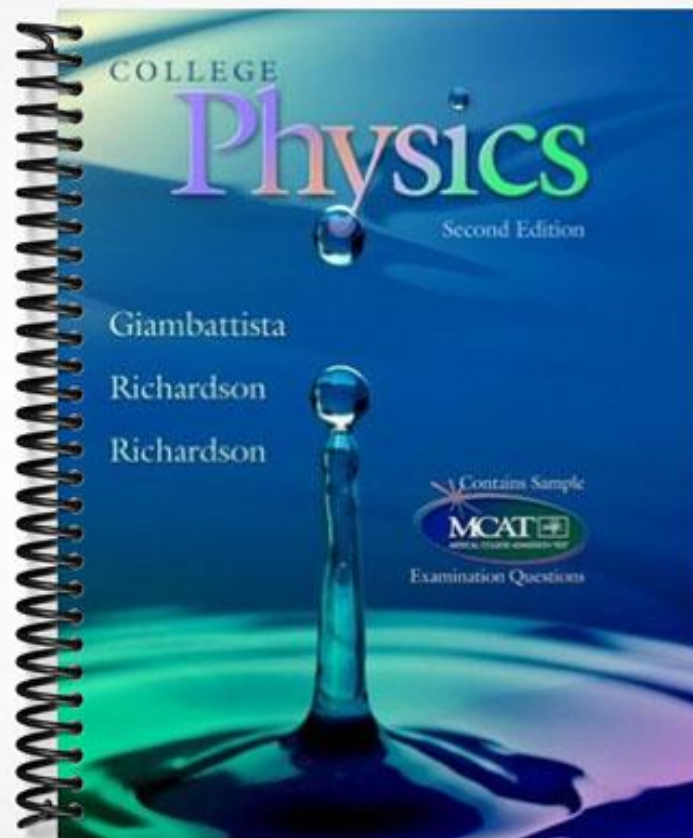


# SOLUTIONS MANUAL



## Chapter 2: Force

### *A. Summary of main points of chapter*

#### 2.1 Force

Forces are interactions between objects, in the form of a push or pull. Forces may be contact forces, or may act at a distance. Anything that exerts a force also has a force exerted on it.

**Measuring Forces:** Forces can be measured using springs ( $F = kx$ ); the SI unit for force is the newton (N).

**Force is a Vector Quantity:** Force also has direction; a complete description of a force is not possible without including directional information. Quantities with both magnitude and direction are called vectors. Quantities with magnitude only (such as mass) are called scalars. Scalars can be added arithmetically; vectors have their own addition rules.

#### 2.2 Net force

Finding the net (total) force on an object is done by adding all the individual forces; however, they are vectors (that is, their direction matters when you are adding them) and so must be added with that in mind.

**Adding vectors graphically:** Collinear vectors (vectors which are either in the same or opposite directions) can be added graphically. A vector is symbolized by an arrow pointing in the direction of the vector, whose length is proportional to the magnitude of the vector. When adding, the second vector starts where the first one ends – the tail of the second is placed at the head of the first. The sum has its tail at the tail of the first vector and its head at the head of the second. Addition and subtraction of vectors in two dimensions can be done either graphically or by using components. This section covers graphical addition.

#### 2.3 Inertia and Equilibrium: Newton's first law of motion

**Introduction to Newton's Laws of Motion:** Newton's three laws of motion form the basis of classical mechanics.

**Newton's First law of Motion: the law of inertia:** if there are no forces on an object, its speed and direction of motion do not change (including if it is at rest).

**Free-body diagrams:** A free-body diagram shows an object and all the forces acting on it (but not forces acting on any other objects). The object itself may be represented by a single point if its size and shape are not important. Even though it is just a sketch, students should try to make the directions of vectors reasonably accurate, and their lengths proportional.

**Equilibrium:** An object is in equilibrium when there is no net force on it; it may be either at rest or moving with constant velocity. If we know that something is in equilibrium (because we

observe it at rest or moving with constant velocity), we can (given sufficient information) find all the forces on it, both magnitude and direction. The  $x$ - and  $y$ -components of the forces are treated separately, so that when we say that something has no net force on it, we are really making two statements: the  $x$ -components of all the forces on it sum to zero, and (independently) the  $y$ -components of all the forces on it sum to zero.

**Nonzero Net Force:** If the net force on an object is not zero, it is not in equilibrium and Newton's Second Law must be used to determine its motion.

## 2.4 Vector addition using components

**Components of a Vector:**  $X$ - and  $y$ -components of vectors can be found using trigonometry; it is crucial to define which angle one is using when taking sines and cosines. The components are scalars, and may be either positive or negative. Before finding the components, a coordinate system must be defined; this is an arbitrary choice, and should be made so as to make the problem as simple as possible.

**Adding Vectors Using Components:** When adding two (or more) vectors using components, the components of all vectors must be found first, then the  $x$ - and  $y$ -components are added separately, and finally the magnitude and angle of the resultant vector can be found from its components (if desired).

**Equilibrium:** If an object is in equilibrium, the net force on it must be zero; therefore each component of the net force must be zero.

**Choosing  $x$ - and  $y$ - Axes:** The choice of axes should make the setup as intuitive as possible. Common choices include:  $x$  horizontal and  $y$  vertical;  $x$  east and  $y$  north;  $x$  parallel to a surface and  $y$  perpendicular to it.

## 2.5 Interaction pairs: Newton's third law of motion

When two bodies interact, there are two forces, one on each body, which are equal in magnitude and opposite in direction. Important points: (1) these two forces act on different objects; they do not "cancel" in any way; (2) the equality of the forces is inherent in the interaction and does not depend on whether one object experiences an acceleration or not.

**Internal and external forces:** Internal forces are those which act on one part of an object and are exerted by another part of the same object (such as the forces which hold solid objects together). External forces are those which are exerted on an object by some other object. It can sometimes be unclear exactly what is part of an object (or system) and what is not; students need practice at this.

## 2.6 Gravitational forces

Gravitational forces are exerted by masses on each other; the magnitude of the force is proportional to the masses and inversely proportional to the square of the distance between them (this is a good opportunity to discuss proportionality). The direction of the force is from one mass towards the other.

**Gravitational Field Strength:** The gravitational field strength is that quantity which, when multiplied by the mass of an object, tells us what the gravitational force on that object will be. This will, of course, be a much more essential concept in electricity and magnetism. Introducing the field concept in the context of gravity is good, as the students are more familiar with gravity, but care should be taken to ensure that students don't get the idea that field strength is always acceleration. The distinction between mass and weight is always a tricky one; students have "pounds = kilograms" lodged firmly in their heads, and who ever heard of newtons or slugs anyway?

## 2.7 Contact forces

**Normal force:** the word "normal" here is used to mean "perpendicular"; this is the force exerted by the surface of one object on the surface of another which prevents the objects from passing through each other. As its name indicates, it is perpendicular to the surfaces; it originates in the electrical forces between atoms.

**Friction:** Friction is also a force exerted between the surfaces of two objects, but it is directed parallel to the surface (rather than perpendicular to it) and acts to prevent the objects from slipping on each other. Its magnitude is proportional to the magnitude of the normal force, and it may be either static (the two objects are at rest with respect to each other) or kinetic (they are moving). In either case, there is a dimensionless constant, characteristic of the two surfaces, which gives the relative strength of the force. (It is good to point out that this description of friction is only an approximation to a very complicated physical situation).

## 2.8 Tension

Tension is the force exerted by a rope, string, cable or other flexible object that can pull but not push.

**Tensile Forces in the Body:** Tension is important in the body also; muscles cannot push, they only pull.

**Ideal Pulleys:** A pulley serves to change the direction of a tension force, and may also (in the case of multiple-pulley systems) change its magnitude. To begin, we will ignore any frictional forces exerted by the pulley, and also ignore its mass.

## 2.9 Fundamental Forces

- (1) Gravity – always attractive, unlimited range.
- (2) Electromagnetic force – unlimited range but may be either attractive or repulsive.

Magnetism is a force between electric charges which are moving with respect to each other. Contact forces are electromagnetic.

- (3) Strong nuclear force, and
- (4) weak nuclear force – both are short range (the effect of the strong is only felt over the size of an atomic nucleus, and of the weak force only one hundredth of that). The strong force binds together the protons and neutrons in atomic nuclei, and the weak force is responsible for some types of radioactive decays.

## ***B. Common errors of students learning this material***

It is not always obvious to students which quantities are vectors and which are scalars, especially with signed scalars such as temperature (they confuse the sign with a direction).

Newton's Third Law is the source of many difficulties. Common errors include assigning both forces to the same object, and insisting that a more massive object (or one which is larger in some sense) must be exerting more force.

Students are often confused by vectors, and many never really do grasp the fundamentals of what a vector actually represents. Adding parallel vectors is usually not too much of a problem, but even antiparallel (a word which the students are not likely to know) vectors present problems. Another confusion comes from students thinking about wind directions – an easterly wind comes from the east, and therefore heads west (this in itself is confusing), whereas physicists always label vectors according to the direction they are going (so a wind blowing to the west would be represented by a vector pointing west).

Free-body diagrams are very useful, but in the traditional lecture course the students' efforts to draw them (if any) are seldom critiqued. This would be a good subject for small-group work. It is common for students to include both members of a pair of 3<sup>rd</sup> Law forces as though they were acting on the same object. Also, students may think that the net force is an extra force that must be added (this becomes particularly evident when discussing rotational dynamics), or that the individual forces “disappear” in the summation process.

Distinguishing between internal and external forces can be relatively easy in simple systems, but can quickly become complicated. Particularly tricky are “hidden” external forces (that is, ones that we are not immediately aware of) such as friction.

The gravitational force does not usually present too many difficulties, except for extended bodies (especially orbits – students get confused as to what the radius of the orbit is, if it is close to the surface of the planet).

Students have trouble with the normal force when a surface is not horizontal (whether it is tilted or completely vertical); they also have trouble with the idea that the normal force “adjusts” itself depending on the weight of the object. Also, the variation of the normal force when the object is accelerated, or when it is stationary but an additional vertical force (either upward or downward) is exerted on it, needs to be addressed. Only under a very limited set of circumstances is the normal force equal to the weight of the object!

When the frictional force is introduced, with the dependence of its magnitude on the magnitude of the normal force, students tend to think that the directions of these forces are related as well. Also, figuring out the direction and magnitude of a static frictional force can be tricky; this is another “adjustable” force with difficulties similar to those of the normal force.

It is important to remember that a tension force is always a pull and never a push; students can get thrown off guard by comparing the direction of the tension force at one end of a rope with the direction at the other end, wondering how it “switches”. It is helpful, in this context, to imagine

cutting the rope in the middle and looking at the forces on each piece due to the other – this gives an opportunity to discuss both 3<sup>rd</sup> law force pairs and internal forces.

The fundamental forces, except for gravity and (somewhat) electromagnetism, are unfamiliar to most students, although many of them find the topic quite interesting.

### ***C. Suggested classroom demonstrations***

Below are some suggestions for classroom demonstrations. For demonstration ideas with detailed instructions, please visit the Instructor's Resources in the Instructor's Edition of the ARIS site for *College Physics* at: <http://www.mhhe.com/grr>.

1. Put two students on skateboards (or use yourself and a TA or volunteer). Push on each other, showing the opposite forces exerted by one on the other (this is not a quantitative demonstration, though).
2. To show that heavier objects do not fall faster than slower ones (except for the effects of air resistance), drop a flat sheet of paper. Then crumple up the paper and drop it again; it falls much faster the second time. Its mass has not changed, but its surface area, and therefore the effect of air resistance on it, has.
3. Reflect a light beam at an oblique angle off a table, so that a spot of light is on the wall. (This doesn't have to be anything as fancy as a laser; an overhead projector will work fine). Have a student walk on the table (or do this yourself), and observe the motion of the spot on the wall – this shows that the table deforms under the weight of the walker as it exerts a normal force on him or her.
4. Drop a feather and a pebble in an evacuated glass tube, showing that they fall at the same speed. You can also take the opportunity to point out that gravity does not vanish in a vacuum.

### ***D. Suggested small-group, Just-in-Time, and active learning exercises***

1. End-of-chapter questions suitable for small-group class work: Conceptual questions 1, 9, 10, 19; Problems 8, 14, 31, 37, 44, 58, 67, 91, 96.
2. End-of-chapter questions suitable for online pretests: Conceptual questions 8, 12, 14; Problems 1, 2, 3, 10, 20, 25, 42, 52, 69.
3. Free-body diagrams (statics). Have the students draw free-body diagrams for a variety of situations, beginning with the simplest (motionless objects with few forces) and gradually becoming more complex. Each force should be labeled on the diagram, telling what the force is and what object is exerting the force. Begin with gravity and normal forces, with horizontal surfaces. Once the students are comfortable with this, move to situations with sloped and/or vertical surfaces, frictional forces, tension forces, and so on.
4. Practice with vectors. Have the students draw vectors representing various familiar quantities (forces, velocities, etc); then have them add these vectors graphically (they

should be collinear). Velocity addition can be done in the context of things moving inside cars, trains, or airplanes.

5. Free-body diagrams including third-law forces (statics). Have the students draw yet more free-body diagrams; in each, identify all forces on the primary object, label each, and identify what object is exerting the force. Then draw, in separate diagrams, the forces exerted by the primary object on all the other objects around it. Example: A book sits motionless on a table. The forces on the book are the downward force of gravity, exerted by the earth, and the upward normal force, exerted by the table. Another diagram would show the earth with an upward force on it exerted by the book, and a third the table with a downward force on it exerted by the book.