

**MASSACHUSETTS INSTITUTE OF TECHNOLOGY**  
**Department of Physics**

**Physics 8.01 TEAL**

**Fall Term 2004**

**Exam 1: Equation Summary**

**One Dimensional Kinematics:**

$$\vec{v} = d\vec{r} / dt, \quad \vec{a} = d\vec{v} / dt$$

$$v_x(t) - v_{x,0} = \int_{t'=0}^{t'=t} a_x(t') dt' \quad x(t) - x_0 = \int_{t'=0}^{t'=t} v_x(t') dt'$$

**Constant Acceleration:**

$$x(t) = x_0 + v_{x,0}(t - t_0) + \frac{1}{2} a_x (t - t_0)^2 \quad v_x(t) = v_{x,0} + a_x (t - t_0)$$
$$y(t) = y_0 + v_{y,0}(t - t_0) + \frac{1}{2} a_y (t - t_0)^2 \quad v_y(t) = v_{y,0} + a_y (t - t_0)$$

where  $x_0, v_{x,0}, y_0, v_{y,0}$  are the initial position and velocities components at  $t = t_0$

**Newton's Second Law: Force, Mass, Acceleration**

$$\vec{F} \equiv m\vec{a} \quad \vec{F}^{total} = \vec{F}_1 + \vec{F}_2 \quad F_x^{total} = ma_x \quad F_y^{total} = ma_y \quad F_z^{total} = ma_z$$

**Newton's Third Law:**

$$\vec{F}_{1,2} = -\vec{F}_{2,1}$$

**Force Laws:**

Universal Law of Gravity:  $\vec{F}_{1,2} = -G \frac{m_1 m_2}{r_{1,2}^2} \hat{r}_{1,2}$ , attractive

Gravity near surface of earth:  $\vec{F}_{grav} = m_{grav} \vec{g}$ , towards earth

Contact force:  $\vec{F}_{contact} = \vec{N} + \vec{f}$ , depends on applied forces

Static Friction:  $0 \leq f_s \leq f_{s,max} = \mu_s N$  direction depends on applied forces

Kinetic Friction:  $f_k = \mu_k N$  opposes motion

Hooke's Law:  $F = k|\Delta x|$ , restoring

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Practice Exam 1

~~Concept Questions: Briefly answer the following questions.~~

~~1. When a car accelerates forward, which force is responsible for this acceleration? State clearly which body exerts this force, and on which body the force acts.~~

~~2. A weightlifter and a barbell are both at rest on a large scale. The weightlifter begins to lift the barbell, ultimately holding it motionless above her head. Does the scale reading ever differ from the combined weight of the two bodies at any time during the lift? Explain.~~

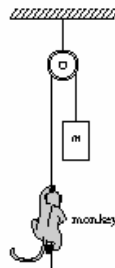
~~3. As a space shuttle burns up its fuel after take off, it gets lighter and lighter and its acceleration larger and larger. Between the moment it takes off and the time at which it has consumed nearly all of its fuel, is its average speed larger than, equal to, or smaller than half its final speed? Explain why.~~

4. Can astronauts floating in orbit tell which objects within their space-ship would be heavy or light on Earth even though everything in the ship is effectively weightless? Explain.

~~5. A monkey clings to a rope that passes over a pulley. The monkey's weight is balanced by the mass  $m$  of a block hanging at the other end of the rope; both monkey and block are motionless. In order to get to the block, the monkey climbs a distance  $L$  (measured along the rope) up the rope.~~

~~(a) Does the block move as a result of the monkey's climbing?~~

~~(b) If so, in which direction and by how much?~~



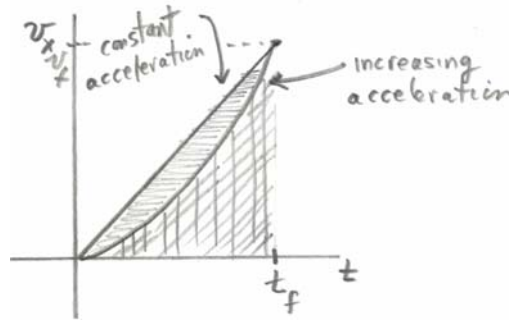


Figure 1: velocity graphs for constant and non-constant acceleration

When the acceleration is constant, the velocity is a linear function of time. Therefore the average velocity is given by (see figure 1)

$$\bar{v}_x = \frac{1}{2}(v_x(t) + v_{x,0}) = \frac{1}{2}v_{x,f}.$$

Hence for an object starting at rest, the average velocity is one half of the final velocity.

Suppose the space shuttle reaches the same final velocity but its acceleration is increasing. In figure 1, Since the average velocity is always less in the non-constant acceleration case than the constant acceleration case, the average velocity for the non-constant acceleration case must be less than one half the final velocity.

Alternatively, we also defined average velocity as  $\bar{v}_x = \Delta x / t_f$ . Since the displacement is the area under graph of velocity vs. time, we see from figure 1, that for the case of non-constant acceleration the displacement is less than the constant acceleration case, hence the average velocity for the non-constant acceleration case is less than one half the final velocity (which is the average velocity for the constant acceleration case.)

4. Can astronauts floating in orbit tell which objects within their space-ship would be heavy or light on Earth even though everything in the ship is effectively weightless? Explain.

**Answer:** Yes. From the equivalence principle, gravitational mass is equal to inertial mass,

$$m_{\text{grav}} = m_{\text{in}}.$$

Therefore if the astronauts apply the same force to two different objects, and measure the accelerations.

$$F = m_1 a_1 = m_2 a_2$$

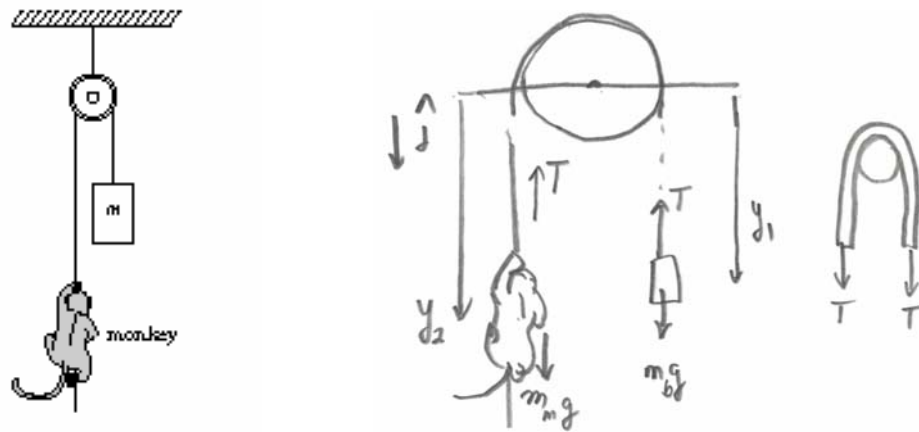
From these measurements, they can determine the inertial mass ratio,

$$\frac{m_1}{m_2} = \frac{a_2}{a_1},$$

The object that has the smaller acceleration has the greater inertial mass, and hence would be heavier on earth.

5. A monkey clings to a rope that passes over a pulley. The monkey's weight is balanced by the mass  $m$  of a block hanging at the other end of the rope; both monkey and block are motionless. In order to get to the block, the monkey climbs a distance  $L$  (measured along the rope) up the rope.

- (a) Does the block move as a result of the monkey's climbing?  
 (b) If so, in which direction and by how much?



**Answer:** The force diagrams are shown in the above figure. As the monkey pulls up on the rope, there is a force down on the rope (tension). This tension is transmitted through the rope (assume a massless rope). This is also the force on the object. Both the monkey and object satisfy Newton's Second Law

$$mg - T = ma_y.$$

So both objects accelerate upwards with the same acceleration.

Note that the length of the rope is

$$l = y_1 + \pi R + y_2.$$

As the monkey climbs, the rope is getting shorter at a rate,

$$\frac{d^2 l}{dt^2} = a_{y,1} + a_{y,2} = 2a_y.$$