

Part I: Newton's Laws of Motion

Instructions: For each scenario below, identify the relevant forces and explain the described motion using Newton's First, Second, and/or Third Laws. Be specific about which law(s) apply and why.

Question 1

Scenario: A person is riding in a car when the driver suddenly brakes hard. The passenger lurches forward, and their seatbelt snaps taut to stop them.

Question: What caused the passenger to lurch forward? Why did the seatbelt need to exert a force? Explain using Newton's laws.

Answer:

Question 2

Scenario: After being struck by a hockey stick, a puck slides across ice and continues moving for a very long distance before slowly coming to a stop.

Question: Why does the puck keep moving after it leaves the stick? Why does it eventually stop? What would happen on a perfectly frictionless surface? Explain using Newton's laws.

Answer:

Question 3

Scenario: Two astronauts in space are floating at rest. One pushes the other away. Both astronauts begin to move in opposite directions.

Question: Why do both astronauts move? How do their speeds compare if one has twice the mass of the other? Explain using Newton's laws.

Answer:

Question 4

Scenario: A book sits motionless on a table. You push down on the book, and it still does not move.

Question: Identify all forces acting on the book. Why doesn't the book accelerate downward? What can you conclude about the net force? Explain using Newton's laws.

Answer:

Question 5

Scenario: A small car and a large truck collide head-on. The car experiences a much larger change in velocity than the truck.

Question: Compare the forces the car and truck exert on each other during the collision. Why does the car's velocity change more? Explain using Newton's laws.

Answer:

Question 6

Scenario: A skateboarder stands on a skateboard and throws a heavy backpack forward. The skateboarder rolls backward.

Question: Why does the skateboarder move backward? How would the outcome change if the backpack were much lighter? Explain using Newton's laws.

Answer:

Question 7

Scenario: A rocket in empty space fires its engines. It accelerates forward even though there is nothing to “push against.”

Question: What force propels the rocket forward? Does Newton’s Third Law require a physical surface to push against? Explain using Newton’s laws.

Answer:

Question 8

Scenario: You are standing in an elevator. As the elevator begins moving upward, you feel briefly heavier. As it decelerates to a stop at the top floor, you feel briefly lighter.

Question: Explain why you feel heavier and lighter at different moments, even though your mass has not changed. Draw and label the forces involved. Explain using Newton’s laws.

Answer:

Question 9

Scenario: Two balls are rolled; one across carpet, the other across a smooth tile floor. The one on the smooth tile travels much farther before stopping.

Question: What force is responsible for stopping the ball in each case? Why does the ball decelerate at different rates on the two surfaces? Explain using Newton’s laws.

Answer:

Question 10

Scenario: Two identical shopping carts are pushed with the same force: one is empty and one is full of groceries. The empty cart accelerates much faster.

Question: Why do the carts accelerate differently despite receiving the same push? What quantity determines how difficult it is to accelerate an object? Explain using Newton's laws.

Answer:

Question 11

Part II: Newton's Law of Universal Gravitation

The gravitational force between two masses is given by:

$$F = G \frac{m_1 m_2}{r^2}$$

where m_1 and m_2 are the masses, r is the distance between their centers, and G is the gravitational constant.

Instructions: For each question, determine how the gravitational force changes. Express your answer as a multiple of the original force (e.g., "the force doubles" or "the force is reduced to one-quarter") and show your reasoning using the formula above.

Question 11

Scenario: Two objects exert a gravitational force F on each other. One of the masses is doubled, while everything else stays the same.

Question: What is the new gravitational force in terms of F ? Explain your reasoning.

Answer:

Question 12

Scenario: Two objects exert a gravitational force F on each other. Both masses are doubled simultaneously, while the distance between them stays the same.

Question: What is the new gravitational force in terms of F ? Explain your reasoning.

Answer:

Question 13

Scenario: Two objects exert a gravitational force F on each other. The distance between them is doubled, while the masses stay the same.

Question: What is the new gravitational force in terms of F ? Why does distance have a stronger effect than mass? Explain your reasoning.

Answer:

Question 14

Scenario: Two objects exert a gravitational force F on each other. The distance between them is reduced to half its original value, while the masses stay the same.

Question: What is the new gravitational force in terms of F ? Explain your reasoning.

Answer:

Question 15

Scenario: Two objects exert a gravitational force F on each other. One mass is doubled and the distance between them is also doubled.

Question: What is the new gravitational force in terms of F ? Do the two changes reinforce or partially cancel each other? Explain your reasoning.

Answer:

Question 16

Scenario: Two objects exert a gravitational force F on each other. The distance between them is tripled, while the masses stay the same.

Question: What is the new gravitational force in terms of F ? Explain your reasoning.

Answer:

Question 17

Scenario: A spacecraft travels away from Earth. At its launch altitude, the gravitational force from Earth is F . The spacecraft climbs to an altitude such that its distance from Earth's center is now three times what it was at launch.

Question: What is the gravitational force on the spacecraft at this new altitude, in terms of F ? Does the spacecraft ever fully escape Earth's gravity? Explain your reasoning.

Answer:

Question 18

Scenario: Consider the gravitational force between Earth and the Moon, and compare it to the gravitational force between Earth and the Sun. The Sun is much more massive than the Moon, but also much farther away.

Question: Which body exerts a larger gravitational force on Earth — the Moon or the Sun? What two competing factors determine the answer? Explain your reasoning using the law of universal gravitation. (You do not need to calculate exact values.)

Answer:
