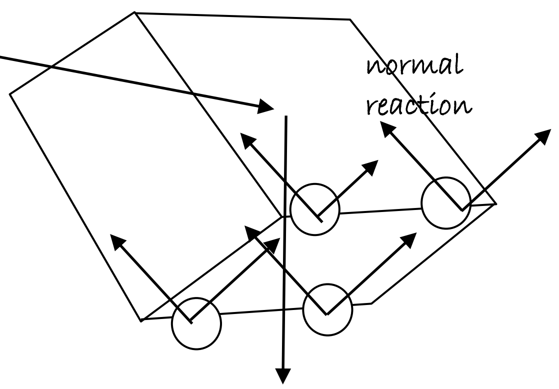
Section 1: Force diagrams and equilibrium

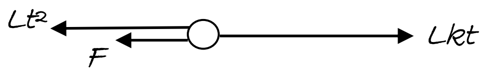
Solutions to Exercise level 3

1.



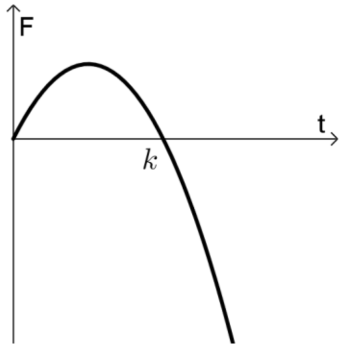
Normal reaction and friction forces act at the point of contact of each wheel

2. (i) Let the frictional force be F, assume for now that it acts in the direction of Q (so when the particle moves, it moves in the direction of P)



Until it moves, $F + Lt^2 = Lkt$

$$F = Lkt - Lt^2 = Lt(k - t)$$



F is at is maximum when $t = \frac{1}{k}$, so maximum F is $L \times \frac{1}{2}k \times \frac{1}{2}k = \frac{1}{4}k^2L$

If $k < 2$, F never reaches its maximum value of L, so therefore it does not move in the direction of P. So it moves in the direction of Q (when F = -L so the friction acts in the opposite direction)

(ii) If $k > 2$, the maximum value of F is reached, so it moves in the direction of P.

(iii) If $k = 2$, the maximum value of F is reached but it is not exceeded, so it still moves in the direction of Q.

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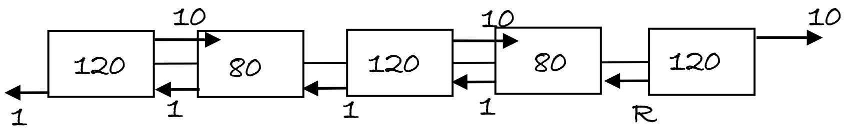
3.



(i) $3 \times 10 = 4 \times 1 + R$

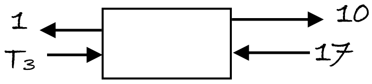
$R = 26$

The resistance to motion is 26 kN

(ii) Car 1: since 26 > 10 the force in the coupling must be a compression, as shown in the diagram and T_1 must be 16 kN.

Car 2: as shown, the force in the coupling must be compression of 17 kN

Car 3: as shown, the force in the coupling must be a compression of 8 kN.



Car 4: as shown, the force in the coupling must be a compression of 9 kN.

(iii) Resistance is proportional to speed, so for the whole train,

resistance $= kv$ for some constant k

Originally, speed = 250 and resistance = 30

$30 = 250k \quad \Rightarrow k = 0.12$

With first car not working, total tractive force = 20

so resistive force = 20

$20 = 0.12v \quad \Rightarrow v = 166.7$ km h^{-1}.

(iv) Let the tractive force on the last car be P

Total tractive force on train = 10 + P

At constant speed the resistance is equal to this, so $10 + P = 0.12v_1$

(where v_1 is the new speed).

For the last car only, at speed of 250, resistance = 1,

so $1 = 250k_1 \quad \Rightarrow k_1 = 0.004$

When the force in the coupling changes from compression to tension, it is momentarily zero, so the resistance is then equal to P.

so $P = 0.004v_1 \quad \Rightarrow 30P = 0.12v_1$

Hence $10 + P = 30P$

$$29P = 10$$

$$P = \frac{10}{29} = 0.345$$

so the tractive force is reduced to below 0.345