Forces

•*Dynamics* is the branch of physics that explores why things move (what causes the *kinematics*).

•We will see that things accelerate and decelerate because of *forces*.
•A *force* is (roughly) a *push* or a *pull*
•The unit of force is the *Newton* (N*)*, a derived unit equal to kg m/s^2 in SI units. This is a *mass* (kg) times an *acceleration* (m/s^2).

•*Contact forces* require physical contact between two objects.
ex. Throwing a baseball or pulling a spring require contact forces.
•*Field forces* do not involve physical contact, but act through empty space. These forces are carried by fields (ex. gravitational field).

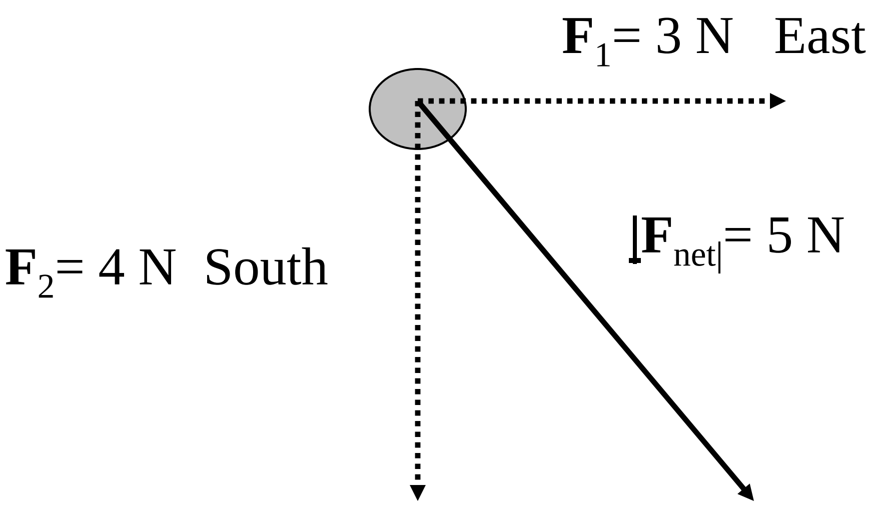
•The *fundamental forces* (gravity, electromagnetism, weak nuclear force, strong nuclear force) are all field forces.

Forces (continued)

•*Force* is a *vector* quantity, with both magnitude and direction.

•If multiple forces act on a single object, we define the *net force* ($\underline{F}_{net}$) as the *vector sum* of all forces acting on the object.

ex. An object acted on by a force of 10 N to the right, and 5N to the left, will experience a net force of 5N to the right.



•Note that we won't differentiate between field forces and contact forces when we find the net force.

Newton's First Law

•*Newton's first law* states that if no force acts on an object, the velocity of the object will not change.
•Commonly put, an object at rest stays at rest, an object in motion stays in motion with constant velocity.

•An alternate statement of the 1st Law (used in the textbook) is: If an object does not interact with other objects, it is possible to identify a reference frame in which the object has zero acceleration.

•A reference frame in which a non-interacting object has zero acceleration is called an *inertial reference frame*.

•From our discussion on relative motion, we know that any reference frame moving with constant velocity relative to an inertial reference is also an inertial reference frame.

NB. This is because the acceleration of an object is the same in reference frames moving with constant velocities with respect to one another.

•Newton's Laws do not apply in *non-inertial reference frames*.

•Non-inertial reference frames are reference frames which are accelerating relative to inertial reference frames.

ex. A railway car moving at a constant velocity is an *inertial reference frame*, but the same railway car accelerating at 2 m/s^2 is a *non-inertial reference frame*, so Newton's first law does not hold.

•Experimentally, we can distinguish inertial reference frames from non-inertial reference frames by seeing if Newton's 1^{st} Law is valid.

•Strictly speaking, the Earth is a non-inertial reference frame because it is spinning.

ex. The *Coriolis force* (Coriolis – French physicist) arises from the fact that the Earth is a non-inertial reference frame.

•However, for most problems, it is appropriate to neglect the Earth's small acceleration. For the purposes of this course, unless explicitly stated, we will assume that the Earth is an inertial reference frame.

Newton's Second Law

- *Newton's Second Law* states that a net force acting on an object produces an acceleration equal to the net force divided by the objects mass (in an inertial reference frame). In equation form:

$$\vec{F}_{net} = m\vec{a}$$

- Since force is a *vector* quantity, and mass is a *scalar* quantity, the *direction* of the acceleration will be the same as the direction of the net force.

  ex. A net force of 10 N at 25°S of E will produce an acceleration at 25°S of E. Note that the direction does not depend on mass.

- Note that Newton's First Law is a special case of Newton's Second Law. If there are no forces on an object, then the object will not accelerate.

What is mass?

- Strictly speaking, the mass of an object is *defined* by Newton's Second Law. *Mass* is the constant of proportionality between a net applied force and the resultant acceleration.

Aside

- Strictly speaking, this is the *inertial mass* of an object.
- Objects also have a *gravitational mass*, which affects how strongly the gravitation force field affects this object (see Chapter 13).
- One of the great problems in physics is understanding the origins of inertial and gravitational masses, and why the two are equal (general theory of relativity, Higgs boson, which will be studied at the LHC).

Working with Newton's Second Law

- Since both force and acceleration are vectors, we will often break both force and acceleration into components to solve $\mathbf{F} = m\mathbf{a}$.
- In component form, we can write Newton's Second Law as:

$$\vec{F}_{net} = m\vec{a} \Leftrightarrow F_{net,x} = ma_x,\ F_{net,y} = ma_y,\ F_{net,z} = ma_z$$

- Remember that since force is a vector, we need to use vector addition to add forces together

- Since *x*, *y*, and *z* are *orthogonal*, the acceleration along each axis depends only on the net force along that axis, and is independent of the forces along other axes.

ex. A force $\vec{F}_{net} = (25\hat{\mathbf{i}} - 15\hat{\mathbf{j}})\mathrm{N}$ will produce no acceleration along *z*.

- Depending on the problem, we may want to choose *x*, *y*, and *z* axes that are different than the usual coordinate system.

Note: even if $\mathbf{F}_{\text{net}} = 0$, there may still be forces acting on the object (just no net force).