**Vertical Friction**

In every problem solved before this quiz, the direction of friction has always been horizontal. However, friction is not only a horizontal force. Static and kinetic friction will act in the direction that is *parallel* to the surface and *resists* the motion of an object. In some cases, that means vertically.

In this section, we use the same forces and concepts, but the directions are all different. Friction now acts vertically and normal force acts horizontally.

There are 5 forces involved in these problems:

**Gravity**

The direction of gravity is always down
The magnitude of gravity is always the mass of an object times free-fall acceleration (9.8 m/s$^2$ on planet earth).

$$F_g = mg$$

**Applied Force**

The applied force is a force of some push or pull being applied to the object in question. It is usually given in a problem, and in real life can be measured with a force meter.

**Normal Force**

The direction of the normal force is *perpendicular* to a surface.
The magnitude of the normal force adapts to a particular situation. The normal force is called a constraint force.

**Static Friction**

The direction of static friction is *parallel* to a surface and always *resists* motion.
Static friction acts on objects that are not moving (slipping).
The magnitude of static friction is any value up to the normal force times the coefficient of static friction.

$$F_{frS}\ \text{max} = \mu_S F_N$$

If the forces making against static friction exceed the maximum static friction, the object moves. In this case, static friction is replaced by kinetic friction.

If the forces against static friction do not exceed the maximum static friction, the object does not move. The magnitude of static friction matches the forces opposing it.

**Kinetic Friction**

The direction of kinetic friction is *parallel* to the surface and always *resists motion* (opposite the velocity).
The magnitude of kinetic friction is equal to the magnitude of the normal force times the coefficient of static friction.

$$F_{frK} = \mu_K F_N$$

Y: Vertical Friction Name ____________________

**Part 1: Vertical Static Friction:**
**Problem Y.1:** A person is pressing a book against a wall.

He presses with a value of 100 N.
The mass of the book is 2 kg, and the coefficient of static friction between the book and the wall is 0.4.

Four forces act on the book:
Applied force, normal force, gravity, and static friction.

The normal force acts to the left. Why?

The magnitude of normal force is equal to the magnitude of the applied force. Why?

The direction of static friction is upward. Why?

Draw a free-body diagram of the book:

| **Name of Force** | **Direction** | **Magnitude** | **How did you determine the magnitude?** |
|---|---|---|---|
| Gravity | | | |
| Applied Force | | | |
| Normal Force | | | |
| Static Friction | | | |

How can you prove that the book does not move in this situation?

**Problem Y.2:** A person is pressing a book against a wall.

He presses with a value of 50 N.
The mass of the book is 4 kg, and the coefficient of static friction between the book and the wall is 0.6.

Four forces act on the book:
Applied force, normal force, gravity, and static friction.

What is the magnitude of the force of gravity?

What is the maximum value of static friction?

Draw a free-body diagram of the book:

| Name of Force | Direction | Magnitude | How did you determine the magnitude? |
|---|---|---|---|
| Gravity | | | |
| Applied Force | | | |
| Normal Force | | | |
| Static Friction | | | |

How can you prove that the book does not move in this situation?

Name ____________________

**Problem Y.3:** A person is pressing a book against a wall.

He presses with a value of 120 N.
The mass of the book is 5 kg, and the coefficient of static friction between the book and the wall is 0.3.

Four forces act on the book:
Applied force, normal force, gravity, and static friction.

What is the magnitude of the force of gravity?

What is the maximum value of static friction?

Draw a free-body diagram of the book. If the book does move, eliminate all forces except gravity.

| **Name of Force** | **Direction** | **Magnitude** | **How did you determine the magnitude?** |
|---|---|---|---|
| Gravity | | | |
| Applied Force | | | |
| Normal Force | | | |
| Static Friction | | | |

Does the book move or not? How do you know?

**Problem Y.4:** A person is pressing a book against a wall.

He presses with a value of 80 N.
The mass of the book is 4 kg, and the coefficient of static friction between the book and the wall is 0.5.

Four forces act on the book:
Applied force, normal force, gravity, and static friction.

What is the magnitude of the force of gravity?

What is the maximum value of static friction?

Draw a free-body diagram of the book. If the book does move, eliminate all forces except gravity.

| **Name of Force** | **Direction** | **Magnitude** | **How did you determine the magnitude?** |
|---|---|---|---|
| Gravity | | | |
| Applied Force | | | |
| Normal Force | | | |
| Static Friction | | | |

Does the book move or not, and how do you know?

**Y.5: Minimum Force to Hold a Book:**

The goal of this problem is to discover the **minimum** force you would need to press to hold a book against the wall without it moving.

**To find the minimum force necessary to hold the book against the wall make the following assumptions:**
**a) the magnitude of static friction (direction up) is equal to the magnitude of gravity (direction down).**
**b) The magnitude of static friction is at its maximum value.**

A book with a mass of 3 kg is being pressed against a wall, with which it has a coefficient of static friction of 0.5. The person is pressing with the minimum force necessary to prevent the book from falling down.
There are four forces acting on the book: gravity, applied force, normal force, and static friction. The static friction is at its maximum value, and you must determine the magnitude of the applied force.
Also, the normal force and applied force acting on the book have equal magnitude because the book is not moving horizontally.

Draw a free-body diagram of the book:

| Name of Force | Direction | Magnitude | How did you determine the magnitude? |
|---|---|---|---|
| Gravity | | | |
| Static Friction | | | |
| Normal Force | | | |
| Applied Force | | | |

What is the minimum applied force necessary to hold the book against the wall?

 Name ___________________

**Y.6:**

A person is holding a book with a mass of 5 kg against a wall with which it has a coefficient of static friction of 0.4.
Draw a free-body diagram below in order to determine the minimum force the person needs to press in order to prevent the book from moving.

Draw a free-body diagram of the book:

| **Name of Force** | **Direction** | **Magnitude** | **How did you determine the magnitude?** |
|---|---|---|---|
| Gravity | | | |
| Static Friction | | | |
| Normal Force | | | |
| Applied Force | | | |

What is the minimum applied force necessary to hold the book against the wall?

Y: Vertical Friction Name ____________________

**Y.7:**

A person is holding a book with a mass of 5 kg against a wall with which it has a coefficient of static friction of 0.4.
Draw a free-body diagram below in order to determine the minimum force the person needs to press in order to prevent the book from moving.

Draw a free-body diagram of the book:

| **Name of Force** | **Direction** | **Magnitude** | **How did you determine the magnitude?** |
|---|---|---|---|
| Gravity | | | |
| Static Friction | | | |
| Normal Force | | | |
| Applied Force | | | |

What is the minimum applied force necessary to hold the book against the wall?

**Part 2: Vertical Kinetic Friction**

Problems Y.1 – Y.7 dealt with a vertical force of static friction. The next set of problems will deal with a vertical force of kinetic friction. In these problems, somebody who is already falling grabs a pole in an attempt to slow themselves down (like a fire pole).

**Problem Y.8:**

A fireman is jumps off of a ledge that is 15 meters tall and grabs the fire pole just as he jumps. Assume his initial velocity is zero.

The fireman with a mass of 70 kg holds the pole with a force of 300 Newtons. The coefficient of kinetic friction between the pole and his hands is 0.25.

Draw a free-body diagram of the fireman. However, it is difficult to draw the normal force on this particular problem, because it acts simultaneously in all horizontal directions. In this case, draw only gravity and kinetic friction and add a note that normal force is also acting on the fireman in all horizontal directions.

| Draw a free-body diagram of the fireman. Indicate normal force with a note. Please indicate the directions of net force, acceleration, and velocity to the side of the free-body diagram. | | | |
|---|---|---|---|
| **Name of Force** | **Direction** | **Magnitude** | **How did you determine the magnitude?** |
| Gravity | | | |
| Normal Force of the pole | All horizontal directions | | |
| Kinetic Friction | | | |

Which of the three forces above is the *reaction force* of the force of the fireman grabbing to pole?

Determine the magnitude of net force acting on the fireman:

Determine the magnitude of acceleration of the fireman:

If the fireman falls 15 meters down, with what speed will he strike the ground?

 Name ___________________

**Problem Y.8:**
A fireman is jumps off of a ledge that is 15 meters tall and grabs the fire pole just as he jumps. Assume his initial velocity is zero.

The firewoman with a mass of 65 kg holds the pole with a force of 350 Newtons. The coefficient of kinetic friction between the pole and her hands is 0.22.

Draw a free-body diagram of the firewoman, indicating normal force in a note. Please indicate the directions of net force, acceleration, and velocity to the side of the free-body diagram.

| **Name of Force** | **Direction** | **Magnitude** | **How did you determine the magnitude?** |
|---|---|---|---|
| Gravity | | | |
| Normal Force of the pole | All horizontal directions | | |
| Kinetic Friction | | | |

Which of the three forces above is the *reaction force* of the force of the firewoman grabbing to pole?

Determine the magnitude of net force acting on the firewoman:

Determine the magnitude of acceleration of the firewoman:

 Name ___________________

According to Newton's Second Law…

| | |
|---|---|
| If net force is in the same direction as velocity… | Speed increases |
| If net force is in the opposite direction from velocity | Speed Decreases |

**Y.9:** Somebody who is *already falling* grabs a pole.
Somebody with a mass of 50 kg is falling at a rate of 20 m/s and is 10 meters above the ground. Suddenly, they are able to grab a pole with a force of 200 N. The coefficient of kinetic friction between their hands and the pole is 0.2.

Draw a free-body diagram of the firewoman, indicating normal force in a note. Please indicate the directions of net force, acceleration, and velocity to the side of the free-body diagram.

| **Name of Force** | **Direction** | **Magnitude** | **How did you determine the magnitude?** |
|---|---|---|---|
| Gravity | | | |
| Normal Force of the pole | All horizontal directions | | |
| Kinetic Friction | | | |

a) Determine the magnitude and direction of net force and acceleration acting on the person.

b) By referring explicitly to Newton's Second Law, and described in the table above, determine if the person increases or decreases in speed.

 Name ___________________

**Y.10:** Somebody who is *already falling* grabs a pole.
Somebody with a mass of 60 kg is falling at a rate of 10 m/s and is 15 meters above the ground. Suddenly, they are able to grab a pole with a force of 350 N. The coefficient of kinetic friction between their hands and the pole is 0.28.

| Draw a free-body diagram of the firewoman, indicating normal force in a note. Please indicate the directions of net force, acceleration, and velocity to the side of the free-body diagram. | | | |
|---|---|---|---|
| **Name of Force** | **Direction** | **Magnitude** | **How did you determine the magnitude?** |
| Gravity | | | |
| Normal Force of the pole | All horizontal directions | | |
| Kinetic Friction | | | |

a) Determine the magnitude and direction of net force and acceleration acting on the person.

b) By referring explicitly to Newton's Second Law, and described in the table above, determine if the person increases or decreases in speed.

**Y.11:** Somebody who is *already falling* grabs a pole.
Somebody with a mass of 40 kg is falling at a rate of 10 m/s and is 15 meters above the ground. Suddenly, they are able to grab a pole with a force of 600 N. The coefficient of kinetic friction between their hands and the pole is 0.8. [They are wearing friction-increasing gloves.]

| Draw a free-body diagram of the firewoman, indicating normal force in a note. Please indicate the directions of net force, acceleration, and velocity to the side of the free-body diagram. | | | |
|---|---|---|---|
| **Name of Force** | **Direction** | **Magnitude** | **How did you determine the magnitude?** |
| Gravity | | | |
| Normal Force of the pole | All horizontal directions | | |
| Kinetic Friction | | | |

a) Determine the magnitude and direction of net force and acceleration acting on the person.

b) By referring explicitly to Newton's Second Law, and described in the table above, determine if the person increases or decreases in speed.

Further steps in these problems:

Problems don't end after you've determined the acceleration! Actually, the interesting results are going to happen by observing what happens as a result of that acceleration.

The following set of problems continue where **Y.9 – Y.11** left off: somebody who is already falling grabs a pole. However, you are now going to determine what happens as a result of them grabbing that pole:

According to Newton's Second Law…

| | |
|---|---|
| If net force is in the same direction as velocity… | Speed increases |
| If net force is in the opposite direction from velocity | Speed Decreases |

If you determine the person's speed is still increasing:
- Determine the speed at which they strike the ground.

But if you determine the person's speed is going to begin decreasing:
- Determine first *if they strike the ground* or if they *stop first*.

One way to answer this question [not the only way] is assume the ground does not exist and to determine their vertical displacement before their speed is equal to zero. If you find that value is greater than their initial height they will strike the ground before their speed reaches zero. But if you find that value is less than their initial height, they will stop before they strike the ground.

If they strike the ground, then determine the speed at which they strike the ground.

If they stop before striking the ground, determine the height at which they stop moving.

Assume that the person grabbing the pole has a *constant acceleration*.
This means that you can use the *kinematic equations* in order to answer the questions above:

| | |
|---|---|
| $v_f = v_i + a \cdot \Delta t$ | $\Delta y = \left(\frac{v_i + v_f}{2}\right)\Delta t$ |
| $\Delta y = v_i \cdot \Delta t + \frac{1}{2}a(\Delta t)^2$ | $v_f^2 = v_i^2 + 2a \cdot \Delta y$ |

**Y.12:**
A person with a mass of 60 kg grabs a pole with a force of 400 N. The coefficient of kinetic friction between the pole and their hands is 0.3. Before grabbing the pole, they were falling at a rate of 8 m/s at a height of 9 m.

a) Draw a free-body diagram of the person. Please name each force, and indicate the normal force with a note rather than an arrow. Indicate the initial velocity to the side of the free-body diagram.

b) Determine the magnitude and direction of net force and acceleration. Indicate the net force and acceleration to the side of the free-body diagram.

c) By referring explicitly to the table above, determine if the person slows down or speeds up as they fall.

d) If you determined that the person slows down, determine whether they will strike the ground.
If you determined that the person speeds up, then simply write "They will strike the ground."

e) If you determined that the person strikes the ground, determine the speed at which they strike the ground.
If you determined that the person strikes the ground, determine the height at which they stop moving.

**Y.13:**
A person with a mass of 40 kg grabs a pole with a force of 500 N. The coefficient of kinetic friction between the pole and their gloves is 0.7. Before grabbing the pole, they were falling at a rate of 5 m/s at height of 10 m.

a) Draw a free-body diagram of the person. Please name each force, and indicate the normal force with a note rather than an arrow. Indicate the initial velocity to the side of the free-body diagram.

b) Determine the magnitude and direction of net force and acceleration. Indicate the net force and acceleration to the side of the free-body diagram.

c) By referring explicitly to the table above, determine if the person slows down or speeds up as they fall.

d) If you determined that the person slows down, determine whether they will strike the ground.
If you determined that the person speeds up, then simply write "They will strike the ground."

e) If you determined that the person strikes the ground, determine the speed at which they strike the ground.
If you determined that the person strikes the ground, determine the height at which they stop moving.

**Y.14:**
A little kid who is unnaturally strong is falling at a rate of 13 m/s at a height of 40 m. She has a mass of only 30 kg and is able to grab the pole with a force of 1500 Newtons. The coefficient of kinetic friction between her hands and the pole is 0.25.

a) Draw a free-body diagram of the person. Please name each force, and indicate the normal force with a note rather than an arrow. Indicate the initial velocity to the side of the free-body diagram.

b) Determine the magnitude and direction of net force and acceleration. Indicate the net force and acceleration to the side of the free-body diagram.

c) By referring explicitly to the table above, determine if the person slows down or speeds up as they fall.

d) If you determined that the person slows down, determine whether they will strike the ground.
If you determined that the person speeds up, then simply write "They will strike the ground."

e) If you determined that the person strikes the ground, determine the speed at which they strike the ground.
If you determined that the person strikes the ground, determine the height at which they stop moving.

**Y.15:**
A person with a mass of 80 kg grabs a pole with a force of 400 N. The coefficient of kinetic friction between the pole and his gloves is 0.8. Before grabbing the pole, he was falling at a rate of 10 m/s at a height of 13 m.

a) Draw a free-body diagram of the person. Please name each force, and indicate the normal force with a note rather than an arrow. Indicate the initial velocity to the side of the free-body diagram.

b) Determine the magnitude and direction of net force and acceleration. Indicate the net force and acceleration to the side of the free-body diagram.

c) By referring explicitly to the table above, determine if the person slows down or speeds up as they fall.

d) If you determined that the person slows down, determine whether they will strike the ground.
If you determined that the person speeds up, then simply write "They will strike the ground."

e) If you determined that the person strikes the ground, determine the speed at which they strike the ground.
If you determined that the person strikes the ground, determine the height at which they stop moving.

**Y.16:**
A person with a mass of 80 kg grabs a pole with a force 1600 N. The coefficient of kinetic friction between the pole and his gloves is 0.75. Before grabbing the pole, he was falling at a rate of 12 m/s at a height of 16 m.

a) Draw a free-body diagram of the person. Please name each force, and indicate the normal force with a note rather than an arrow. Indicate the initial velocity to the side of the free-body diagram.

b) Determine the magnitude and direction of net force and acceleration. Indicate the net force and acceleration to the side of the free-body diagram.

c) By referring explicitly to the table above, determine if the person slows down or speeds up as they fall.

d) If you determined that the person slows down, determine whether they will strike the ground.
If you determined that the person speeds up, then simply write "They will strike the ground."

e) If you determined that the person strikes the ground, determine the speed at which they strike the ground.
If you determined that the person strikes the ground, determine the height at which they stop moving.

**Y.17:**
A person with a mass of 55 kg grabs a pole with a force of 850 N. The coefficient of kinetic friction between the pole and their gloves is 0.65. Before grabbing the pole, they were falling at a rate of 8 m/s at height of 80 m.

a) Draw a free-body diagram of the person. Please name each force, and indicate the normal force with a note rather than an arrow. Indicate the initial velocity to the side of the free-body diagram.

b) Determine the magnitude and direction of net force and acceleration. Indicate the net force and acceleration to the side of the free-body diagram.

c) By referring explicitly to the table above, determine if the person slows down or speeds up as they fall.

d) If you determined that the person slows down, determine whether they will strike the ground.
If you determined that the person speeds up, then simply write "They will strike the ground."

e) If you determined that the person strikes the ground, determine the speed at which they strike the ground.
If you determined that the person strikes the ground, determine the height at which they stop moving.

**Part 3: Qualitative Free-Body Diagram Analysis**
**Y.100A:**

A person is pressing a book against the wall, and it is not moving.

Draw a **qual**itative free-body diagram of
- the book (4 forces), which is not moving
- the person pressing the book (4 forces), which is not moving
- the wall (2 forces included in the free-body diagram, obviously many more forces affect the wall, but only two will be included here.)

For each force, identify the direction of the force, the name of the force, and the agent causing the force.

Y: Vertical Friction

Name ____________________

Free-Body Diagram of the book:

| Name of Force | Direction | Agent |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

The net force on the book is zero. Why?

Free-Body Diagram of the person pushing the book:

| Name of Force | Direction | Agent |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

The net force on the person is zero. Why?

Free-Body Diagram of the wall:

| Name of Force | Direction | Agent |
|---|---|---|
| | | |
| | | |

There are many other forces on the wall that are not included here! The wall has a net force of zero and does not move.

Y: Vertical Friction Name ____________________

Y100A Answer:

| Free-Body Diagram of the book: | | | The net force on the book is zero. Why? |
|---|---|---|---|
| Name of Force | Direction | Agent | |
| A. Gravity | Down (In) | Earth | |
| B. Static Friction | Up | The surface of the wall | |
| C. Applied Force | Right | The person | |
| D. Normal Force | Left | The wall | |

| Free-Body Diagram of the person pushing the book: | | | The net force on the person is zero. Why? |
|---|---|---|---|
| Name of Force | Direction | Agent | |
| E. Gravity | Down (In) | Earth | |
| F. Normal Force | Up | Floor | |
| G. Reaction to applied force | Left | The book | |
| H. Static Friction | Right | The floor | |

| Free-Body Diagram of the wall: | | | There are many other forces on the wall that are not included here! The wall has a net force of zero and does not move. |
|---|---|---|---|
| Name of Force | Direction | Agent | |
| I. Book pressing on Wall | Right | The book | |
| J. Static Friction | Down | The book | |

**Y100B:** Identifying pairs of forces:

According to Newton's Third Law, every force comes as a part of an **action-reaction pair**. If there is a force of A acting on B, there is always a force of B acting on A with equal magnitude and opposite direction, and these two forces are called an action reaction pairs.
Identify the action-reaction force pairs in this situation.
Note that the two forces in an action-reaction force pair act on two different objects, and thus they always appear in *two different* free-body diagrams.
There are 3 action-reaction pairs in our free-body diagrams.

There are also pairs of forces in these free-body diagrams that have equal magnitude and opposite direction but are NOT action-reaction pairs.
We will call these pairs of **balanced forces**.
These are pairs of a force that would create motion and a *constraint force* that is preventing motion. The balanced force pairs, unlike the action-reaction pairs, act on one object and appear in the *same* free-body diagram.
For each balanced force pair, identify which force is a constraint force and explain *why* the forces balance each other out. Also, please state *explicitly* that each pair of balanced forces is NOT an action-reaction pair and why.
There are four pairs of balanced forces.

Y100B Answers:

**Action Reaction Pairs: (3)**

Forces C and G are action reaction pairs.
The person pushes the book to the left, and the book pushes the person to the right.

Forces I, and D. are action reaction pairs.
The book presses to the right into the wall, and the wall pushes the book to the left (normal force).

Forces B. and J. are action-reaction pairs.
Static friction holds the book up and pulls the wall down. (But obviously not enough to have any impact on the wall.)

**Balanced Force Pairs: (4)**

Forces A and B, both acting on the book, have equal magnitude and opposite direction because the book is not moving vertically and static friction is a constraint force, but they are not and action reaction pair because they are *both* forces on the book.

Forces C and D, both acting on the book, have equal magnitude and opposite direction because the book is not moving horizontally and the normal force is a constraint force, but they are not action-reaction pairs because they are both forces on the book.

Forces E and F, both acting on the person, have equal magnitude and opposite direction because the person is not moving vertically and the normal force is a constraint force, but they are not an action-reaction pair because they are both forces acting ot he person.

Forces G and H, both acting on the person, have equal magnitude and opposite direction because the person is not moving horizontally and static friction is a constraint force, but they are not an action-reaction pair because they are both forces acting on the person.

Remember that action reaction pairs ALWAYS act on two different objects, never on the same object.

**Y.100C:**

Technically, according to Newton's Third Law, *every* force should be part of an action-reaction pair. To this end, we are going to expand the analysis above to include two more bodies: the floor and the earth.

Draw free-body diagrams of the *floor* and the *earth* that include only two forces each. Obviously, more than two forces forces act on both the floor and the earth, but do not include these in the free-body diagram.

Once this is completed, when combined with Y7A, you should have 5 free-body diagrams and 14 total forces. Identify *all 7* action-reaction pairs In this problem. Remember that every action-reaction acts on two different free-body diagrams, have equal magnitude and opposite direction.

<table>
<tr><td colspan="3">Free-Body Diagram of the floor:</td><td rowspan="4">There are many other forces on the floor that are not included here! The wall has a net force of zero and does not move.</td></tr>
<tr><td>Name of Force</td><td>Direction</td><td>Agent</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

<table>
<tr><td colspan="3">Free-Body Diagram of the earth:</td><td rowspan="4">There are many other forces on the wall that are not included here! The forces included here have no impact on the earth due to its high mass.<br><br>The net force on the earth is not zero, but we don't need to worry about that right now.</td></tr>
<tr><td>Name of Force</td><td>Direction</td><td>Agent</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Y100C: Answers:

<table>
<tr><td colspan="3">Free-Body Diagram of the floor:</td><td rowspan="4">There are many other forces on the floor that are not included here! The wall has a net force of zero and does not move.</td></tr>
<tr><td>Name of Force</td><td>Direction</td><td>Agent</td></tr>
<tr><td>K. Person's Foot Pressing</td><td>Down</td><td>Person</td></tr>
<tr><td>L. Static Friction</td><td>Right</td><td>Person</td></tr>
</table>

<table>
<tr><td colspan="3">Free-Body Diagram of the earth:</td><td rowspan="4">There are many other forces on the wall that are not included here! The forces included here have no impact on the earth due to its high mass.<br>The net force on the earth is not zero, but we don't need to worry about that right now.</td></tr>
<tr><td>Name of Force</td><td>Direction</td><td>Agent</td></tr>
<tr><td>M. Gravity of Person</td><td>Out</td><td>Person</td></tr>
<tr><td>N. Gravity of Book</td><td>Out</td><td>Book</td></tr>
</table>

The action reaction pairs are:
A and N
B and J
C and G
D and I
E and M
F and K
H and L

We have 14 forces, and 7 action-reaction pairs.
We are in full compliance with Newton's Third Law.

Y100D: The person-book system

Now, we are going to combine the person and the book to create one system.

Look at the free-body diagram of the *person* and the free-body diagram of the *book*.
Each free-body diagram has 4 forces, for a total of 8 forces.

We are going to combine these free-body diagrams to create one system, called the person-book system.

When combining the free-body diagrams we will have 8 forces.
Six of them are **external forces** and two of them are **internal forces**.

The **external forces** have an agent that is outside the system,
and the **internal forces** have an agent that is inside the system. The internal forces are a force between two forces of the system.

Identify the internal and external forces. Then, draw a complete free-body diagram of the person-book system. The free-body diagram should contain the six external forces but not the two internal forces.

Y: Vertical Friction Name ____________________

Y100D; Answers:

The external forces are A, B, D, E, F, and H.
The internal forces are C and G.

<table>
<tr><td colspan="3">Free-Body Diagram of the person-book system:</td><td rowspan="8">The net force on the system is zero. Why?</td></tr>
<tr><td>Name of Force</td><td>Direction</td><td>Agent</td></tr>
<tr><td>Gravity on the Person</td><td>Down (in)</td><td>Earth</td></tr>
<tr><td>Gravity on the Book</td><td>Down (in)</td><td>Earth</td></tr>
<tr><td>Normal Force on the person</td><td>Up</td><td>Floor</td></tr>
<tr><td>Static Friction on the person’s foot</td><td>Left</td><td>Floor</td></tr>
<tr><td>Normal Force on the book</td><td>Right</td><td>Wall</td></tr>
<tr><td>Static Friction on the book</td><td>Up</td><td>Wall</td></tr>
</table>

**Three things to notice about the free-body diagram of the system:**
The two *internal forces* are an action-reaction pair! In fact, internal forces are *always* an action-reaction pair within a system. This is why internal forces have no effect on the motion of a system, because they always have equal magnitude and opposite direction.

Two of the external forces are gravity. There should really be combined to one force of gravity that acts on the center of mass of the system.

The force of the static friction acting on the person's foot and the normal force acting on the book are equal magnitude and opposite direction because they are balanced forces. They are not an action-reaction pair, but they must cancel each other out because the system is not in motion.