

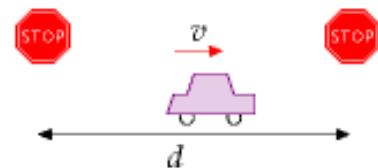
Exercise 1

Addendum

Power to move a car

- Energy to accelerate = energy put in braking

$$\frac{E_{kin}}{\text{time btw brakes}} = \frac{0.5m_{car}v^2}{d/v} = \frac{m_{car}v^3}{2d}$$



- Energy to move in a tube of air

$$\frac{1}{2}m_{air}v^2 = \frac{1}{2}\rho A_{eff}vtv^2 = \frac{1}{2}\rho c_{drag}A_{car}tv^3$$



- Power to move the car:

$$\frac{m_{car}v^3}{2d} + \frac{\rho c_{drag}A_{car}v^3}{2}$$

braking power air drag power

- braking > drag if $m_{car} > \rho c_{drag}Ad$

$$=m_{air(\text{tube})}$$

- $A=2 \text{ m}^2$, $c_d = 0.3$, $m_{\text{car}} = 1630\text{kg}$, $\rho=1.29 \rightarrow d = 2.1 \text{ km}$
- city-driving (d btw stops < 2 km): brake-dominant
 \rightarrow save energy by lower m_{car} , lower v , regenerative braking
- long-distance driving ($d \gg 2 \text{ km}$): drag-dominant
 \rightarrow save energy by lower c_d , lower A_{car} , lower v
- Power of engine:
 - $\varepsilon = 25\%$
 - $v = 30 \text{ m/s}$ (108 km/h)
 - $\rightarrow P = 84 \text{ kW}$

$$P = \frac{\frac{m_{\text{car}} v^3}{2d} + \frac{\rho c_{\text{drag}} A_{\text{car}} v^3}{2}}{\varepsilon_{\text{transmission}}}$$

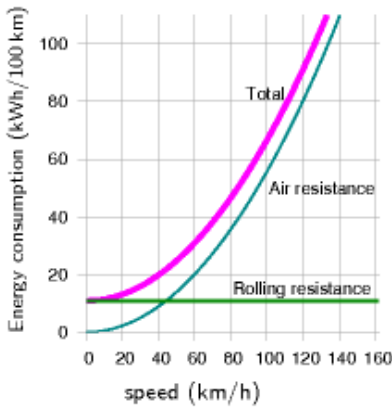
Rolling resistance

wheel	c_{roll}
car rubber tyre on road	0.010
bike tyre on road	0.005
steel on rail (train)	0.002

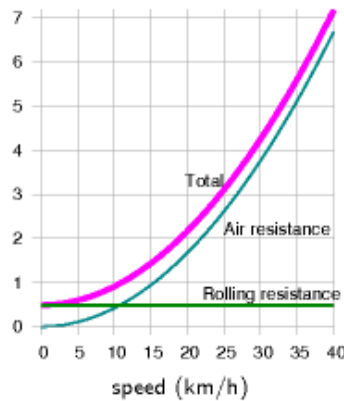
- $= m_{\text{car}} * C_{\text{roll}}$
- for $c_r = 0.01$, $F=100 \text{ N}$ for $m_{\text{car}} = 1000 \text{ kg}$
- = like pushing the car up a slope of 1/100
- for $v = 30 \text{ m/s}$ (108 km/h), $P = F*v = 3 \text{ kW}$
- with $\varepsilon = 25\%$, this becomes 12 kW

Car vs bike vs train

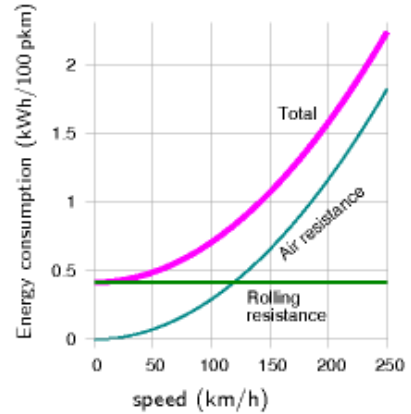
Car
 $m=1000$ kg
 $\epsilon = 0.25$
 $c_d A = 1$ m²
 $c_r = 0.01$



Bike
 $m=90$ kg
 $\epsilon = 0.25$
 $c_d A = 0.75$ m²
 $c_r = 0.005$



Train (8 wagons)
 $M=400'000$ kg
 $\epsilon = 0.9$
 $c_d A = 11$ m²
 $c_r = 0.002$



Battery cars

$m=740$ kg, without batteries
 $\epsilon = 0.85$ (charging / discharging)
 $c_d A = 0.8$ m²
 $c_r = 0.01$
 $v=15$ m/s (50 km/h)
 $d = 500$ m
 (with 50% regenerative braking)

Allow for 500 kg battery:
 difficult with Pb-acid (40 Wh/kg)
 → range < 200 km
 possible with Li-ion (120 Wh/kg)
 → range > 500 km

