Chapter 3

Terms

Be able to define or discuss the following terms and ideas, with their SI units if appropriate.

1. Applying Newton's second law to a situation with non-constant net force
2. Air resistance (i.e. drag)
3. Four fundamental interactions
4. Inverse square law
5. Gravitational force (Newton's law of gravitation)
6. Universal gravitational constant
7. Relative position vector
8. Center-to-center distance between bodies (i.e. between planets, stars, star and planet, etc.)
9. Approximate gravitational force on a body near the surface of Earth
10. Gravitational field
11. Gravitational field strength
12. Direction of gravitational force
13. Electric force (Coulomb's law)
14. Charge of a particle
15. Direction of the electric force
16. Reciprocity (i.e. Newton's third law)
17. Iterative prediction of motion
18. Iterative calculations of velocity and position of a particle
19. Multiparticle system
20. Center of mass
21. Conservation of momentum (especially know the circumstances when the momentum of a system is conserved)
22. Impulse

Equations

Understand the meaning and know the SI units of all symbols in these equations; know how to perform each mathematical operation, such as trig functions; know how to solve for any unknown quantity; understand how changing one quantity affects another quantity (if all other quantities remain constant); be able to apply one or more equations to solve a problem.

- Air resistance for a large projectile (like a baseball):

$$\vec{F}_{drag} = cv^2(-\hat{v}) \tag{1}$$

- Gravitational force law:

$$\vec{F}_{grav\ on\ 2\ by\ 1} = -G\frac{m_1 m_2}{|\vec{r}|^2}\hat{r} \qquad \vec{r} = \vec{r}_2 - \vec{r}_1 \tag{2}$$

- Gravitational force law near Earth's surface:

$$|\vec{F}_{grav}| = mg \tag{3}$$

where

$$g = 9.8 \text{ N/kg} \tag{4}$$

- Magnitude of the gravitational field due to a body of mass M at a distance $|\vec{r}|$:

$$g = \frac{GM}{|\vec{r}|^2} \tag{5}$$

- Coulomb's law:

$$\vec{F}_{elec\ on\ 2\ by\ 1} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}|^2}\hat{r} \qquad \vec{r} = \vec{r}_2 - \vec{r}_1 \tag{6}$$

- Newton's Third Law:

$$\vec{F}_{on\ 1\ by\ 2} = -\vec{F}_{on\ 2\ by\ 1} \tag{7}$$

- Update form of the momentum principle:

$$\vec{p}_f = \vec{p}_i + \vec{F}_{net,ext}\Delta t \tag{8}$$

- Update the position of the object for a given velocity (Euler method):

$$\vec{r}_f \approx \vec{r}_i + \vec{v}_f \Delta t \tag{9}$$

- Impulse:

$$\text{net impulse} = \vec{F}_{net}\Delta t = \Delta\vec{p} \tag{10}$$

- Momentum principle for a multiparticle system:

$$\vec{F}_{net,ext} = \frac{d\vec{p}_{sys}}{dt} \tag{11}$$

- Total momentum of a multiparticle system:

$$\vec{p}_{sys} = \vec{p}_1 + \vec{p}_2 + \vec{p}_3 + ... = M_{total}\vec{v}_{cm} \tag{12}$$

- Conservation of momentum:

$$\begin{aligned} \vec{p}_{sys,i} &= \vec{p}_{sys,f} \\ \vec{p}_{1i} + \vec{p}_{2i} + ... &= \vec{p}_{1f} + \vec{p}_{2f} + ... \end{aligned}$$

- For a two-body system, if momentum is conserved then:

$$\begin{aligned} \Delta\vec{p}_{sys} &= 0 \\ \Delta\vec{p}_1 &= -\Delta\vec{p}_2 \end{aligned}$$

Skills

1. Use steps to interatively predict motion.
2. Calculate the gravitational force on a body.
3. Calculate the electric force on a charged particle.
4. Calculate the net gravitational force or net electric force on an object.
5. Calculate the net force on a particle, its momentum, its average velocity, and its position iteratively.
6. Predict how the force due to air resistance (i.e. drag) changes for a falling object like a baseball or skydiver; predict how the net force changes for the falling object.

Lab Skills

1. Measure the internal forces on particles during a collision or explosion and verify Newton's third law (reciprocity).
2. Write a computer program that iteratively calculates net force, velocity, and position of a particle; examples include a gravitational orbit and projectile motion with air resistance.