# 5.8: Summary

## Key Takeaways

Newton's Three Laws are a theory of classical physics that allow the motion of an object to be fully described by introducing the concepts of force and mass.

Newton's First Law states that objects will not accelerate if no net force is exerted on the object. In particular, this allows inertial frames of reference to be defined as those frames of reference where Newton's First Law holds true.

Newton's Second Law connects dynamics and kinematics by relating the net force exerted on an object (i.e. the vector sum of the forces exerted on an object) to its acceleration and its mass:

$$\vec F^{net}=\sum_i \vec F_i=m\vec a$$

Newton's Third law states that forces always come in pairs that are exerted on different objects. If object A exerts a force on object B, then object B exerts a force that is equal in magnitude but opposite in direction on object A.

A force is a mathematical tool introduced in Newton's theory to model how different objects can influence each other. Mass can be thought of as a quantity of matter and is an intrinsic property of an object. Inertial mass refers to how that quantity of matter resists acceleration, whereas gravitational mass refers to how that quantity of mass experiences the force of gravity. As far as we can tell, inertial and gravitational mass are the same.

When applying Newton's theory, the most important part is to identify the forces that act on one object. This can be represented graphically by using a free-body diagram. The following is a common list of forces to consider when identifying the forces exerted on an object:

- Weight (is the object near the surface of a planet?).
- Normal forces (is the object in contact with any surface? There could be more than one!).
- Frictional forces (are there static or kinetic friction forces associated with the normal forces?).
- Tension forces (is something like a rope pulling on the object?).
- Drag forces (is the object moving through a fluid?).
- Spring forces (is there a spring pushing or pulling on the object?).
- Applied forces (is anything else pushing or pulling on the object?).

When applying Newton's Second Law, one needs to choose a coordinate system so that Newton's Second Law can be written out for each component. It is usually good to choose the coordinate system such that the $x$ axis is parallel to the acceleration vector of the object.

When using Newton's Laws to model the motion of an object of mass $m$ in a non-inertial frame of reference that is accelerating with acceleration $\vec a$ relative to an inertial frame of reference, an additional inertial force, $\vec F_I=-m\vec a$, must be included on the the object.

## Important Equations

Newton's Second Law, in vector form, can be written as:

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

which is just a short-hand notation for the scalar equations written out for each component:

$$\sum F_x=ma_x$$
$$\sum F_y=ma_y$$
$$\sum F_z=ma_z$$

The force of gravity (or weight), $\vec F_g$, near the surface of the Earth is given by:

$$\vec F_g=m\vec g$$

where Earth's gravitational field has a magnitude of $g = 9.8\text{N}/\text{kg}$.

The force of kinetic friction exerted by one surface on another is given by::

$$f_k = \mu_k N$$

where $N$ is the normal force between the two surfaces and $\mu_k$ is the coefficient of kinetic friction. The force of kinetic friction on a object is in the opposite direction from its motion.

The maximum value of the magnitude of the force of static friction between two surfaces with a coefficient of static friction $\mu_s$ between them, can be written as:

$$f_s \leq \mu_s N$$

The force of static friction is exerted in the direction opposite of the impeding motion.

Hookes' Law for the force exerted by a spring, is given by the following vector equation:

$$\vec{F} = -kx\hat{x}$$

where $x$ is the distance by which the spring is compressed or extended relative to its rest length.

## Important Definitions

**Mass:** A property of matter which describes its resistance to acceleration. SI units: [kg]. Common variable(s): $M$, $m$.

**Force:** A mathematical object used to describe the interactions of an object with its environment. SI units: [N]. Common variable(s): $\vec{F}$.

**Spring constant:** A value which describes the stiffness of a spring, when the restoring force of the spring is modeled using Hooke's Law. SI units: [$\text{Nm}^{-1}$]. Common variable(s): $k$.

**Gravitational field:** The strength of the gravitational force per unit mass at a particular location. Under the equivalence principle, this is numerically equal to the acceleration of free-falling object. SI units: [N/kg (field), $\text{ms}^{-2}$ (acceleration)]. Common variable(s): $\vec{g}$.

**Coefficient of friction:** A constant used to determine the magnitude (or maximal magnitude if static friction) of a friction force between two surfaces based on the normal force exerted perpendicular to those two surfaces. SI units: none. Common variable(s): $\mu$.

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