Name:______________________________ Date:_____________________

Mr. Croom's Physics Chapter 4: Force and the Law of Motion

Air Resistance Notes

Air Friction

Air friction, or air drag, is an example of fluid friction. Unlike the standard model of surface friction, such friction forces are velocity dependent. The velocity dependence may be very complicated, and only special cases can be treated analytically. At very low speeds for small particles, air resistance is approximately proportional to velocity and can be expressed in the form

$$f_{drag} = -bv$$

where the negative sign implies that it is always directly opposite the velocity. For higher velocites and larger objects the frictional drag is approximately proportional to the square of the velocity:

$$f_{drag} = -\frac{1}{2}C\rho A v^2$$

where ρ is the air density, A the crosssectional area, and C is a numerical drag coefficient.

Terminal Velocity

Terminal Velocity

When an object which is falling under the influence of gravity or subject to some other constant driving force is subject to a resistance or drag force which increases with velocity, it will ultimately reach a maximum velocity where the drag force equals the driving force. This final, constant velocity of motion is called a "terminal velocity", a terminology made popular by skydivers. For objects moving through a fluid at low speeds so that turbulence is not a major factor, the terminal velocity is determined by viscous drag. The expression for the terminal velocity is of the form

$$v_{terminal} = \frac{mg'}{b} \quad \text{for drag of form} \quad -bv$$ Motion analysis

Objects moving at high speeds through air encounter air drag proportional to the square of the velocity. This quadratic drag leads to a terminal velocity of the form

$$v_{terminal} = \sqrt{\frac{2mg}{C\rho A}} \quad \text{for drag of form} \quad -\frac{1}{2}C\rho A v^2$$ Examples

Quadratic Velocity Dependence

For large objects moving through air, the air resistance is approximately proportional to the square of the velocity. The form of the resistance is

$$f_{drag} = -\frac{1}{2}C\rho A v^2$$

where ρ is the air density, A the crosssectional area, and C is a numerical drag coefficient. The drag coefficient C is 0.5 for a spherical object and can reach 2 for irregularly shaped objects according to Serway. An object falling through the air will reach a terminal velocity when the drag force is equal to the weight:

$$F_{net} = mg - \frac{1}{2}C\rho A v^2 = 0$$

This gives a terminal velocity

$$v_{terminal} = \sqrt{\frac{2mg}{C\rho A}}$$

Terminal Velocity Examples

Falling object	Mass	Area	Terminal velocity	
Skydiver	75 kg	0.7 m^2	60 m/s	134 mi/hr
Baseball (3.66cm radius)	145 gm	42 cm^2	33 m/s	74 mi/hr
Golf ball (2.1 cm radius)	46 gm	14 cm^2	32 m/s	72 mi/hr
Hail stone (0.5 cm radius)	.48 gm	.79 cm^2	14 m/s	31 mi/hr
Raindrop (0.2 cm radius)	.034 gm	.13 cm^2	9 m/s	20 mi/hr

Data from Serway, Physics for Scientists and Engineers, Table 6.1. A drag coefficient C=0.5 is assumed, falling through air.

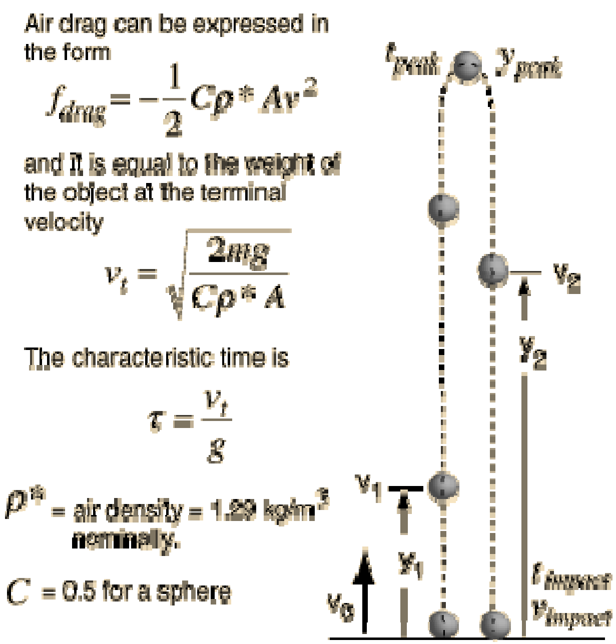
Hailstone Terminal Velocity

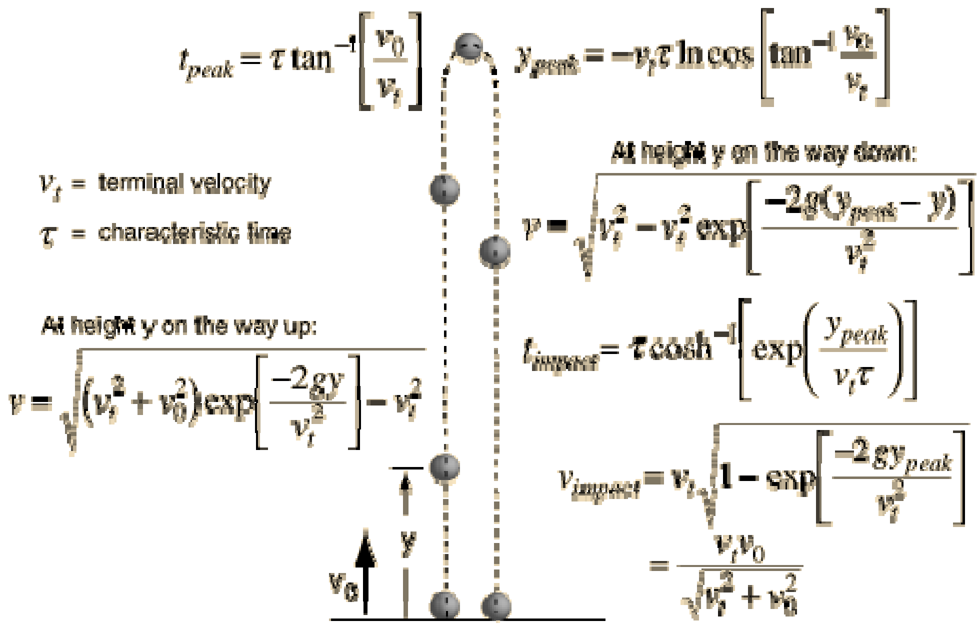
Contributing to the danger of large hailstones is the fact that they fall faster than small ones. That is, the terminal velocity increases with the size of the hailstone. Assuming the hailstones to be spherical and using a drag coefficient of C = 0.5 gives the following :

Radius (cm)	v (km/hr)	v(m/s)	v(mi/hr)
.01	7	1.9	4.3
0.1	22	6.1	13.7
0.2	31	8.6	19.3
0.5	49	13.6	30.5
1.0	69.5	19.3	43.2
2.0	98.3	27.3	61
3.0	120	33.4	74.8
5.0	155	43.2	96.6
10.0	220	61	136

Vertical Trajectory

Objects moving at high speeds through air encounter air drag proportional to the square of the velocity. Describing the motion of objects under this quadratic drag usually requires numerical techniques rather than straight analytic formuli since the drag force and the gravitational force are not acting along the same line. The case of the vertical trajectory can be treated analytically since the forces are colinear. It is common practice to express the velocity and time in terms of the terminal velocity v_t and a characteristic time τ.





Two common approaches to the quadratic drag force are:

1. Express the drag in terms of a single drag coefficient c: $$f_{drag} = -cv^2$$	2. Assume that drag is proportional to cross-sectional area and express in terms of area and a shape-dependent drag coefficient C: $$f_{drag} = -\frac{1}{2} C\rho * Av^2$$