6.S: Newton's Laws of Motion (Summary)

Key Terms

dynamics	study of how forces affect the motion of objects and systems
external force	force acting on an object or system that originates outside of the object or system
force	push or pull on an object with a specific magnitude and direction; can be represented by vectors or expressed as a multiple of a standard force
free fall	situation in which the only force acting on an object is gravity
free-body diagram	sketch showing all external forces acting on an object or system; the system is represented by a single isolated point, and the forces are represented by vectors extending outward from that point
Hooke's law	in a spring, a restoring force proportional to and in the opposite direction of the imposed displacement
inertia	ability of an object to resist changes in its motion
inertial reference frame	reference frame moving at constant velocity relative to an inertial frame is also inertial; a reference frame accelerating relative to an inertial frame is not inertial
law of inertia	see Newton’s first law of motion
net external force	vector sum of all external forces acting on an object or system; causes a mass to accelerate
newton	SI unit of force; 1 N is the force needed to accelerate an object with a mass of 1 kg at a rate of 1 m/s^2
Newton’s first law of motion	body at rest remains at rest or, if in motion, remains in motion at constant velocity unless acted on by a net external force; also known as the law of inertia
Newton’s second law of motion	acceleration of a system is directly proportional to and in the same direction as the net external force acting on the system and is inversely proportional to its mass
Newton’s third law of motion	whenever one body exerts a force on a second body, the first body experiences a force that is equal in magnitude and opposite in direction to the force that it exerts
normal force	force supporting the weight of an object, or a load, that is perpendicular to the surface of contact between the load and its support; the surface applies this force to an object to support the weight of the object
tension	pulling force that acts along a stretched flexible connector, such as a rope or cable
thrust	reaction force that pushes a body forward in response to a backward force
weight	force $\vec{w}$ due to gravity acting on an object of mass m

Key Equations

Net external force	$\vec{F}_{net} = \sum \vec{F} = \vec{F}_1 + \vec{F}_2 + \ldots$	(6.S.1)
Newton's first law	$\vec{v} = constant\ when\ \vec{F}_{net} = \vec{0}\ N$	(6.S.2)
Newton's second law, vector form	$\vec{F}_{net} = \sum \vec{F} = m\vec{a}$	(6.S.3)
Newton's second law, scalar form	$\vec{F}_{net} = ma$	(6.S.4)
Newton's second law, component form	$\sum \vec{F}_x = m\vec{a}_x, \sum \vec{F}_y = m\vec{a}_y, \sum \vec{F}_z = m\vec{a}_z$	(6.S.5)
Newton's second law, momentum form	$\vec{F}_{net} = \frac{d\vec{p}}{dt}$	(6.S.6)
Definition of weight, vector form	$\vec{w} = m\vec{g}$	(6.S.7)
Definition of weight, scalar form	$w = mg$	(6.S.8)
Newton's third law	$\vec{F}_{AB} = -\vec{F}_{BA}$	(6.S.9)
Normal force on an object resting on a horizontal surface, vector form	$\vec{N} = -m\vec{g}$	(6.S.10)
Normal force on an object resting on a horizontal surface, scalar form	$N = mg$	(6.S.11)
Normal force on an object resting on an inclined plane, scalar form	$N = mg\cos\theta$	(6.S.12)
Tension in a cable supporting an object of mass m at rest, scalar form	$T = w = mg$	(6.S.13)

Summary

5.1 Forces

- Dynamics is the study of how forces affect the motion of objects, whereas kinematics simply describes the way objects move.
- Force is a push or pull that can be defined in terms of various standards, and it is a vector that has both magnitude and direction.
- External forces are any outside forces that act on a body. A free-body diagram is a drawing of all external forces acting on a body.
- The SI unit of force is the newton (N).

5.2 Newton's First Law

- According to Newton's first law, there must be a cause for any change in velocity (a change in either magnitude or direction) to occur. This law is also known as the law of inertia.
- Friction is an external force that causes an object to slow down.
- Inertia is the tendency of an object to remain at rest or remain in motion. Inertia is related to an object's mass.
- If an object's velocity relative to a given frame is constant, then the frame is inertial. This means that for an inertial reference frame, Newton's first law is valid.
- Equilibrium is achieved when the forces on a system are balanced.
- A net force of zero means that an object is either at rest or moving with constant velocity; that is, it is not accelerating.

5.3 Newton's Second Law

- An external force acts on a system from outside the system, as opposed to internal forces, which act between components within the system.
- Newton's second law of motion says that the net external force on an object with a certain mass is directly proportional to and in the same direction as the acceleration of the object.
- Newton's second law can also describe net force as the instantaneous rate of change of momentum. Thus, a net external force causes nonzero acceleration.

5.4 Mass and Weight

- Mass is the quantity of matter in a substance.
- The weight of an object is the net force on a falling object, or its gravitational force. The object experiences acceleration due to gravity.
- Some upward resistance force from the air acts on all falling objects on Earth, so they can never truly be in free fall.
- Careful distinctions must be made between free fall and weightlessness using the definition of weight as force due to gravity acting on an object of a certain mass.

5.5 Newton's Third Law

- Newton's third law of motion represents a basic symmetry in nature, with an experienced force equal in magnitude and opposite in direction to an exerted force.
- Two equal and opposite forces do not cancel because they act on different systems.
- Action-reaction pairs include a swimmer pushing off a wall, helicopters creating lift by pushing air down, and an octopus propelling itself forward by ejecting water from its body. Rockets, airplanes, and cars are pushed forward by a thrust reaction force.
- Choosing a system is an important analytical step in understanding the physics of a problem and solving it.

5.6 Common Forces

- When an object rests on a surface, the surface applies a force to the object that supports the weight of the object. This supporting force acts perpendicular to and away from the surface. It is called a normal force.
- When an object rests on a nonaccelerating horizontal surface, the magnitude of the normal force is equal to the weight of the object.
- When an object rests on an inclined plane that makes an angle θ with the horizontal surface, the weight of the object can be resolved into components that act perpendicular and parallel to the surface of the plane.
- The pulling force that acts along a stretched flexible connector, such as a rope or cable, is called tension. When a rope supports the weight of an object at rest, the tension in the rope is equal to the weight of the object. If the object is accelerating, tension is greater than weight, and if it is decelerating, tension is less than weight.
- The force of friction is a force experienced by a moving object (or an object that has a tendency to move) parallel to the interface opposing the motion (or its tendency).
- The force developed in a spring obeys Hooke's law, according to which its magnitude is proportional to the displacement and has a sense in the opposite direction of the displacement.
- Real forces have a physical origin, whereas fictitious forces occur because the observer is in an accelerating or noninertial frame of reference.

5.7 Drawing Free-Body Diagrams

- To draw a free-body diagram, we draw the object of interest, draw all forces acting on that object, and resolve all force vectors into x- and y-components. We must draw a separate free-body diagram for each object in the problem.
- A free-body diagram is a useful means of describing and analyzing all the forces that act on a body to determine equilibrium according to Newton's first law or acceleration according to Newton's second law.

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