**Forces and Interaction: Action-Reaction Pairs**

In each case, draw a free body diagram of the object. For every force you draw, identify the reaction force.

1. A book sitting at rest on a table.

   **FBD**
   
   ![Free Body Diagram](image)
   
   **Action**
   
   *Earth pulls down on Book*
   *Table pushes up on Book*
   
   **Reaction**
   
   *Book pulls up on Earth*
   *Book pushes down on Table*


   **FBD**
   
   ![Free Body Diagram](image)
   
   **Action**
   
   *Girl pushes Book forward*
   *Table pushes up on Book*
   *Table pulls back on Book*
   *Earth pulls down on Book*
   
   **Reaction**
   
   *Book pushes back on Girl*
   *Book pushes down on Table*
   *Book pushes forward on Table*
   *Book pulls up on Earth*

3. An apple falling from a tree. Include air resistance.

   **FBD**
   
   ![Free Body Diagram](image)
   
   **Action**
   
   *Earth pulls down on Apple*
   *Air pushes up on Apple*
   
   **Reaction**
   
   *Apple pulls down on Earth*
   *Apple pushes down on Air*

4. A helicopter hovering stationary in the air.

   **FBD**
   
   ![Free Body Diagram](image)
   
   **Action**
   
   *Earth pulls down on Helicopter*
   *Air pushes up on Helicopter*
   
   **Reaction**
   
   *Helicopter pulls up on Earth*
   *Helicopter pushes down on Air*

5. A rocket flying through space.

   **FBD**
   
   ![Free Body Diagram](image)
   
   **Action**
   
   *Gas pushes Rocket forward*
   
   **Reaction**
   
   *Rocket pushes Gas backward*

6. An airplane flying in a straight line through the air.

   **FBD**
   
   ![Free Body Diagram](image)
   
   **Action**
   
   *Earth pulls down on Plane*
   *Air pushes Plane forward*
   *Air pushes Plane upward*
   *Air pushes back on Plane*
   
   **Reaction**
   
   *Plane pulls up on Earth*
   *Plane pushes Air backward*
   *Plane pushes Air downward*
   *Plane pushes Air forward*
Equal Force ≠ Equal Acceleration

7. A father (80 kg) and his young son (25 kg) are standing on ice. The son pushes his father backward with a force of 15 N. What will the father’s acceleration be? What will the son’s acceleration be?

\[ a_F = \frac{F_{SF}}{m_F} = \frac{(15 \text{ N})}{(80 \text{ kg})} = 0.1875 \text{ m/s}^2 \]
\[ F_{SF} = 15 \text{ N}, \quad a_F = 0.188 \text{ m/s}^2 \]

\[ a_S = \frac{F_{FS}}{m_S} = \frac{(15 \text{ N})}{(25 \text{ kg})} = 0.6 \text{ m/s}^2 \]
\[ F_{FS} = 15 \text{ N}, \quad a_S = 0.6 \text{ m/s}^2 \]

8. A person firing a rifle (80 kg) fires a bullet (mass = 0.030 kg). The bullet is fired forward with an acceleration of 10,000 m/s². How much backwards acceleration does the person experience?

\[ F_{PB} = m_B \times a_B = (0.030 \text{ kg}) \times (10,000 \text{ m/s}^2) = 300 \text{ N} \]
\[ a_B = \frac{F_{PB}}{m_B} = \frac{300 \text{ N}}{(0.030 \text{ kg})} = 10,000 \text{ m/s}^2 \]

\[ a_P = \frac{F_{PA}}{m_p} = \frac{(300 \text{ N})}{(80 \text{ kg})} = 3.75 \text{ m/s}^2 \]
\[ F_{PA} = 300 \text{ N}, \quad a_P = 3.75 \text{ m/s}^2 \]

9. A person (70 kg) takes a step forward on an airplane (300,000 kg) with an acceleration of 3 m/s². How much backwards acceleration does the airplane experience as a result of the person stepping forward?

\[ F_{AP} = m_P \times a_P = (70 \text{ kg}) \times (3 \text{ m/s}^2) = 210 \text{ N} \]
\[ a_P = \frac{F_{AP}}{m_A} = \frac{210 \text{ N}}{(300,000 \text{ kg})} = 0.0007 \text{ m/s}^2 \]

\[ F_{PA} = \frac{F_{AP}}{m_P} = \frac{(210 \text{ N})}{(70 \text{ kg})} = 3 \text{ m/s}^2 \]
\[ a_A = \frac{F_{PA}}{m_A} = \frac{(210 \text{ N})}{(300,000 \text{ kg})} = 0.0007 \text{ m/s}^2 \]

10. What is all 200 people on the airplane took a step forward at the same time? What would the resulting force and acceleration on the airplane be then?

\[ F_{PA} = 200 \times (210 \text{ N}) = 42,000 \text{ N} \]
\[ a_P = \frac{F_{PA}}{m_A} = \frac{(42,000 \text{ N})}{(300,000 \text{ kg})} = 0.14 \text{ m/s}^2 \]

\[ F_{PA} = 42,000 \text{ N}, \quad a_P = 0.14 \text{ m/s}^2 \]

11. A person (70 kg) jumps off of a building and falls with an acceleration of 9.8 m/s². How fast does the Earth accelerate upwards towards him?

\[ F_{EP} = m_p \times g = (70 \text{ kg}) \times (9.8 \text{ m/s}^2) = 686 \text{ N} \]
\[ a_E = \frac{F_{EP}}{m_E} = \frac{686 \text{ N}}{(6 \times 10^{24} \text{ kg})} = 1.14 \times 10^{-22} \text{ m/s}^2 \]

\[ F_{EP} = 686 \text{ N}, \quad a_E = 1.14 \times 10^{-22} \text{ m/s}^2 \]

12. How far does the person fall towards the Earth in 1 second? How far does the Earth move towards the person in 1 second?

\[ d_p = \frac{1}{2} a_P t^2 = \frac{1}{2} (9.8 \text{ m/s}^2)(1 \text{ s})^2 = 4.9 \text{ m} \]
\[ d_E = \frac{1}{2} a_E t^2 = \frac{1}{2} (1.14 \times 10^{-22} \text{ m/s}^2)(1 \text{ s})^2 = 5.7 \times 10^{-23} \text{ m} \]

\[ d_p = 4.9 \text{ m} \]
\[ d_E = 5.7 \times 10^{-23} \text{ m} \]

\[ (this \ is \ about \ ten \ trillion \ times \ smaller \ than \ the \ width \ of \ an \ atom!) \]

13. What if all 6 billion (6 x 10⁹) people on Earth jumped of a building at the same time on the same side of the Earth. What would be the acceleration then?

\[ F_{PE} = (6,000,000,000 \times 686 \text{ N}) = 4.11 \times 10^{12} \text{ N} \]
\[ a_E = F_{PE} / m_E = (4.11 \times 10^{12} \text{ N}) / (6 \times 10^{24} \text{ kg}) = 6.86 \times 10^{-13} \text{ m/s}^2 \]

\[ F_{PE} = 4.11 \times 10^{12} \text{ N}, \quad a_E = 6.86 \times 10^{-13} \text{ m/s}^2 \]

14. How far would the Earth move in 1 second as a result of everyone jumping at once?

\[ d_E = \frac{1}{2} a_E t^2 = \frac{1}{2} (6.86 \times 10^{-13} \text{ m/s}^2)(1 \text{ s})^2 = 3.43 \times 10^{-11} \text{ m} \]
\[ d_E = 3.43 \times 10^{-11} \text{ m} \]

\[ (this \ is \ STILL \ about \ one \ thousand \ times \ smaller \ than \ the \ width \ of \ an \ atom!!) \]