**1** Two particles $P$ and $Q$, of masses 0.2 kg and 0.5 kg respectively, are at rest on a smooth horizontal plane. $P$ is projected towards $Q$ with speed $2\,\text{m s}^{-1}$.

**(a)** Write down the momentum of $P$. [1]

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**(b)** After the collision $P$ continues to move in the same direction with speed $0.3\,\text{m s}^{-1}$.

Find the speed of $Q$ after the collision. [2]

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**1** Particles $P$ of mass $m$ kg and $Q$ of mass 0.2 kg are free to move on a smooth horizontal plane. $P$ is projected at a speed of $2\,\text{m s}^{-1}$ towards $Q$ which is stationary. After the collision $P$ and $Q$ move in opposite directions with speeds of $0.5\,\text{m s}^{-1}$ and $1\,\text{m s}^{-1}$ respectively.

Find $m$. [3]

**1** Two particles $P$ and $Q$ of masses 0.2 kg and 0.3 kg respectively are free to move in a horizontal straight line on a smooth horizontal plane. $P$ is projected towards $Q$ with speed $0.5\,\text{m s}^{-1}$. At the same instant $Q$ is projected towards $P$ with speed $1\,\text{m s}^{-1}$. $Q$ comes to rest in the resulting collision.

Find the speed of $P$ after the collision. [3]

**1** Two particles $P$ and $Q$, of masses 0.3 kg and 0.2 kg respectively, are at rest on a smooth horizontal plane. $P$ is projected at a speed of $4\,\text{m s}^{-1}$ directly towards $Q$. After $P$ and $Q$ collide, $Q$ begins to move with a speed of $3\,\text{m s}^{-1}$.

**(a)** Find the speed of $P$ after the collision. [2]

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After the collision, $Q$ moves directly towards a third particle $R$, of mass $m$ kg, which is at rest on the plane. The two particles $Q$ and $R$ coalesce on impact and move with a speed of $2\,\text{m s}^{-1}$.

**(b)** Find $m$. [2]

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**1** Two particles $P$ and $Q$, of masses $m$ kg and 0.3 kg respectively, are at rest on a smooth horizontal plane. $P$ is projected at a speed of $5\,\text{m s}^{-1}$ directly towards $Q$. After $P$ and $Q$ collide, $P$ moves with a speed of $2\,\text{m s}^{-1}$ in the same direction as it was originally moving.

**(a)** Find, in terms of $m$, the speed of $Q$ after the collision. [2]

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After this collision, $Q$ moves directly towards a third particle $R$, of mass 0.6 kg, which is at rest on the plane. $Q$ is brought to rest in the collision with $R$, and $R$ begins to move with a speed of $1.5\,\text{m s}^{-1}$.

**(b)** Find the value of $m$. [2]

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**1** Two particles $P$ and $Q$ of masses 0.2 kg and 0.5 kg respectively are at rest on a smooth horizontal plane. Particle $P$ is projected with a speed $6\,\text{m}\,\text{s}^{-1}$ directly towards $Q$. After $P$ and $Q$ collide, $P$ moves with a speed of $1\,\text{m}\,\text{s}^{-1}$.

Find the two possible speeds of $Q$ after the collision. [3]

**3** Three particles $P$, $Q$ and $R$, of masses 0.1 kg, 0.2 kg and 0.5 kg respectively, are at rest in a straight line on a smooth horizontal plane. Particle $P$ is projected towards $Q$ at a speed of $5\,\text{m s}^{-1}$. After $P$ and $Q$ collide, $P$ rebounds with speed $1\,\text{m s}^{-1}$.

**(a)** Find the speed of $Q$ immediately after the collision with $P$. [3]

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$Q$ now collides with $R$. Immediately after the collision with $Q$, $R$ begins to move with speed $V\,\text{m s}^{-1}$.

**(b)** Given that there is no subsequent collision between $P$ and $Q$, find the greatest possible value of $V$. [3]

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**1** Two particles $P$ and $Q$, of masses 0.1 kg and 0.4 kg respectively, are free to move on a smooth horizontal plane. Particle $P$ is projected with speed $4\,\text{m}\,\text{s}^{-1}$ towards $Q$ which is stationary. After $P$ and $Q$ collide, the speeds of $P$ and $Q$ are equal.

Find the two possible values of the speed of $P$ after the collision. [3]

**1** Particles $P$ of mass 0.4 kg and $Q$ of mass 0.5 kg are free to move on a smooth horizontal plane. $P$ and $Q$ are moving directly towards each other with speeds $2.5\,\text{m s}^{-1}$ and $1.5\,\text{m s}^{-1}$ respectively. After $P$ and $Q$ collide, the speed of $Q$ is twice the speed of $P$.

Find the two possible values of the speed of $P$ after the collision. [4]

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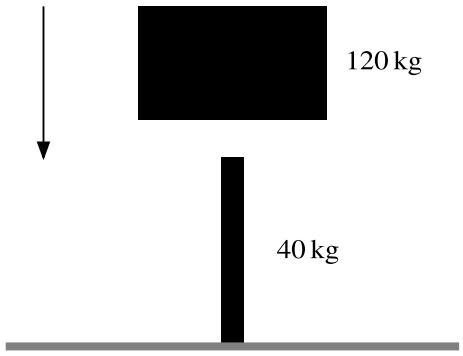


A metal post is driven vertically into the ground by dropping a heavy object onto it from above. The mass of the object is 120 kg and the mass of the post is 40 kg (see diagram). The object hits the post with speed $8\,m\,s^{-1}$ and remains in contact with it after the impact.

**(a)** Calculate the speed with which the combined post and object moves immediately after the impact. [2]

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**(b)** There is a constant force resisting the motion of magnitude 4800 N.

Calculate the distance the post is driven into the ground. [3]

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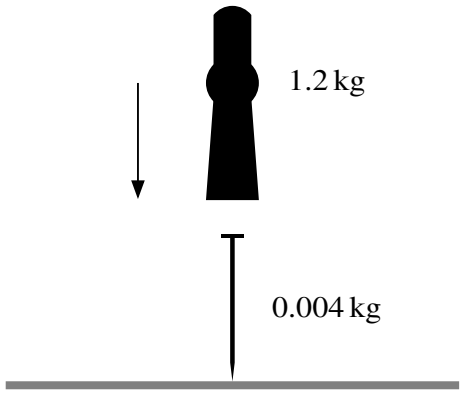


A machine for driving a nail into a block of wood causes a hammerhead to drop vertically onto the top of a nail. The mass of the hammerhead is 1.2 kg and the mass of the nail is 0.004 kg (see diagram). The hammerhead hits the nail with speed $v$ m s$^{-1}$ and remains in contact with the nail after the impact. The combined hammerhead and nail move immediately after the impact with speed 40 m s$^{-1}$.

**(a)** Calculate $v$, giving your answer as an exact fraction. [2]

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**(b)** The nail is driven 4 cm into the wood.

Find the constant force resisting the motion. [3]

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**5** A particle $A$ of mass 0.5 kg is projected vertically upwards from horizontal ground with speed 25 m s$^{-1}$.

**(a)** Find the speed of $A$ when it reaches a height of 20 m above the ground. [2]

When $A$ reaches a height of 20 m, it collides with a particle $B$ of mass 0.3 kg which is moving downwards in the same vertical line as $A$ with speed 32.5 m s$^{-1}$. In the collision between the two particles, $B$ is brought to instantaneous rest.

**(b)** Show that the velocity of $A$ immediately after the collision is 4.5 m s$^{-1}$ downwards. [2]

**(c)** Find the time interval between $A$ and $B$ reaching the ground. You should assume that $A$ does not bounce when it reaches the ground. [4]

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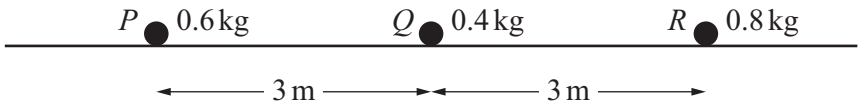


Three particles $P$, $Q$ and $R$, of masses 0.6 kg, 0.4 kg and 0.8 kg respectively, are at rest in a straight line on a smooth horizontal plane. The distance from $P$ to $Q$ is 3 m, and the distance from $Q$ to $R$ is also 3 m (see diagram). $P$ is projected directly towards $Q$ with speed $3\,\text{m}\,\text{s}^{-1}$. After $P$ and $Q$ collide, $P$ continues to move in the same direction with speed $1.5\,\text{m}\,\text{s}^{-1}$.

**(a)** Find the speed of $Q$ after the collision. [2]

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In the subsequent collision between $Q$ and $R$, these particles coalesce.

**(b)** Find the speed of the combined particle after this collision. [1]

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**(c)** Find the time that it takes from when $P$ is initially projected until the instant at which $P$ collides with the combined particle. [4]

**5** Two particles, $P$ and $Q$, of masses $2m$ kg and $m$ kg respectively, are held at rest in the same vertical line. The heights of $P$ and $Q$ above horizontal ground are 1 m and 2 m respectively. $P$ is projected vertically upwards with speed $2\,\text{m}\,\text{s}^{-1}$. At the same instant, $Q$ is released from rest.

**(a)** Find the speed of each particle immediately before they collide. [4]

**(b)** It is given that immediately after the collision the downward speed of $Q$ is $3.5\,\text{m}\,\text{s}^{-1}$.

Find the speed of $P$ at the instant that it reaches the ground. [5]

**5** A particle, $A$, is projected vertically upwards from a point $O$ with a speed of $80\,\text{m}\,\text{s}^{-1}$. One second later a second particle, $B$, with the same mass as $A$, is projected vertically upwards from $O$ with a speed of $100\,\text{m}\,\text{s}^{-1}$. At time $T$ s after the first particle is projected, the two particles collide and coalesce to form a particle $C$.

**(a)** Show that $T = 3.5$ . [4]

**(b)** Find the height above $O$ at which the particles collide. [1]

**(c)** Find the time from $A$ being projected until $C$ returns to $O$. [5]

**6** Three particles $A$, $B$ and $C$ of masses 0.3 kg, 0.4 kg and $m$ kg respectively lie at rest in a straight line on a smooth horizontal plane. The distance between $B$ and $C$ is 2.1 m. $A$ is projected directly towards $B$ with speed $2\,\text{m s}^{-1}$. After $A$ collides with $B$ the speed of $A$ is reduced to $0.6\,\text{m s}^{-1}$, still moving in the same direction.

**(a)** Show that the speed of $B$ after the collision is $1.05\,\text{m s}^{-1}$. [2]

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After the collision between $A$ and $B$, $B$ moves directly towards $C$. Particle $B$ now collides with $C$. After this collision, the two particles coalesce and have a combined speed of $0.5\,\text{m s}^{-1}$.

**(b)** Find $m$. [2]

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**(c)** Find the time that it takes, from the instant when $B$ and $C$ collide, until $A$ collides with the combined particle. [5]

**6** A particle $A$ is projected vertically upwards from level ground with an initial speed of $30\,\text{m}\,\text{s}^{-1}$. At the same instant a particle $B$ is released from rest 15 m vertically above $A$. The mass of one of the particles is twice the mass of the other particle. During the subsequent motion $A$ and $B$ collide and coalesce to form particle $C$.

Find the difference between the two possible times at which $C$ hits the ground. [8]

**7** A particle $P$ of mass 0.2 kg is projected vertically upwards from horizontal ground with speed $25\,\text{m}\,\text{s}^{-1}$.

**(a)** Show that the speed of $P$ when it reaches 20 m above the ground is $15\,\text{m}\,\text{s}^{-1}$. [2]

When $P$ reaches 20 m above the ground it collides with a second particle $Q$ of mass 0.1 kg which is moving downwards at $20\,\text{m}\,\text{s}^{-1}$. $P$ is brought to instantaneous rest in the collision.

**(b)** Find the velocity of $Q$ immediately after the collision. [2]

When $P$ reaches the ground it rebounds back directly upwards with half of the speed that it had immediately before hitting the ground.

**(c)** Find the height above the ground at which $P$ and $Q$ next collide. [6]

**7** Two particles $A$ and $B$, of masses 0.4 kg and 0.2 kg respectively, are moving down the same line of greatest slope of a smooth plane. The plane is inclined at 30° to the horizontal, and $A$ is higher up the plane than $B$. When the particles collide, the speeds of $A$ and $B$ are $3\,\text{m s}^{-1}$ and $2\,\text{m s}^{-1}$ respectively. In the collision between the particles, the speed of $A$ is reduced to $2.5\,\text{m s}^{-1}$.

**(a)** Find the speed of $B$ immediately after the collision. [2]

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After the collision, when $B$ has moved 1.6 m down the plane from the point of collision, it hits a barrier and returns back up the same line of greatest slope. $B$ hits the barrier 0.4 s after the collision, and when it hits the barrier, its speed is reduced by 90%. The two particles collide again 0.44 s after their previous collision, and they then coalesce on impact.

**(b)** Show that the speed of $B$ immediately after it hits the barrier is $0.5\,\text{m s}^{-1}$. Hence find the speed of the combined particle immediately after the second collision between $A$ and $B$. [7]

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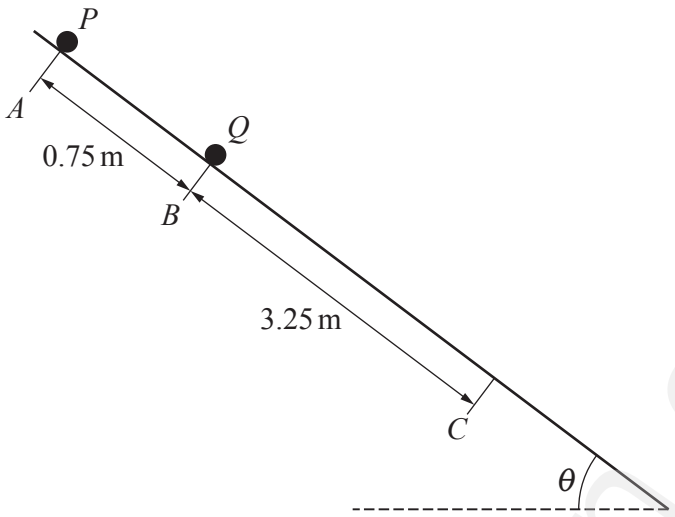


The diagram shows two particles $P$ and $Q$ which lie on a line of greatest slope of a plane $ABC$. Particles $P$ and $Q$ are each of mass $m$ kg. The plane is inclined at an angle $\theta$ to the horizontal, where $\sin\theta = 0.6$. The length of $AB$ is 0.75 m and the length of $BC$ is 3.25 m. The section $AB$ of the plane is smooth and the section $BC$ is rough. The coefficient of friction between each particle and the section $BC$ is 0.25. Particle $P$ is released from rest at $A$. At the same instant, particle $Q$ is released from rest at $B$.

**(a)** Verify that particle $P$ reaches $B$ 0.5 s after it is released, with speed 3 m s$^{-1}$. [3]

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**(b)** Find the time that it takes from the instant the two particles are released until they collide. [4]

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The two particles coalesce when they collide. The coefficient of friction between the combined particle and the plane is still 0.25 .

**(c)** Find the time that it takes from the instant the particles collide until the combined particle reaches $C$. [5]

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