Newton's Laws of Motion

Newton's Second Law
The acceleration of an object is directly proportional to the net force acting on it, and inversely proportional to its mass. The direction of the acceleration is in the direction of the net force acting on the object.

This is often written as an equation:

$$\sum \vec{F} = m\vec{a}$$

The symbol $\sum \vec{F}$ means the *vector sum of all forces* acting on an object, which we define as the **net force**.

Note: In the SI system, the unit of force is called the **Newton** (N). The Newton is a derived unit representing the force required to impart an acceleration of $1\ m/s^2$ to a mass of $1\ kg$. Thus,

$$1\ N = 1\ kg \cdot m/s^2$$

Example 1
What net force would be required to accelerate (a) a $1250\ kg$ car at $4.9\ m/s^2$, and (b) a $175\ g$ apple at the same rate?

Example 2

What average net force is required to bring a $1500\ kg$ car to rest from a speed of $108\ km/h$ within a distance of $55\ m$?

Example 3

A fully loaded airplane with a mass of $2.17 \times 10^5\ kg$ accelerates at full throttle down a level runway. The engines push with a combined horizontal net force of $753\ kN$. If the plane starts from rest, how far will it move during the $33.5\ s$ that it takes to reach liftoff velocity?

Worksheet

1. What is meant by the net force that acts on an object?

2. Suppose a cart is being moved by a certain net force. If the net force is doubled, by how much does the cart's acceleration change?

3. Suppose a cart is being moved by a certain net force. If a load is dumped into the cart so its mass is doubled, by how much does the acceleration change?

4. State Newton's second law in words and then in the form of an equation.

5. How much force does a $20000\ kg$ rocket develop to accelerate $1\ m/s^2$?

6. If the force of friction acting on a sliding crate is $100\ N$, how much force must be applied to maintain a constant velocity? What will be the net force acting on the crate? What will be the acceleration?

7. Calculate the acceleration of a $2000\ kg$, single-engine airplane just before takeoff when the thrust of its engine is $500\ N$.

8. Calculate the acceleration of a $300000\ kg$ jumbo jet just before takeoff when the thrust for each of its four engines is $30000\ N$.

9. Calculate the acceleration if you push with a $20\ N$ horizontal force on a $2\ kg$ block on a horizontal, friction-free air table.

10. What acceleration would the block in question 9 have if there were a $4\ N$ frictional force?

11. Calculate the horizontal force that must be applied to a $1\ kg$ puck to make it accelerate on a horizontal, frictionless air table with the same acceleration it would have if it were dropped and fell freely ($9.8\ m/s^2$).

12. Calculate the horizontal force that must be applied to produce an acceleration of $17.6\ m/s^2$ for a $1.2\ kg$ puck on a horizontal, frictionless air table.

13. If an object has no acceleration, can you conclude that no forces are exerted on it? Explain.

14. If a $1\ N$ net force accelerates a $1\ kg$ mass at $1\ m/s^2$, what is the acceleration caused by a net force of $2\ N$ on a $2\ kg$ mass?

15. What is the acceleration of a 747 jumbo jet, mass $30000\ kg$, in takeoff when the thrust for each of its four engines is $30000\ N$?

16. A certain force applied to a $2\ kg$ mass accelerates the mass at $3\ m/s^2$. How much acceleration will the same force produce on a $4\ kg$?

17. A horizontal force of $100\ N$ is required to push a crate across a factory floor at a constant speed. What is the net force acting on the crate? What is the force of friction acting on the crate?

18. If a four engine jet accelerates down the runway at $2\ m/s^2$ and one of the jet engines fails, how much acceleration will the other three produce?

19. If a loaded truck that can accelerate at $1\ m/s^2$ loses its load and has three-fourths of the original mass, what acceleration can it attain from the same driving force?

20. An occupant of a car has a chance of surviving a crash if the deceleration during the crash is not more than $-294\ m/s^2$. Calculate the force on a $70\ kg$ person decelerating at this rate.

Answers

1. The vector sum of all the forces acting on the object.

2. The acceleration would be doubled.

3. The acceleration would be halved.

4. The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

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

5. $20000\ N$

6. $100\ N$; 0; 0

7. $0.25\ m/s^2$

8. $0.4\ m/s^2$

9. $10\ m/s^2$

10. $8\ m/s^2$

11. $9.8\ N$

12. $21.2\ N$

13. No. There could be two or more forces acting on the object in such a way that they are cancelling out (i.e. they add up to zero).

14. $1\ m/s^2$

15. $4\ m/s^2$

16. $1.5\ m/s^2$

17. The net force would be zero since the crate has a constant speed. The frictional force would be $-100\ N$ so that when the applied force and friction are added, the result is zero.

18. $1.5\ m/s^2$

19. $1.3\ m/s^2$

20. $-20580\ N$