

~~6.5 Surprising Bounce – Lecture Demo~~

~~In lectures we dropped a tennis ball on top of a much heavier basketball from a height of about 3 m. The tennis ball bounced up much higher than 3 m. Calculate how high the tennis ball bounced up by approximating the bounce as the result of two one-dimensional collisions in which first the basketball bounced off the floor and then collided with the falling tennis ball. Thus, in this second collision the two balls had velocities in opposite directions. Assume that the collisions were elastic.~~

~~6.6 Center of Mass Motion and Internal Energy~~

~~A 6 kg object is moving in 1 dimension with a speed of 350 m/sec on a horizontal frictionless surface. It explodes and breaks apart into one fragment of 2 kg and one of 4 kg with velocities along the initial direction of motion of 250 m/sec and 400 m/sec, respectively.~~

- ~~What is the total momentum before and after the object explodes? Is momentum conserved?~~
- ~~What is the total kinetic energy before and after the object explodes? Is mechanical energy conserved?~~
- ~~What is the center-of-mass velocity before and after the object explodes? Does it change?~~
- ~~Answer the questions under a) and b), but evaluate all quantities in the center-of-mass frame of reference. Do any of your conclusions change?~~

~~6.7 Oscillating Masses on Frictionless Table – PIVoT~~

~~Two masses, A and B are connected by a spring. The mass of A is m , and the mass of B is $3m$; the mass of the spring is negligible. The spring, with spring constant k , is compressed so that the potential energy stored in the spring is U_0 . The system is placed on a horizontal frictionless table. The compressed spring is released at time $t = 0$ at which time the two masses have zero speed.~~

- ~~What is the initial total mechanical energy of the system (A , B , and the spring)?~~
- ~~How much potential energy is stored in the spring when A and B have kinetic energies K_A and K_B , respectively?~~
- ~~At some point in time the speed of A is v_A . What then is the speed of B ?~~
- ~~If A is moving in the $+x$ direction, in what direction is B then moving?~~
- ~~What is the period, T , of the oscillations of the two masses?~~

~~6.8 Proton Collision – page 294, problem 38~~

~~6.9 Space Shuttle~~

~~A Space Shuttle has to increase its speed by firing its thruster rockets. The exhaust gas speed relative to the Shuttle is about 2.5 km/sec, and the mass of the shuttle is about 10^5 kg. What is the mass of the fuel used in increasing the speed from 8.0 km/sec to 8.5 km/sec?~~

6.10 Saturn V

The Saturn V rocket was used in the Apollo program. It had an initial mass of 2.85 million kg. The burn rate of the rocket was 13.8×10^3 kg/sec (about 14 tons per sec!), which delivered a thrust of 34 million Newtons. Its final mass was 0.77 million kg (770 tons!). Assume that the entire launch is vertically up. In the discussions in lectures (and in Tipler's derivation) air drag was ignored. This, of course is an over-simplification, as air drag must play an important roll. You too may ignore air drag. Use $g = 10$ m/sec².

- What was the exhaust speed?
- How long did the engines burn (this is called the burn time)?
- What was the acceleration at liftoff?
- What was the acceleration just before the engines stopped?
- What was the final speed of the rocket?

6.11 Kerosene Rocket – page 271, problem 54

~~The energy for the proton traveling along \overline{PB} is~~

$$E'_1 = \frac{mv_1^2}{2} = (0.695)^2 \cdot \frac{mv_1^2}{2} = 0.483 \cdot E_1 \approx 3.9 \times 10^{-13} \text{ J}$$

~~The energy for the proton traveling along \overline{PC} is~~

$$E'_2 = \frac{mv_2^2}{2} = (0.719)^2 \cdot \frac{mv_1^2}{2} = 0.516 \cdot E_1 \approx 4.1 \times 10^{-13} \text{ J}$$

Problem 6.9

~~We can use Equation (51) on page 263 which relates the initial velocity and mass (v_i and M_i) to the velocity and mass at a later time (v_f and M_f) given the exhaust gas speed u_{ex} .~~

$$v_f - v_i = u_{ex} \ln \left(\frac{M_i}{M_f} \right)$$

~~We are told that $v_i = 8 \times 10^3$ m/s, $v_f = 8.5 \times 10^3$ m/s, and $u_{ex} = 2.5 \times 10^3$ m/s. If we assume that the shuttle uses all its fuel, then $M_f = 10^5$ kg and $M_i = M_F + M_f$ where M_F is the mass of the fuel. We can solve the above equation for M_F by the following sequence of steps.~~

$$v_f - v_i = u_{ex} \ln \left(\frac{M_F + M_f}{M_f} \right)$$

$$\frac{v_f - v_i}{u_{ex}} = \ln \left(\frac{M_F + M_f}{M_f} \right)$$

$$e^{\frac{v_f - v_i}{u_{ex}}} = \frac{M_F + M_f}{M_f}$$

$$M_F = M_f e^{\frac{v_f - v_i}{u_{ex}}} - M_f \approx 2.2 \times 10^4 \text{ kg}$$

Problem 6.10

Rocket motion is discussed in Lecture Supplement "Rocket Equations - supplements for 10/20/99" on the 801 Home Page.

(a) If the exhaust speed is u_{ex} and the burn rate is R then the thrust F_{th} is given by

$$F_{th} = u_{ex} R \quad \implies \quad u_{ex} = \frac{F_{th}}{R}$$

We are told that $F_{th} = 34 \times 10^6$ N and $R = 13.8 \times 10^3$ kg/s, thus the exhaust speed is

$$u_{ex} = \frac{F_{th}}{R} = \frac{34 \times 10^6}{13.8 \times 10^3} \approx 2.5 \times 10^3 \text{ m/s}$$

(b) The engines will burn until there is no more fuel. If the initial mass of the rocket and fuel is $M_i = 2.85 \times 10^6$ kg and the final mass of the rocket (with no fuel) is $M_f = 0.77 \times 10^6$ kg then the mass of fuel M_F is

$$M_F = M_i - M_f = 2.85 \times 10^6 - 0.77 \times 10^6 = 2.08 \times 10^6 \text{ kg}$$

If the burn rate is constant, then the burn time T is given by

$$R = \frac{M_F}{T} \quad \implies \quad T = \frac{M_F}{R} = \frac{2.08 \times 10^6}{13.8 \times 10^3} \approx 151 \text{ s}$$

(c) The force equation for the rocket is

$$M(t) \cdot a = F_{th} - M(t) \cdot g \quad \implies \quad a = \frac{F_{th}}{M(t)} - g$$

where $M(t)$ is the mass of the rocket and fuel inside the rocket at time t . The initial mass is $M(0) = M_i$, so the initial acceleration is

$$a = \frac{F_{th}}{M_i} - g = \frac{34 \times 10^6}{2.85 \times 10^6} - 10 \approx 1.9 \text{ m/s}^2$$

(d) The final mass is $M(T) = M_f$, so the acceleration just before the engines stop is

$$a = \frac{F_{th}}{M_f} - g = \frac{34 \times 10^6}{0.77 \times 10^6} - g \approx 34 \text{ m/s}^2$$

(e) The solution to the above differential equation is

$$v_f = -u \ln \left(\frac{M_f}{M_i} \right) - gt$$

At $t = T = \frac{M_F}{R}$, $RT = M_F$ and $M_i - M_F = M_f$, so the speed is

$$v_f = -2.5 \times 10^3 \cdot \ln \left(\frac{0.77 \times 10^6}{2.85 \times 10^6} \right) - 10 \cdot 151 \approx 1.8 \times 10^3 \text{ m/s}$$

Problem 6.11 (~~Ohanian, page 271, problem 54~~)

~~We are told that the reaction products have a mass of 4.4 kg and that these products have a kinetic energy of 4.2×10^7 J. If the velocity of this mass is u then~~

$$\frac{4.4 \cdot u^2}{2} = 4.2 \times 10^7 \quad \implies \quad u = 4.4 \times 10^3 \text{ m/s}$$