These equations will be useful in answering the questions that follow.

average velocity (m s^{-1}) $v_{av} = \frac{s}{t}$ where s is displacement or distance travelled (m) and t is time taken (s)

average velocity (m s^{-1}) $v_{av} = \frac{v + u}{2}$ where v is final velocity and u is initial velocity (m s^{-1}), constant acceleration

acceleration (m s^{-2}) $a = \frac{v - u}{t}$

force (Newton, N) $F = ma$ where m is mass (kg) and a is acceleration (m s^{-2})

Part 1: Simulated 100 m race

Figure 1 shows data obtained when a 72 kg athlete ran on a treadmill. The exercise simulates three main phases of a 100 m race: drive; maintenance; and slowing down.

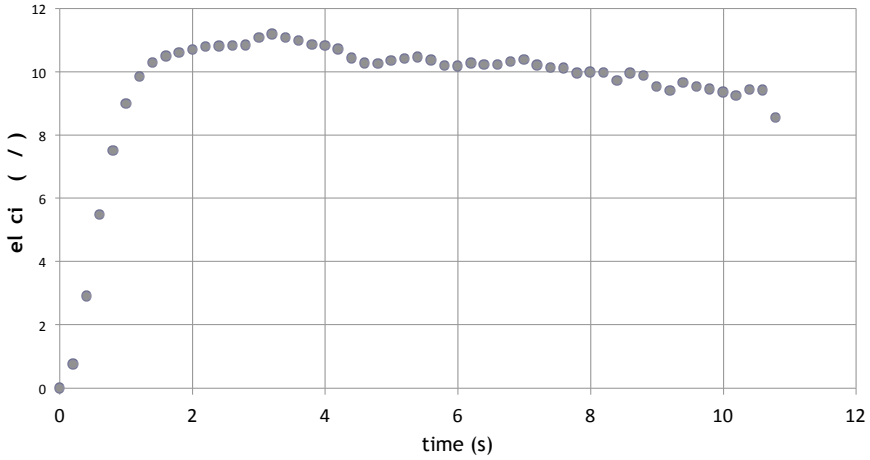

Figure 1. Velocity-time graph for simulated 100 m sprint on treadmill

1. Describe the runner's motion (acceleration, deceleration, or constant speed) during each phase of the race.

   drive (0–3 s) .....

   maintenance (4–7 s) .....

   slowing down (8–10 s) .....

2. Which of Newton's laws of motion best explains each of the following?

   a. The runner pushes against the ground at the beginning of the race. .....

   b. He accelerates rapidly during the first few seconds. .....

   c. His speed reaches a maximum value. .....

   d. His speed reduces towards the end of the race. .....

3. Use the velocity-time graph to estimate how far the runner travels in the first four seconds of the race. Describe the process you used to determine this distance. (Hint: total distance travelled is equal to the area under the curve.)

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4. Determine the runner's average acceleration during the first two seconds of the race. Describe the process you used to determine this acceleration. (Hint: Use a = (v – u) / t.)

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5. Use your answer to question 4 to calculate average force exerted by the runner during the first two seconds of the race.

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6. During which phase of the race is the runner exerting maximum force? Explain your answer.

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7. Comment on the runner's performance in the simulated 100 m race and identify any areas where his coach might want to intervene to bring about improvement.

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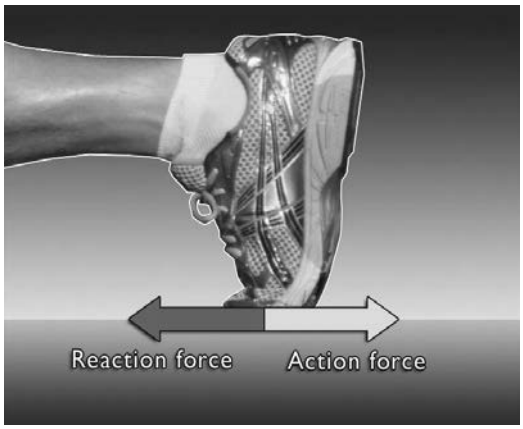
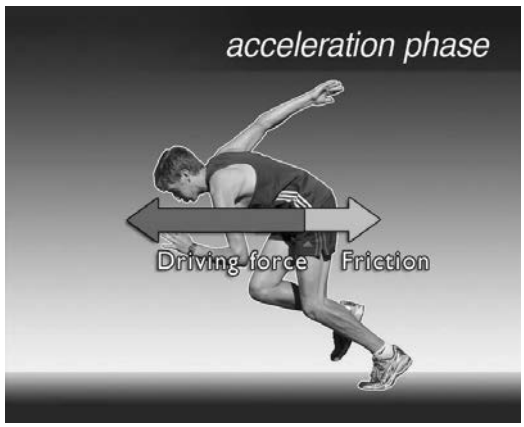
- The following images from *Profile of a runner* show forces acting on the runner during the start and acceleration (drive) phases of the race.





8. Explain the origin of forces acting on the runner's foot at the start of a race, and how they enable him to accelerate from rest.

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Part 2: Usain Bolt's World and Olympic record 100 m run

In the 2008 Beijing Olympic Games, Jamaican athlete Usain Bolt ran the 100 m in a record time of 9.685 s. His performance throughout the race is summarised in Figure 2.

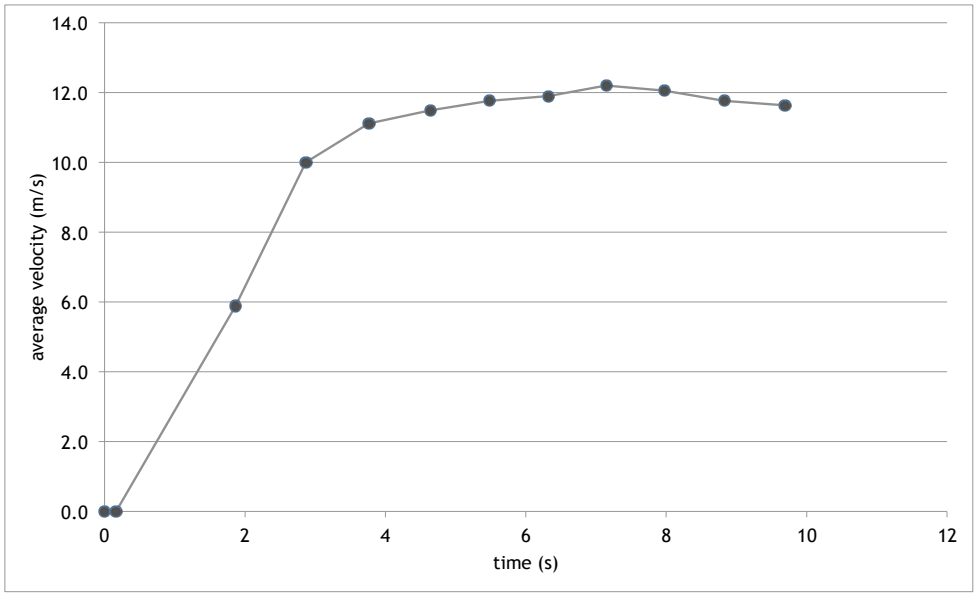

Figure 2. Velocity-time graph of Usain Bolt 100 m race, 2008 Beijing Olympics

1. Estimate Bolt's maximum velocity in m s^{-1} and km h^{-1} (show your working).

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2. Estimate the distance he travelled in reaching his maximum velocity? Describe the process you used to estimate this distance.

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3. Elite athletes win races because of their *speed endurance*, that is, their ability to maintain the same top speed for more of a race. Using the velocity-time graph, comment on Bolt's speed endurance.

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- Figure 3 contains a breakdown of Bolt's performance over each 10 m section of the race. His reaction time of 0.165 s is not included in the first 10 m split. Total race time was 9.685 s.

SECTION (m)	TIME (s)	SECTION (m)	TIME (s)
0 – 10	1.70	50 – 60	0.84
10 – 20	1.00	60 – 70	0.82
20 – 30	0.90	70 – 80	0.83
30 – 40	0.87	80 – 90	0.85
40 - 50	0.85	90 - 100	0.86

Figure 3: 10 m timing splits

4. What was Bolt's average speed over the final 10 m of the race? How does this compare with his speeds during the first 40 m of the race?

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5. During the final 20 m of the race Bolt began celebrating his impending victory, which caused a slight reduction in his speed. Estimate the time he might have recorded in the absence of his celebrations. Describe the process you used to estimate this time.

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