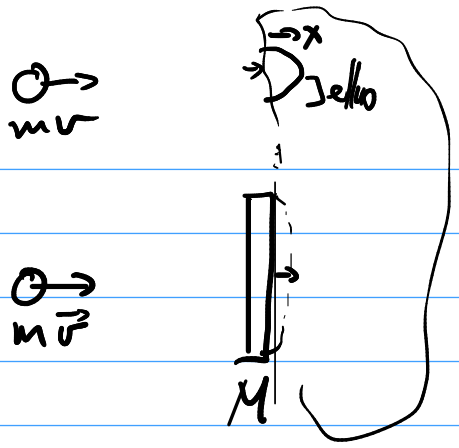


$$\frac{kx^2}{2} = \frac{mv^2}{2}$$

$$\vec{p} = \text{const}$$

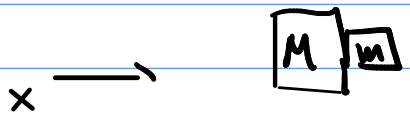
$$mv + M \cdot 0 = mv_f + Mv_f$$

$$v_f = \frac{mv}{M+m}$$

P-protection →

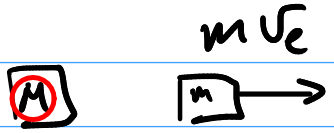
$$\frac{kx_p^2}{2} = \frac{(M+m)}{2} v_f^2 = \frac{M+m}{2} \left(\frac{m}{m+M}\right)^2 v^2$$

$$\frac{kx_p^2}{2} = \frac{m}{M+m} \frac{1}{2} mv^2$$

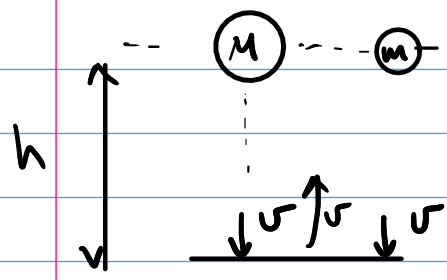


x: $p_x = M \cdot v_{i_x}^{\,0} + m v_{i_x}^{\,0} = 0 = M v_{M_x} + m v_{m_x}$

$= M v_{M_x} + m v_e$

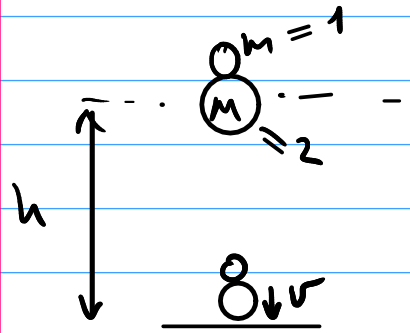


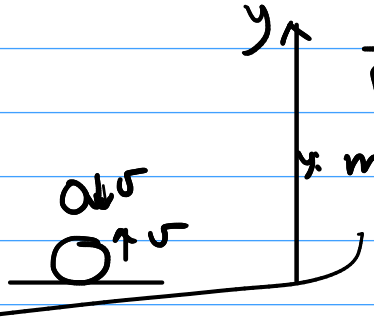
$$v_{M_x} = -\frac{m v_e}{M}$$



$$\cancel{mgh} = \frac{\cancel{m}v^2}{2}$$

$$v = \sqrt{2gh}$$





$$\vec{p} = p_y \hat{y} = \text{const}$$

$$m(-v) + M(v) = m v_1 + M v_2$$

Energy: $\frac{mv^2}{2} + \frac{Mv^2}{2} = \frac{mv_1^2}{2} + \frac{Mv_2^2}{2}$

$$v_2 = \frac{(M-m)v - m v_1}{M}$$

$$(m+M)\frac{v^2}{2} = \frac{m v_1^2}{2} + \frac{M}{2}\left[\frac{(M-m)v - m v_1}{M}\right]^2$$

$$= \frac{m v_1^2}{2} + \frac{M}{2}\left[\frac{\cancel{M}\left[\left(1-\frac{m}{M}\right)v - \frac{m}{M}v_1\right]}{\cancel{M}}\right]^2$$

$$= \frac{m v_1^2}{2} + \frac{M}{2}\left[v - \underbrace{\frac{m}{M}(v+v_1)}_{\ll 1}\right]^2$$

$m \ll M$

$\frac{m}{M} \ll 1$

$$= \frac{m v_1^2}{2} + \frac{M}{2}v^2\left[1 - \underbrace{\frac{m}{M}\frac{v+v_1}{v}}_{\ll 1}\right]^2$$

$(1-x)^2 \approx 1 - 2x$

$= 1 - 2x + x^2$ ($x^2 \to 0$)

$$\simeq \frac{m v_1^2}{\cancel{2}} + \frac{M}{\cancel{2}}v^2\left(1 - \frac{2m}{M}\frac{v+v_1}{v}\right)$$

$$= \frac{M+m}{\cancel{2}}v^2$$

$$m v_1^2 + \cancel{M}v^2\left(-\frac{\cancel{2}m}{\cancel{M}}\frac{v+v_1}{v}\right) = \cancel{m}v^2$$

$$v_1^2 - 2(v+v_1)v = v^2$$

$$\Rightarrow v_1 = 3v \Rightarrow 9h$$