8 Read the passage below and answer the questions that follow.

Torque from a Vehicle Engine

An internal combustion engine used on a vehicle operates over a limited rotational speed which can be controlled by the driver. As the driver increases the depression on the accelerator pedal, the input power to the engine will increase to a maximum when the throttle is fully opened. The power delivered to the wheels of the vehicle will also reach a maximum value.

The output torque of the engine is transmitted to the forward driving force on the vehicle's wheels. The transmission of the output torque of the engine is done through a gearbox which consists of several gear ratios capable of providing the required driving force to suit the different driving speeds and accelerations.

The gear ratio is the ratio of the rotational speed of the vehicle's engine to the rotational speed of the vehicle's wheel. A high gear ratio is required at low vehicle's speeds to provide a higher torque.

A vehicle starts to move off with the highest gear ratio, namely gear 1. As the vehicle's speed increases, the gear ratio changes from gear 1 to gear 4, with gear 4 being the lowest gear ratio. The lowest gear ratio is to provide for the maximum speed achievable. Thus, the forward driving force on the vehicle's wheels will change with the speed of the vehicle for different gears.

As the vehicle moves, it encounters a total resistive force that opposes its motion.

Fig. 8.1 shows how the speed of the vehicle affects the available force F at the wheels for different gears and the total resistive force on a 1200 kg vehicle when the input power to the engine is maintained at the maximum value. The available force is the maximum forward driving force that can be transmitted to the wheels.

To stop the vehicle quickly from a certain speed, the driver steps on the brake pedal to produce a braking force on the wheels, and at the same time, the power of the engine is removed completely. The maximum braking force of the car is 9300 N.

When a vehicle moves up an inclined slope, it encounters a climbing resistance that depends on the gradient of the slope. The gradient of the slope is defined as the ratio of the increase in height to the horizontal distance moved in percentage value.

The chart in Fig. 8.2 shows how the climbing resistance is affected by the gradient of the slope.

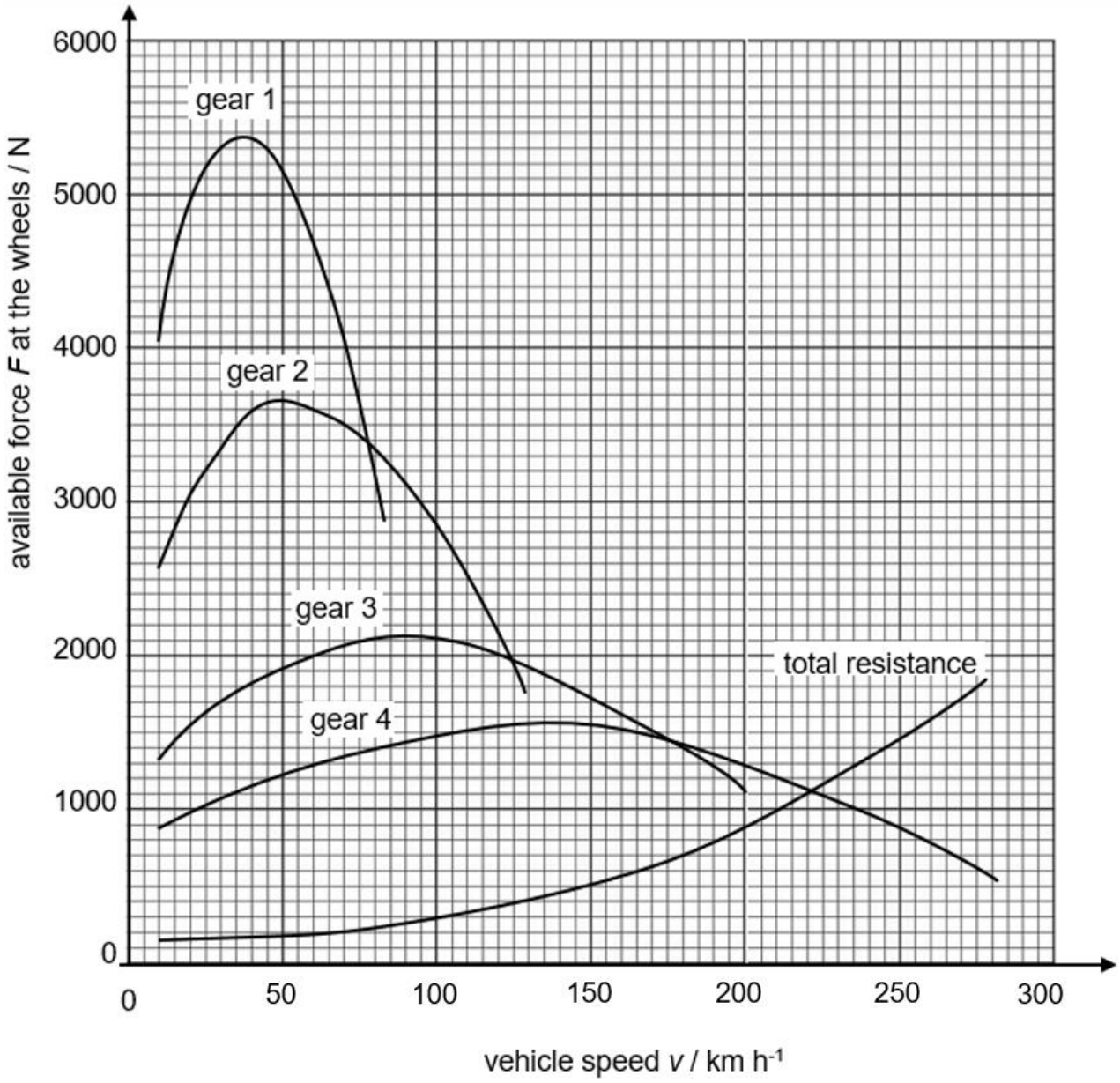
6000
5000
4000
3000
2000
1000
0
available force F at the wheels / N
gear 1
gear 2
gear 3
gear 4
total resistance
0
50
100
150
200
250
300
vehicle speed v / km h-1

Fig. 8.1

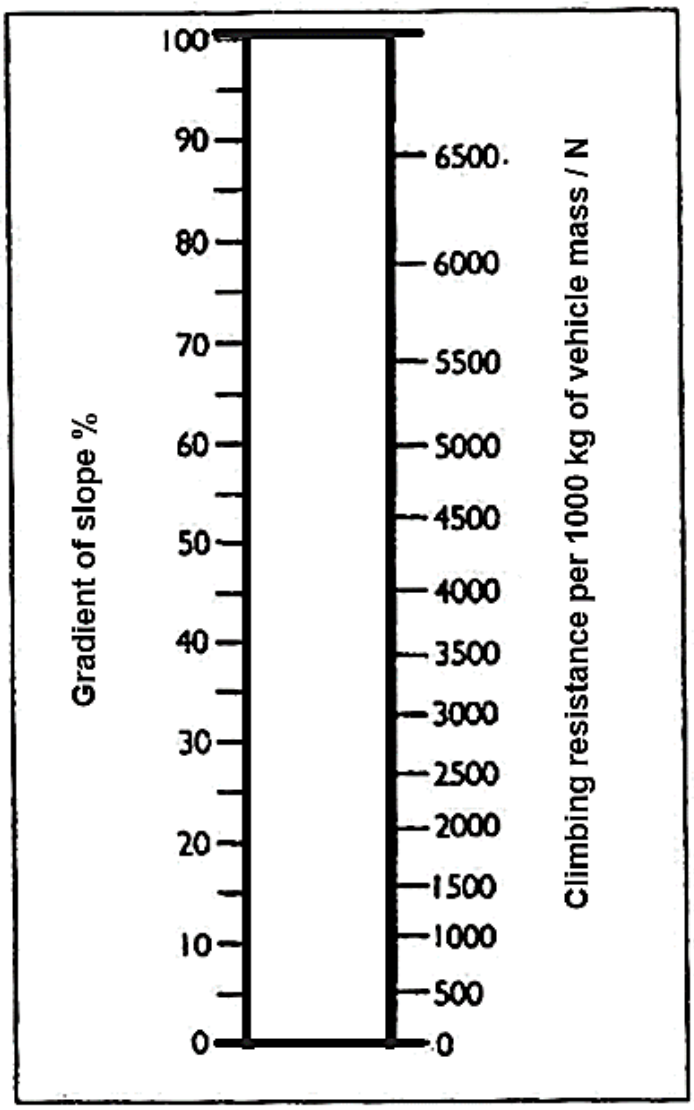

Fig. 8.2

(a) Explain why gear 1 is used to accelerate the vehicle from rest.

_____

_____ [1]

(b) Explain what is meant by the term *available force* at the wheels.

_____

_____ [1]

(c) The vehicle is travelling at 100 km h^{-1} on a horizontal road and gear 3 is engaged by a driver.

(i) State the available force at the wheels and the resistive force.

available force = _____ N

resistive force = _____ N [2]

(ii) Calculate the maximum acceleration.

maximum acceleration = ... $m\ s^{-2}$ [2]

(iii) Explain why gear 3 is the optimum gear for maximum power output at a speed of 100 km h^{-1}.

.....

..... [1]

(iv) The driver wishes to overtake another vehicle which is also travelling at 100 km h^{-1}. Explain whether he needs to change gear.

.....

..... [2]

(d) (i) Starting from the definition of work done, show that the power output of the vehicle is given by the expression

power output = driving force x speed

[2]

(ii) Explain why for a given power delivered to the engine, the available force at the wheels for gear 3 is smaller than that for gear 2.

.....

.....

.....

..... [2]

(e) State the maximum possible speed of the vehicle.

maximum possible speed = ... km h^{-1} [1]

(f) The vehicle is moving up a slope inclined at 20° to the horizontal.

(i) Show that the gradient of the slope, in percentage, is 36%.

[1]

(ii) Use Fig. 8.2 to determine the climbing resistance on the car.

climbing resistance = ... N [2]

(iii) Using the answer to **(f)(ii)** and **Fig. 8.1**, estimate and explain the maximum speed at which the vehicle can move up the slope.

.....

..... [2]

(g) The vehicle is travelling up the slope with a speed of 40 km h^{-1}. The driver intends to stop the car by applying the maximum braking force.

Estimate the distance moved along the slope before the car stop.

distance moved = ... m [3]

[Total: 22]

END OF PAPER 2