CSEC Physics Handout

Dynamics 2

Newton's Laws

SPECIFIC OBJECTIVES (4.2 – 4.5)

Candidates should be able to:

4.2 state Newton's three law of motion

4.3 define the Newton

4.4 use Newton's laws to explain common dynamical systems

4.5 use Newton's laws for the solution of problem

CONTENT

Newton's Laws of Motion may be regarded as the foundation of dynamics…the field of study to which consideration is given to the inter-relationships between force, mass and motion.

It is useful to be reminded that "change of motion" is one of the defining effects of a force (see Module 3) and an important one at that.

It ought to be surprising that "momentum" is also a concept intimately involved in Newton's Laws of Motion because, as was dealt with in the preceding section, momentum is fundamental to understanding what happens when bodies exert forces on one another either through collision or other kinds of interaction.

Newton's Laws of Motion

These are universal laws and may be stated as follows:

1st Law: Everybody remains at rest or, if moving, continues with uniform motion in a straight line unless acted on by an unbalanced (external) force.

2nd Law: The rate of change of linear momentum of a body is proportional to the resultant external force acting on that body and takes place in the straight line in which that force acts.

3rd Law: If a body A exerts a force on a body, then the body B exerts an equal but opposite force on body A. Both forces are of the same type.

Since the laws are universal they are applicable to all physical systems without exception. However, their application may be better appreciated by considering simple physical systems in three different states of motion, first.

Explanations Based on Newton's First Law:

1. Systems with a body which has constant velocity.

   1.1 equal to zero (i.e. state of rest) (v = 0)

   Examples:

   A book at rest on a table top

   A block of wood floating on the surface of calm water

   A balloon filled with helium floating in a fixed position in still air

   Explanation:

   Law 1: In each case the body concerned (underlined) has NO unbalanced or resultant force acting on it. There are, however, different external forces actions on the body but these balance one another to give zero resultant. The body is at rest and continues in its state of rest. Its velocity does NOT CHANGE and remains zero.

   1.2 not equal to zero ($v \neq 0$) (i.e. moving)

   Examples:

   A moving car being driven at constant speed on a straight level road

   A skater gliding in a straight line on SMOOTH level ice

   A parachutist descending vertically with constant speed in air

   A passenger in a motor car after the brakes are suddenly applied

   Explanation:

   Law 1: In each case the body concerned (underlined) has NO unbalanced or resultant force acting on it. Several forces, however, act on the body but they balance and give zero resultant. The body is moving with constant velocity and so continues to move with the same velocity. Its velocity does not change so long as there is no unbalanced force acting. For the examples given in 1.1 and 1.2, the bodies concerned either remain in their state of rest or continue to move with uniform speed in a straight line because there is no resultant force acting on them. This property of all bodies is often referred to as inertia, which is often described as “the reluctance of a body to have its motion altered” or “the need for an unbalanced force to alter the uniform motion or state of rest of a body”.

2. Systems with a body which has velocity

2.1 ONLY the magnitude of which is:

2.11 increasing

Examples:

2.111 A 100 m Olympic runner coming out of the blocks

2.112 A racing car shortly after the start of a race

2.113 A stone falling freely under gravity.

2.12 decreasing

Examples

2.121 A motor car after the brakes have been applied

2.122 A cannon ball after falling into mud

2.123 A book sliding across a (rough) table top

2.2 ONLY the direction of which is changing

Examples:

2.21 A planet in orbit around the Sun

2.22 A ball being whirled at constant speed in a circle by means of a string

2.23 A constantly moving “crazy” ant in a disturbed nest

2.3 BOTH the magnitude and direction of which are changing

Examples:

2.31 A molecule of a gas

2.32 A ball in a pin-ball game machine

2.33 A piece of seaweed drifting in turbulent water

Explanation

Law 1: In each of the examples for 2.1, 2.2 and 2.3 the body concerned may have several forces acting on it. However, these factors do NOT balance one another and the body has net, resultant or unbalanced force acting on it. The velocity of the body must therefore be changing. Since velocity is a vector quantity then the changing velocity is one with a changing magnitude ONLY, or a changing direction ONLY or one for which BOTH magnitude and direction are simultaneously changing.

The detailed dynamics which applies to Examples 2.21 and 2.22 is given in CIRCULAR MOTION.

Explanations Based on Newton's Second Law

Newton's Second Law of Motion incorporates and extends what has been said in the First Law. The second law also provides a quantitative basis for the relationship between the resultant force acting on a body and its changing motion.

When a resultant force acts on a body the velocity of that body will not be constant but changing. For a body (of fixed mass) in this situation, this implies that its momentum will also be changing because momentum, by definition, depends on and is proportional to the velocity of the body.

Newton's Second Law of Motion asserts that the rate of change of momentum of a body in such a situation is proportional to the resultant force, F, which causes the velocity and momentum of the body to be changing in the first place.

So in words Newton's Second Law may be expressed as:

> Rate of change of momentum is proportional to resultant force acting, or in words and symbols, as
>
> Rate of change of P α F, or as
>
> Rate of change of (m v) α F, or as
>
> m x Rate of change of v α F, or using only symbols and calculus notation, as

$\frac{dP}{dt} = \frac{d(mv)}{dt} = m\frac{dv}{dt} \ \alpha \ F$, since m is being considered to be constant and t is time.

Directional Relationships

Now, since momentum is a vector quantity, then "change in momentum" is a vector and so also is "rate of change of momentum". Newton's Second law also asserts that the direction associated with the "rate of change of momentum" of a body acted upon by a force is the SAME as the direction of the force which, as we know, is also a vector quantity.

For rectilinear/ straight line motion, a positive sign for both quantities implies that the force acting on the body serves to speed it up. A negative sign for both quantities, on the other hand, implies that the force F is serving to decelerate the moving body.

Use of 2nd Law to Solve Problems

In the relationship

m x Rate of change of v α F,

We recognize that "Rate of change of v" is the acceleration, a, of the body on which the resultant force F acts.

So m a α F

- ⇨ F α ma
- ⇨ F = k ma where k is a constant

Inertial Equation and the Newton

On the SI system the units of m, a, and F are so defined that k has the value of 1 and has no units.

F = ma (called the inertial equation) therefore implies that definition of the unit of force as

"that resultant force which when acting on a mass of one kilogram imparts to it an acceleration of 1 ms^{-1}".

This force is called "one Newton" and is represented as '1 N".

From the inertial equation, we see that

(i) a α F (for constant m)

(ii) a α 1/m (for constant F) and

That if any of the three related quantities are "known" or "given", then the third may be found by rearranging and substitution.

Explanation and Problem Solving Involving Newton's Third Law

This law relates to the bodies (or systems) exerting forces on each other.

In the definition given, it was seen that the law affirms that a body cannot exert a force on another without itself experiencing an equal and opposite force.

The law is therefore universal and applies not only to collision but interactions of all kinds between bodies. The forces involved are often referred to as an "action-reaction pair" but there is no way of distinguishing between action and reaction as the forces always exist together.

When applying the law to solve numerical problems it is important to remember therefore that:

(i) the action-reaction forces are equal in magnitude

(ii) they act in opposite directions

(iii) they act ON different bodies

(iv) They may <u>not</u> be the only forces acting on the bodies concerned

(v) They may cause equal and opposite changes in momentum of the two bodies concerned