is symmetrical and concluded that both objects must be treated equally. The hammer exerts a force against

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* The terms *push* or *pull* usually invoke the idea of a living thing exerting a force. So strictly speaking, to say "the wall pushes on you" is to say "the wall exerts a force as though it were pushing on you." As far as the balance of forces is concerned, there is no observable difference between the forces exerted by you (alive) and the wall (nonliving).

the nail, but is itself halted in the process. The same interaction that drives the nail also slows the hammer. Such observations led Newton to his third law—the law of action and reaction.

5.2 Newton's Third Law

Newton's third law states:

> Whenever one body exerts a force on a second body, the second body exerts an equal and opposite force on the first.

One force is called the **action force**. The other is called the **reaction force**. It doesn't matter which force we call *action* and which we call *reaction*. They are equal. The important thing is that neither force exists without the other. The action and reaction forces make up a *pair* of forces. Newton's third law is often stated as "to every action there is always opposed an equal reaction."

In every interaction, forces always occur in pairs. For example, in walking across the floor you push against the floor, and the floor in turn pushes against you. Likewise, the tires of a car push against the road, and the road in turn pushes back on the tires. In swimming you push the water backward, and the water pushes you forward. There is a pair of forces acting in each instance. The forces in these examples depend on friction; a person or car on ice, by contrast, may not be able to exert the action force against the ice to produce the needed reaction force.

Fig. 5-3 What happens to the boat when she jumps to shore?

▶ **Questions**

1. Does a stick of dynamite contain force?
2. A car accelerates along a road. Strictly speaking, what is the force that moves the car?

▶ **Answers**

1. No, a force is not something a body has, like mass, but is an interaction between one object and another. A body may possess the capability of exerting a force on another object, but it cannot possess force as a thing in itself. Later you will see that something like a stick of dynamite possesses *energy*.

2. It is the road that pushes the car along. Really! Except for air resistance, only the road provides a horizontal force on the car. How does it do this? The rotating tires push back on the road (action). The road, in turn, pushes forward on the tires (reaction). The next time you see a car moving along a road, tell your friends that it is the road that pushes the car along. If at first they don't believe you, convince them that there is more than meets the eye of the casual observer. Turn them on to some physics.

5.3 Identifying Action and Reaction

Often the identification of the pair of action and reaction forces is not immediately obvious. As a example, what are the action and reaction forces in the case of a falling boulder, say, when there is no air resistance? You might say that the earth's gravitational force on the boulder is the action force, but can you identify the reaction force? Is it the weight of the boulder? No, weight is simply another name for the force of gravity. Is it caused by the ground where the boulder strikes? No, the ground does not act on the boulder until the boulder strikes it.

It turns out that there is a simple recipe for treating action and reaction forces. It is this: Make a statement about one of the forces in the pair, say the action force, in this form:

Body A exerts a force on body B.

Then the statement about the reaction force is simply

Body B exerts a force on body A.

This is easy to remember; all you need to do is switch A and B around. So, in the case of the falling boulder, the action is that the earth (body A) exerts a force on the boulder (body B). Then reaction is that the boulder exerts a force on the earth.

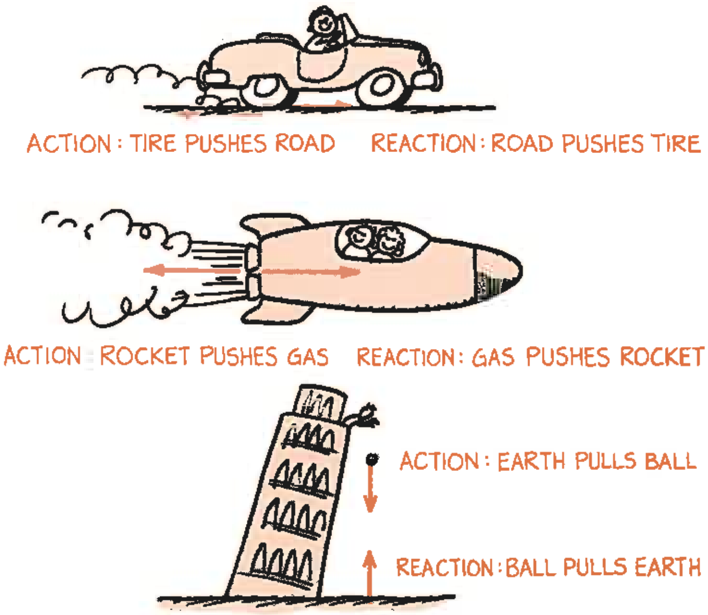

Fig. 5-4 Force-pair between body A and body B. Note that when action is *A exerts force on B*, the reaction is simply *B exerts force on A*.

5.4 Action and Reaction on Bodies of Different Masses

Interestingly enough, the boulder pulls up on the earth with every bit as much force as the earth pulls down on it. The forces are equal in strength and opposite in direction. We say that the boulder falls to the earth; could we also say that the earth falls to the boulder? The answer is yes, but not as much. Although the forces on the boulder and the earth are the same, the masses are quite unequal. Recall that Newton's second law states that the respective accelerations will be not only proportional to the net forces, but inversely proportional to the masses as well. Considering the massiveness of the earth, it is no wonder that we don't sense its very small, or infinitesimal, acceleration. Strictly speaking, however, the earth moves up toward the falling boulder. So, when you step off a curb, the street really does come up ever so slightly to meet you!

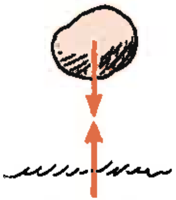

Fig. 5-5 The earth is pulled up by the boulder with just as much force as the boulder is pulled downward by the earth.

A similar but less exaggerated example occurs in the firing of a rifle. When the rifle is fired, the force the rifle exerts on the bullet is exactly equal and opposite to the force the bullet exerts on the rifle; hence the rifle kicks. At first thought, you might expect the rifle to kick more than it does, or wonder why the bullet moves so fast compared to the rifle. According to Newton's second law, we must also consider the masses involved.

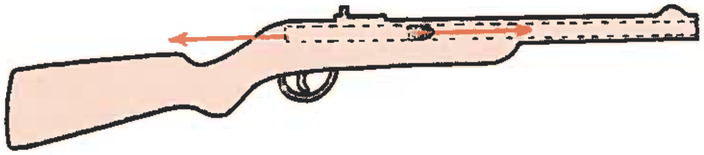

Fig. 5-6 The force that is exerted against the recoiling rifle is just as great as the force that drives the bullet along the barrel. Why then, does the bullet undergo more acceleration than the rifle?

Suppose we let F represent both the action and reaction forces, m the mass of the bullet, and $\mathbf{m}$ the mass of the rifle. Then the acceleration of the bullet and rifle are found by taking the ratio of force to mass. The acceleration of the bullet is given by

$$\mathbf{a} = \frac{F}{m}$$

while the acceleration of the rifle is

$$a = \frac{F}{\mathbf{m}}$$

Do you see why the change in motion of the bullet is so huge compared to the change of motion of the rifle? A given force exerted on a small mass produces a large acceleration, while the same force exerted on a large mass produces a small acceleration. Different sized symbols have been used to indicate the differences in relative masses and resulting accelerations.

▶ **Question**

Suppose you're riding in the front seat of a speeding bus and you note that a bug splatters onto the windshield. Without question, a force has been exerted upon the unfortunate bug and it has undergone a sudden deceleration. Is the corresponding force that the bug exerts against the windshield greater, less, or the same? Is the resulting deceleration of the bus greater than, less than, or the same as that of the bug?

Fig. 5-7 Does the dog wag the tail or does the tail wag the dog? Or both?

Have you ever noticed Newton's third law at work when a dog wags its tail? If the tail is relatively massive compared to the dog, note that the tail also wags the dog! The effect is less noticeable for dogs with tails of relatively small mass.

5.5 Why Action and Reaction Forces Don't Cancel

Action and reaction forces act on different bodies. If the action is caused by A acting on B, then the reaction is caused by B acting on A. The action force acts on B; the reaction force acts on A. The action and reaction forces never act on the same object. Hence action and reaction forces never cancel one another.

This is often misunderstood. Suppose for example that a friend who hears about Newton's third law says that you can't move a football by kicking it. The reason offered is that the reaction force by the kicked ball is equal and opposite to your kicking force. The net force would be zero. So if the ball was at rest to begin with, it will remain at rest—no matter how hard you kick it! What do you say to your friend?

▶ **Answer**

The force the bug exerts against the windshield is just as great as the force the windshield exerts against it. The two forces comprise an action-reaction pair. The accelerations, however, are very different. This is because the masses involved are different. The bug undergoes an enormous deceleration, while the bus undergoes a very tiny deceleration. Indeed, a person in the bus doesn't feel the tiny slowing down of the bus as it is struck by the bug. Let the bug be more massive, like another bus for example, and the slowing down is quite evident!

You know that if you kick a football, it will accelerate. Does this acceleration contradict Newton's third law? No! Your kick acts on the ball. No other force has been applied to the ball. The net force on the ball is very real, and the ball accelerates. What about the reaction force? Aha, that doesn't act on the *ball*; it acts on your *foot*. The reaction force decelerates your foot as it makes contact with the ball. Tell your friend that you can't cancel a force on the ball with a force on your foot.

Now, if two people kick the same ball with equal and opposite forces at the same time (Figure 5-9), then the net force on the ball would be zero—but not for your single kick.

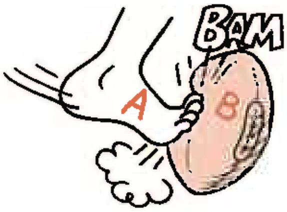

Fig. 5-8 If the action force acts on B, then the reaction force acts on A. Only a single force acts on each, so no cancellation can occur.

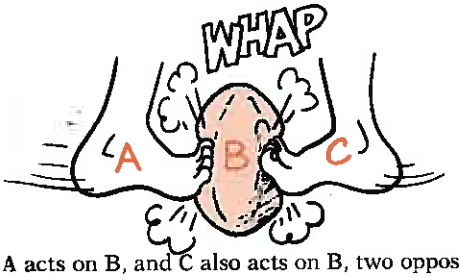

Fig. 5-9 When A acts on B, and C also acts on B, two opposite forces act on B and cancellation can occur.

5.6 The Horse-Cart Problem

A situation similar to the kicked football is shown in the comic strip "Horse Sense" (next page). The horse believes that its pull on the cart will be cancelled by the opposite and equal pull by the cart on the horse and make acceleration impossible. This is the classical horse-cart problem which is a stumper for many students at the university level. Through careful thinking, you can understand it here.

The horse-cart problem can be looked at from different points of view. First, there is the point of view of the farmer who is concerned only with his cart (the cart system). Then, there is the point of view of the horse (the horse system). Finally, there is the point of the horse and cart together (the horse-cart system).

First look at the farmer's point of view: The farmer is concerned only with the force that is exerted on his cart. A net force on the cart, divided by the mass of the cart, will produce a very real acceleration. The farmer doesn't care about the reaction on the horse.

Now look at the horse's point of view: It's true that the opposite reaction force by the cart on the horse restrains the horse. Without this force the horse could freely gallop to the market.


HORSE SENSE
GIDDIUP! PULL THE CART SO WE CAN GET GOING.
FOR ME TO PULL THE CART WOULD BE A FUTILE EFFORT.
YOU SEE, IF I PULL ON THE CART, THE CART WILL PULL BACK ON ME. BY NEWTON'S 3rd LAW, THE FORCES ARE EQUAL AND OPPOSITE-SO THEY'LL CANCEL OUT. A ZERO NET FORCE WON'T GET US MOVING.
PHYSICS PHYSICS PHYSICS
$a_{CART} = \frac{F_{CART}}{m_{CART}}$
PHYSICS PHYSICS
I DON'T CARE ABOUT THE FORCE EXERTED ON YOU. I'M INTERESTED IN THE FORCE YOU EXERT ON THE CART! YOU PULL THE CART AND I GUARANTEE IT WILL MOVE!
BUT HOW CAN I MOVE FORWARD WHEN THE CART PULLS BACKWARD ON ME?
PHYSICS PHYSICS PHYSICS
JUST PUSH BACKWARD ON THE GROUND. BY NEWTON'S 3rd LAW, THE GROUND WILL PUSH FORWARD EQUALLY ON YOU --- THEN I'LL SIMPLY FOLLOW ALONG!
THAT GROUND IS DOING A VERY GOOD JOB!
PHYSICS GRUMBLE PHYSICS
Hewitt Drew it!

This force tends to hold the horse back. So how does the horse move forward? By pushing backward on the ground. The ground, in turn, pushes forward on the horse. In order to pull on the cart, the horse pushes backward on the ground. If the horse pushes the ground with a greater force than its pull on the cart, there will be a net force on the horse. Acceleration occurs. When the cart is up to speed, the horse need only push against the ground with enough force to offset the friction between the cart wheels and the ground.

Finally, look at the horse-cart system as a whole. From this viewpoint the pull of the horse on the cart and the reaction of the cart on the horse are internal forces—forces that act and react within the system. They contribute nothing to the acceleration of the horse-cart system. From this viewpoint they can be neglected. The system can be accelerated only by an outside force. For example, if your car is stalled, you can't get it moving by sitting inside and pushing on the dashboard; you must get outside and make the ground push the car. The horse-cart system is similar. It is the outside reaction by the ground that pushes the system.

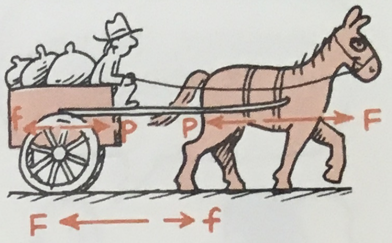

Fig. 5-10 All the pairs of forces that act on the horse and cart are shown: (1) the pulls *P* of the horse and cart on each other; (2) the pushes *F* of the horse and ground on each other; and (3) the friction *f* between the cart wheels and the ground. Notice that there are two forces each applied to the cart and to the horse. Can you see that the acceleration of the horse-cart system is due to the net force *F* – *f*?

▶ **Questions**

1. From Figure 5-10, what is the net force that acts on the cart? That acts on the horse? That tends to make the ground recoil?
2. Once the horse gets the cart up to the desired speed, must the horse continue to exert a force on the cart?

5.7 Action Equals Reaction

This chapter began with a discussion of how, when you push against a wall, the wall in turn pushes back on you. Suppose for some reason you punch the wall. Bam, your hand is hurt. Your

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▶ **Answers**

1. The net force on the cart is $P - f$; on the horse, $F - P$; on the ground, $F - f$.
2. Yes, but only enough to counteract the wheel friction of the cart and air resistance. Interestingly enough, air resistance would be absent if there were a wind blowing in the same direction and just as fast as the horse and cart. If the wind blows just enough faster to provide a force to counteract friction, the horse could wear rollerskates and simply coast with the cart all the way to the market.

Fig. 5-11 If you hit the wall, it hits you equally hard.

friends see your damaged hand and ask what happened. What can you truthfully say? You can say that the wall hit your hand. How hard did the wall hit your hand? Every bit as hard as you hit the wall. You cannot hit the wall any harder than the wall can hit back on you.

Hold a sheet of paper in midair and tell your friends that the heavyweight champion of the world could not strike the paper with a force of 200 N (nearly 50 pounds). You are correct. And the reason is that the paper is not capable of exerting a reaction force of 200 N. You cannot have an action force unless there can be a reaction force. Now, if you hold the paper against the wall, that is a different story. The wall will easily assist the paper in providing 200 N of reaction force, and then quite a bit more if need be!

For every action, there is an equal and opposite reaction. If you push hard on the world, the world pushes hard on you. If you touch the world gently, the world will touch you gently in return. The way you touch others is the way others touch you.

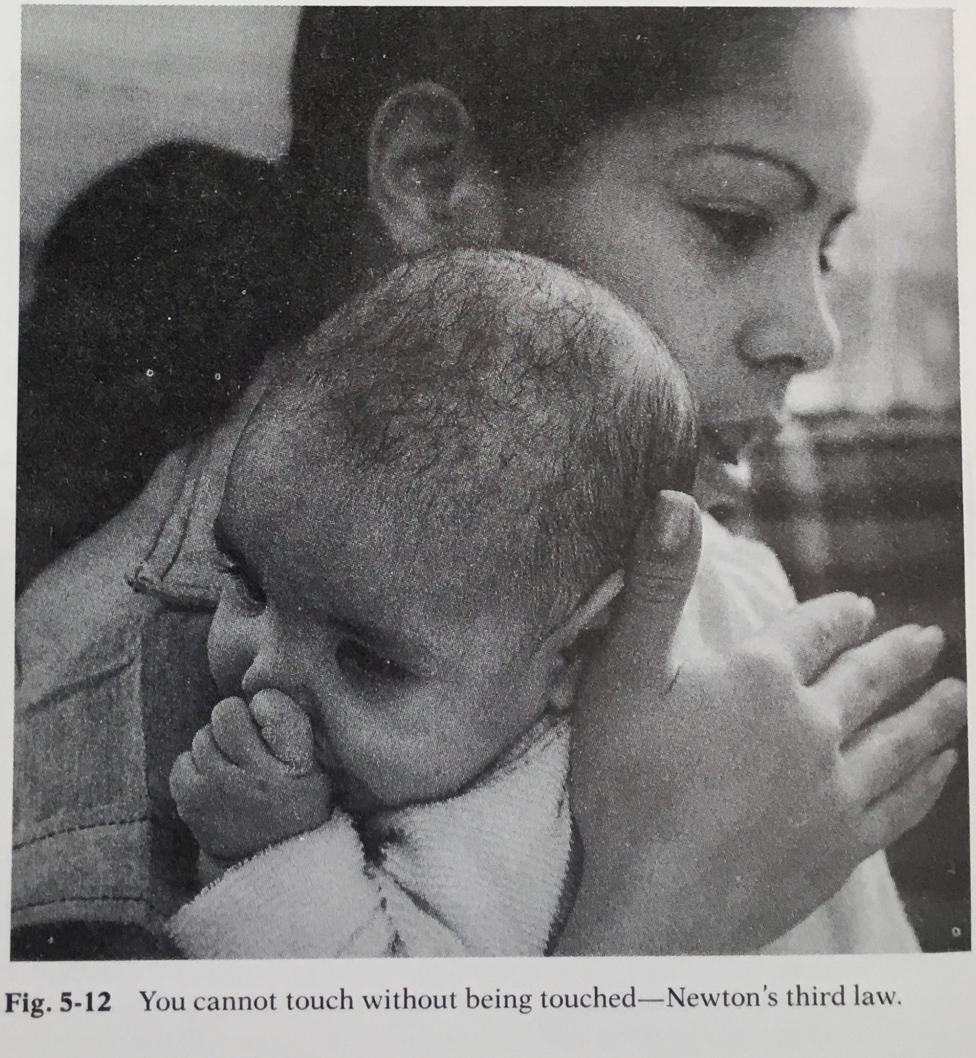

Fig. 5-12 You cannot touch without being touched—Newton's third law.

5 Chapter Review

Concept Summary

An interaction between two things produces a pair of forces.

- Each thing exerts a force on the other.
- The two forces are called the action and reaction forces.
- Action and reaction forces are equal in strength and opposite in direction.

Important Terms

action force (5.2)
Newton's third law (5.2)
reaction force (5.2)

Review Questions

1. What evidence can you cite to support the idea that a wall can push on you? (5.1)

2. What is meant by saying that a force is due to an interaction? (5.1)

3. When a hammer interacts with a nail, which exerts a force on which? (5.1)

4. When a hammer exerts a force on a nail, how does the amount of force compare to that of the nail on the hammer? (5.2)

5. Why do we say that forces occur only in pairs? (5.2)

6. When you walk along a floor, what exactly pushes you along? (5.2)

7. When swimming, you push the water backward—call this *action*. Then what exactly is the reaction force? (5.3)

8. If action is a bowstring acting on an arrow, identify the reaction force. (5.3)

9. When you jump up, the world really does recoil downward. Why can't this motion of the world be noticed? (5.4)

10. When a rifle is fired, how does the size of the force of the rifle on the bullet compare to the force of the bullet on the rifle? How do the accelerations of the rifle and bullet compare? Defend your answer. (5.4)

11. Since action and reaction are always equal in size and opposite in direction, why don't they simply cancel one another and make net forces greater than zero impossible? (5.5)

Questions 12–15 refer to Figure 5-10.

12. a. Besides the force of gravity, how many forces are exerted on the cart?
    b. Using the letter symbols shown in the figure, what is the net force on the cart? (5.6)

13. a. How many forces besides gravity are exerted on the horse?
    b. What is the net force on the horse?
    c. How many forces are exerted *by* the horse on other objects? (5.6)

14. a. How many forces are exerted *on* the horse-cart system?
    b. What is the net force on the horse-cart system? (5.6)

15. In order to increase its speed, why must the horse push harder against the ground than it pulls on the wagon? (5.6)

16. If you hit a wall with a force of 200 N, how much force is exerted on you? (5.7)

17. Why cannot you hit a feather in mid-air with a force of 200 N? (5.7)

18. How does the saying "you get what you give" relate to Newton's third law? (5.7)

Think and Explain

1. Newton realized that the sun pulls on the earth with the force of gravity and causes the earth to move in orbit around the sun. Does the earth pull equally on the sun? Defend your answer.

2. Why is it easier to walk on a carpeted floor than on a smooth polished floor?

3. If you walk on a log that is floating in the water, the log moves backward. Why is this so?

4. If you step off a ledge, you noticeably accelerate toward the earth because of the gravitational interaction between the earth and you. Does the earth accelerate toward you as well? Explain.

5. Suppose you're weighing yourself while standing next to the bathroom sink. Using the idea of action and reaction, why will the scale reading be less when you push downward on the top of the sink (Figure A)? Why will the scale reading be more if you pull upward on the bottom of the sink?

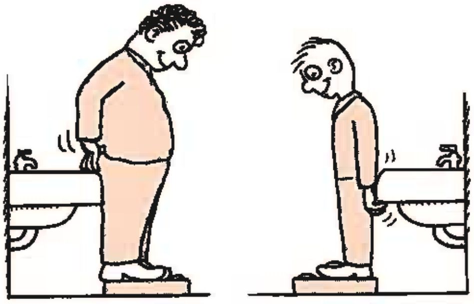

Fig. A

6. What is the reaction counterpart to a force of 1000 N exerted by the earth on an orbiting communications satellite?

7. If action equals reaction, why isn't the earth pulled into orbit around the communications satellite in the preceding question?

8. A pair of 50-N weights are attached to a spring scale as shown in Figure B. Does the spring scale read 0, 50, or 100 N? (*Hint*: Would it read any differently if one of the strings were held by your hand instead of being attached to the 50-N weight?)

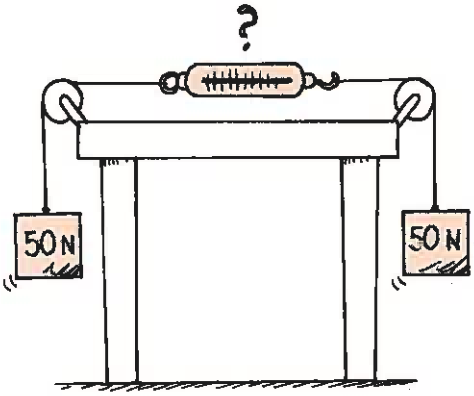

Fig. B

9. If a bicycle and a massive truck have a head-on collision, upon which vehicle is the impact force greater? Which vehicle undergoes the greater change in its motion? Defend your answers.

10. People used to think that a rocket could not be fired to the moon because it would have no air to push against once it left the earth's atmosphere. Now we know that the idea is mistaken, for several rockets have gone to the moon. What exactly is the force that propels a rocket when in a vacuum?

11. Since the force that acts on a bullet when a gun is fired is equal and opposite to the force that acts on the gun, doesn't this imply a zero net force, and therefore the impossibility of an accelerating bullet? Explain.