Experiment 2

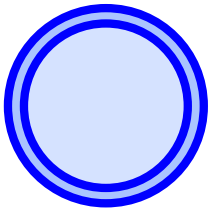
1) You are to devise a simple, fast, and non-destructive method to measure the variation in thickness of the shell of a large numbers of the balls in each shipment arriving at a number of stores, to determine if the variation in thickness is much less than 10%.

2) You are to devise a method to measure the thickness and density of the outer and inner cylinders without damaging them so that rods not within specifications will not be used in the machine.

Both problems can be solved by measuring the moment of inertia and mass of the objects.

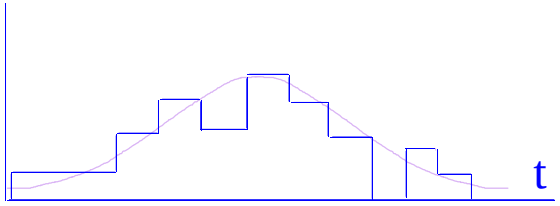
In (1) we need speed and only need to measure variation in thickness. We can roll the balls down a ramp.

In (2) we need to measure absolute thickness and density but do not need to process many objects. We can use a torsion pendulum.

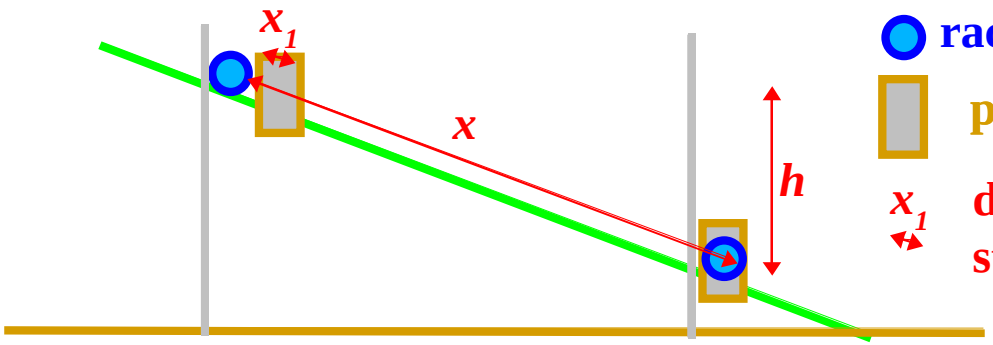


$$I = \frac{2}{5} M \frac{R^5 - r^5}{R^3 - r^3}$$

$$I = \frac{mr^2}{2} + \frac{M(R^2 + r^2)}{2}$$



The Rolling Ball

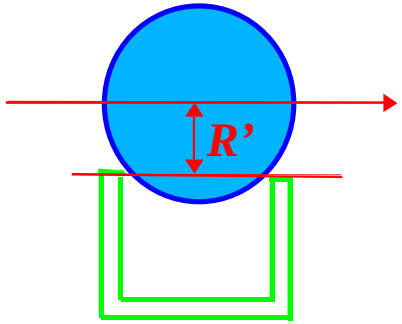


racketball

photogate timer

x_1 distance before starting timer

rolling radius *R'*



$$Mgh = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2$$

$$v = R'\omega$$

$$Mgh = \frac{1}{2}v^2\left(M + \frac{I}{R'^2}\right)$$

$$t \to \left(1 + \sqrt{\frac{x_1}{x}}\right)t$$

$$\frac{I}{M} = \left(\frac{ght^2}{2x^2} - 1\right)R'^2$$

$$\frac{2}{5}R^2 \le \frac{I}{M} \le \frac{2}{3}R^2$$

- We must measure many balls of each type so that we can experimentally determine the spread in thickness for each type. Plot histograms.
- Solve for *I/M* early to check for mistakes. It must be between a solid sphere and a shell. It should be close to a shell.
- Compare expected error on thickness to measured RMS.
- Is initial velocity and position reproducible? Improve your technique to get a small error.
- Plot *v* versus *r* to solve for *r* and *dr/dt*.

The Cylinder and the Torsion Pendulum

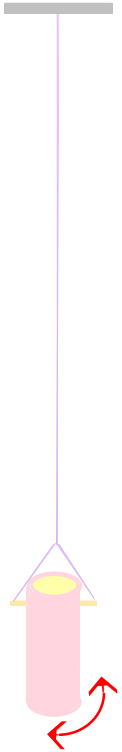
- **We want an absolute measurement of the cylinder radii and densities.**
- **Measure *R*, *r*, *T*, and total *M*.**
- **Calibrate restoring torque constant κ by using a solid cylinder for which *I* can be calculated.**
- **Minimizing wobble of cylinder is most critical experimental problem.**

$$N=-\kappa\theta=I\ddot{\theta}$$

$$\omega=\dot{\theta}$$

$$T=2\pi\sqrt{I/\kappa}$$

$$\frac{M}{M_{tot}}=\frac{I_{tot}}{\frac{1}{2}M_{tot}R^2}-\left(\frac{r}{R}\right)^2$$



Experiment 2 Analysis

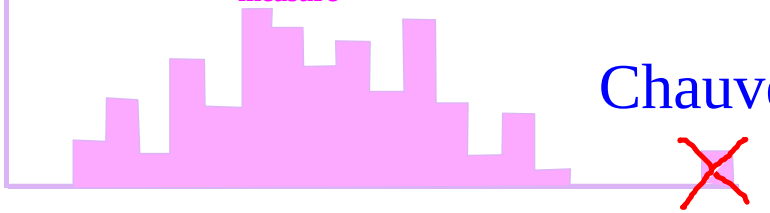
$$v = \frac{2x}{t} = \sqrt{\frac{2gh}{1 + \frac{2}{5}\frac{R^5 - r^5}{R'^2(R^3 - r^3)}}}$$

$\sigma_r = dr/dt \quad \sigma_t$

$$\sigma_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

We are trying to find any differences between balls that we can (R or r). In this sense, the error on R can be ignored. Errors on h and g are common for all balls and can be ignored.

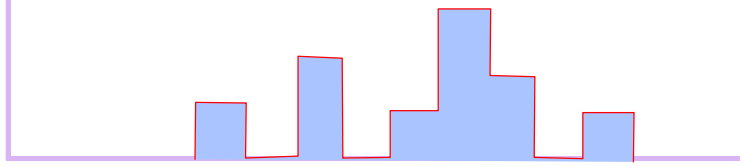
N **calculate measurement error: $\sigma_{measure}$**



Chauvenet

t_{one_ball}

N calculate measured RMS variation of average time for Penn balls: σ_{tball}



$\overline{t}_{ball}$

Now calculate spread in time due to ball manufacture:

$\sigma^2_{manufacture} = \sigma^2_{tbar} - \sigma^2_{measure}$