Please submit written answers to the Homework Questions to your Tutor at your tutorial in Week 2. The remaining questions will form the basis of your tutorial session. NB Assessed tutorial work counts 12.5% of your total semester work. Marks are shown as a guide in square brackets for your homework questions.

Homework Questions

Q1 A ball is thrown vertically straight up in the air and passes a certain window 0.30s after being released. It passes the same window on its way back down 1.50s later. What was the initial velocity of the ball?  

![Diagram of a ball thrown vertically upwards.]

Q2 A ball is thrown at initial speed $v_0$ at an angle of 45° to the horizontal in order to achieve maximum range, $s$. If the ball is then thrown vertically upwards with the same initial speed so that it rises to a height, $h$, derive a simple equation for $h$ in terms of $s$.  

Q3 (a) The two protons in a hydrogen molecule are 0.74×10^{-10} m apart. What is the electrostatic force between them?  
(b) A point charge of +3 μC is at the origin and another point charge of −4 μC is at a point 10 cm away along the x-axis. What is the magnitude and direction of the electric field at a point 15 cm from the origin along the positive y-axis?  

Q4 A particle of mass 2 g and carrying a charge $q$ is suspended from a light, insulating thread. A second particle carrying an equal but opposite charge is held near to the first particle in the same horizontal plane and causes it to deflect. When the particles are separated by 25 cm, it is observed that the thread makes an angle of 45° to the vertical. By considering the forces acting on the suspended particle, find the magnitude of charge $q$.  

Tutorial Session Questions

**Q5** A projectile is fired in such a way that its horizontal range is equal to three times its maximum height. What is the angle of projection?

**Q6** A projectile is fired at an angle $\theta$ and initial velocity $v$ to the horizontal along an inclined plane which makes an angle $\alpha$ to the horizontal ($\theta > \alpha$). Show that the horizontal distance travelled along the ramp is given by $S$ where:

\[
S = \frac{2v^2}{g} (\sin \theta \cos \theta - \cos^2 \theta \tan \alpha).
\]

**Q7** Two identical small conducting spheres are positioned with their centres 0.3 m apart. One is given a charge of +12 nC and the other a charge of −18 nC.

(a) What is the electrostatic force exerted by one sphere on the other?

(b) If the two spheres are now connected by a conducting wire, how will the force change when the charge has come to equilibrium? (Assume that all the charge now resides on the spheres, and none on the wire.)

**Q8** Two identical beads have a mass of 0.5 g and carry a charge $q$. They are placed in an insulating hemispherical bowl of radius $R = 25$ cm with frictionless walls. The beads move into an equilibrium position as shown, where they are 25 cm apart. What is the magnitude of the charge $q$?
**Department of Physics & Astronomy**  
**Mechanics, Vibrations and Waves**

**PHY101 Tutorial Sheet 3**  
(Distributed in Week 3, 2011 for the tutorial to be held during Week 4)

Please submit written answers to the Homework Questions to your Tutor at your tutorial in Week 4. Most tutors will accept tutorial homework up to the end of the week in fairness to all students since tutorial sessions are held throughout the week. The remaining questions will form the basis of your tutorial session. NB Assessed tutorial work counts 12.5% of your total semester work. Marks are shown as a guide in square brackets for your homework questions.

**Homework Questions**

**Q1**  A 30 g bullet is fired into a 13 kg stationary block of wood suspended by a light wire from the ceiling. The bullet remains embedded in the wooden block. The height change of the bullet-block combination is 4.6 cm. What was the original speed of the bullet just prior to impact?  

**Q2**  (i) A 300 g bird flying along at 6.0 ms\(^{-1}\) sees a 10 g insect heading straight toward it with a speed of 30 ms\(^{-1}\). The bird opens its mouth and enjoys a nice lunch. What is the bird’s speed immediately after swallowing the insect?  

(ii) A table tennis ball is dropped from a height of 90 cm onto a solid wood table. The coefficient of restitution (corresponding to the ball-table collision) is 0.74. Find the heights of the 5\(^{th}\) bounce. Derive any equations that you use.

**Q3**  Six identical capacitors, each of capacitance \(C\), are connected in the network shown in the figure. What is the effective capacitance of the combination?
Tutorial Session Questions

**Q4** Fast moving $\alpha$-particles of mass $m$ make collisions in a cloud chamber with gas atoms of mass $M$ and negligible initial velocity. After a collision, the velocities of the scattered $\alpha$-particles and the recoiling gas atoms are $v$ and $V$ respectively, the former being inclined at an angle $\theta$ and the latter at an angle $\phi$ to the original $\alpha$-particle direction.

(a) Show that:

$$2v \cos(\theta + \phi) = \left\{1 - \frac{M}{m}\right\}V$$

(b) When the chamber is filled with helium, the angle between the scattered $\alpha$-particle and the recoiling helium atom is always close to $90^\circ$. What conclusion can be drawn from this about the $\alpha$-particles and the helium atoms?

Please point out the significance of this experiment.

**Q5** A uniform line of charge, of density $200 \mu C \ m^{-1}$, is formed into a semicircle of radius 10 cm. Calculate the electric field at the centre of the curvature.

**Q6** A rod of length $L$ carries a uniform linear charge density $\lambda$. Find the potential at a distance $d$ from an end of the rod:

(a) measured along the same line as the rod

(b) measured perpendicular to the rod.

[You may wish to use the result $\int \frac{dx}{\sqrt{a^2 + x^2}} = \ln \left( x + \sqrt{a^2 + x^2} \right)$.]
Mechanics, Vibrations and Waves

PHY101 Tutorial Sheet 4
(Distributed in Week 4, 2011 for the tutorial to be held during Week 5)

Please submit written answers to the Homework Questions to your Tutor at your tutorial in Week 4. Most tutors will accept tutorial homework up to the end of the week in fairness to all students since tutorial sessions are held throughout the week. The remaining questions will form the basis of your tutorial session. NB Assessed tutorial work counts 12.5% of your total semester work. Marks are shown as a guide in square brackets for your homework questions.

Homework Questions

Q1 An air-filled parallel plate capacitor has plates of area 9.5 cm² separated by a gap of 1.6 mm. A potential difference of 25.0 V is applied to the plates. Calculate:

(a) the electric field between the plates;
(b) the surface charge density on the plates
(c) the charge on each plate
(d) the capacitance.

Q2 A parallel plate capacitor has plates of area \( A \) and separation \( d \). Two sheets of different dielectrics, with dielectric constant \( k_1 \) and \( k_2 \) and both of thickness \( d/2 \), are introduced to fill the gap, as shown in the figure. What is the capacitance of the capacitor now?

[5]

Q3 The motor driving a large grindstone is switched off when a rotational speed of 360 rpm (revolutions per minute) has been achieved. After 15 s, the speed has decreased to 210 rpm. If the angular deceleration remains constant, how many additional revolutions does the stone make before coming to rest?

[5]

Q4 A large metal flywheel is used for storing energy and has a mass of \( 3 \times 10^5 \) kg and a diameter of 3.2 m. If the flywheel can be driven up to a speed of 520 rpm, calculate:

a) the maximum energy that can be stored in it and
b) the average power output (rate of doing work) when the speed of rotation is reduced from 520 to 320 rpm in a time period of 6 s.

[5]
Tutorial Session Questions

Q5 Two long parallel wires of radius $d$ carry opposite charge densities of $\pm \mu$ per unit length, and their centres are separated by a distance $D$. By considering the electric field between the wires, show that the capacitance per unit length of the wires is given by

$$C = \frac{\pi \varepsilon_0}{\ln\left(\frac{D-d}{d}\right)}.$$  

(Hint! Use superposition.)

Q6 The system of a cloud and the earth can be considered as the two plates of a capacitor. Calculate the capacitance provided by such a cloud of area 1.2 km² at a height of 800 m above the ground. If the air breaks down at a field of $3 \times 10^6$ V m⁻¹, calculate the maximum charge the cloud can carry before it is discharged by a lightning strike to earth.

Q7 Four point masses of mass 2 kg, 6 kg, 1.5 kg and 3 kg are positioned at points (2,2), (1,-1), (-3,-4) and (-3,3) respectively. The system of masses rotates around the origin (0,0) at 560 revolutions per minute. Calculate:

(i) the moment of inertia of the system of masses and
(ii) its rotational kinetic energy.
Please submit written answers to the Homework Questions to your Tutor at your tutorial in Week 6. Most tutors will accept tutorial homework up to the end of the week in fairness to all students since tutorial sessions are held throughout the week. The remaining questions will form the basis of your tutorial session. NB Assessed tutorial work counts 12.5% of your total semester work. Marks are shown as a guide in square brackets for your homework questions.

Homework Questions

Q1 A thin, uniform circular plate has mass $m = 20$ kg and radius $r = 0.75$ m. Calculate the moment of inertia:

a) about an axis through its centre and perpendicular to the plane of the plate and
b) the rotational kinetic energy of the plate if it is rotating 15 revolutions per second. [5]

Q2 An imperfect battery is connected to a variable resistance, and both terminal voltage and current measured under differing load conditions. If the terminal voltage is 11.0 V when the current is 2.0 A and 7 V at 10 A, what are the EMF and internal resistance of the battery? [5]

Q3 A large bank of capacitors, of capacitance 5 mF ($5 \times 10^{-3}$ F), is to be charged from a 100 V source of EMF. In order not to damage the supply, the current must be limited to a maximum of 5 A.
(a) What resistance must be included in series with the capacitors?
(b) How long will it take for the capacitors to reach 95% of their total charge? [5]

Q4 A light, flexible cable is wrapped a solid cylinder of mass $M$ and radius $R$. The cylinder rotates with negligible friction about a stationary horizontal axis. The free end of the cable is tied to a box of mass $m$ which is released with no initial velocity at a distance $h$ above the floor. As the block falls, the cable unwinds without stretching or slipping, turning the cylinder. Show that the speed of the falling box just as it strikes the floor is given by $v$ where:

$$v = \sqrt{\frac{2gh}{M} + \frac{M}{2m}}.$$ [5]
Tutorial Session Questions

**Q5**  Show that the moment of inertia of a solid sphere centred on the origin (0,0) and rotating about the x-axis is equal to \((2/5)MR^2\) where M is its mass and R is its radius. (You will need to use the result for the moment of inertia of a thin disk rotating about an axis through its centre and perpendicular to the plane of the disk).

**Q6 a)** Using the parallel axis theorem, calculate the moment of inertia of a door of mass 35 kg, height 2.2 m, width 1.1 m and thickness 0.06 m about an axis through its hinges.

b) What is torque and how is it related to angular acceleration?

c) Discuss the conservation of angular momentum.
Please submit written answers to the Homework Questions to your Tutor at your tutorial in Week 6. Most tutors will accept tutorial homework up to the end of the week in fairness to all students since tutorial sessions are held throughout the week. The remaining questions will form the basis of your tutorial session. NB Assessed tutorial work counts 12.5% of your total semester work. Marks are shown as a guide in square brackets for your homework questions.

**Homework Questions**

Q1 A space traveller lands on a small planet, “Timbron 10”, whose circumference is 12,500 km. He releases a hammer and a table tennis ball simultaneously from rest and from a height of 1.6 m, timing their fall to take 0.66 s. Determine the density of Timbron 10. What can you conclude about the atmosphere of this planet? [5]

Q2 Earth’s radius is 6370 km and the Moon’s radius is 1738 km. The acceleration due to gravity on the surface of the Moon is 1.62 m/s. What is the ratio of the average density of the moon to that of the Earth? [5]

Q3 Use Kirchhoff’s junction rule and loop rule (twice) to find the effective resistance of the two resistors connected in parallel as shown, and demonstrate that this agrees with the expression derived in the lectures $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$. [5]
Tutorial Session Questions

Q4
A charged capacitor, \( C \), is discharged through a resistor, \( R \). Calculate how the power dissipated in the resistance varies with time. What is the time constant for the decay of the power (i.e., the time required for it to fall to \( e^{-1} \) of its original value)?

\[ C \quad \quad \quad \quad \quad R \]

**Q5**
A lightning conductor on a tall church consists of an aluminium strip 1 cm by 3 cm with a length of 10 m down the spire, joined onto a strip 1.5 cm by 5 cm with a length of 30 m down the wall to the ground. What is the effective resistance of the full length of conductor? (The resistivity of aluminium is \( 2.7 \times 10^{-8} \) \( \Omega \) m.)

**Q6**
By using Newton’s Law of Gravitation and Coulomb’s Law, compare the magnitudes of the gravitational and electrostatic forces between two electrons separated by 1 nm (10\(^{-9}\) m).

**Q7**
Suppose you leave the solar system and arrive at a planet that has twice the mass/volume ratio of the Earth and 10 times Earth’s radius. What would you weigh on this planet compared to what you weigh on Earth?
Homework Questions

**Q1**
A particle of mass 10 g is suspended freely on a spring and undergoes SHM with a frequency 7 Hz and amplitude 12 cm. The particle passes through the equilibrium position at t=0 with negative velocity.

a) Write down expressions for the displacement, velocity and acceleration of the particle as a function of time [2]

b) Find:
   i) The velocity of the particle at t=0,
   ii) The acceleration at t=0,
   iii) The maximum acceleration,
   iv) The displacement of the particle from equilibrium at t=0.2 s,
   v) The spring constant of the spring,
   vi) The total energy of the particle. [3]

**Q2**
A Simple Harmonic Oscillator has amplitude A and angular frequency ω.

a) Write an expression for its kinetic and potential energy as a function of time [1]

b) Show that the total energy is constant and given by E=1/2kA². [1]

c) Draw a graph of the kinetic and potential energy as a function of the displacement x [1]

d) For what value of x/A is the kinetic energy equal to the potential energy? [2]

**Q3**
There are three observers, all non accelerating. Observer B is moving at velocity v_{BA} with respect to observer A. Observer C is moving at velocity v_{CB} with respect to observer B. All three observers and all their relative velocities are directed along the same straight line. Show using matrix multiplication that the matrix for transforming the coordinates of an event from the reference frame of observer A to the reference frame of observer C using the Galilean transformations from lecture 1 can be written

\[
\begin{pmatrix}
  1 & 0 \\
-(v_{BA} + v_{CB}) & 1
\end{pmatrix},
\]

where the coordinates of an event are arranged \( \begin{pmatrix} t \\ x \end{pmatrix} \) as in class. [5]
Q4 A ball is thrown into the air at 45 degrees to the horizontal. Sketch a spacetime diagram for the x component of its position from take-off till it lands. Sketch a spacetime diagram for the y component of its position from take-off till it lands. Bear in mind that the acceleration due to gravity is directed downwards (in the -y direction).

Tutorial Session Questions

Q5
A particle moving with simple harmonic motion of amplitude 10 cm has a time period of 25 ms.
Find:
   a) The angular frequency,
   b) The velocity when the displacement is 3 cm from the equilibrium,
   c) The acceleration when the displacement is 3 cm from the equilibrium.

Q6
A block of mass m=100 g is attached to a spring of constant 1000 N/m and slides on a frictionless surface. The spring is compressed 10 cm from its rest position and held by a latch.
   a) What is the potential energy stored in the spring?
   b) When the latch is released the block undergoes SHM. Find the maximum velocity of the block
   c) Before releasing the latch, another block of mass M=500 g is placed in front of the first one so that it can be pushed. After releasing the latch, at what point will the heaviest block be detached from the lightest? What is the velocity of the heaviest block after it is detached?

Q7 At time t=0 s, a car passes the starting gate of a straight race track travelling at velocity $v_1=25$ m/s. At time t=10 s, a second car passes the starting gate travelling at $v_2=35$ m/s. Both cars travel in the same direction.
(a) Draw a spacetime diagram for the world lines of the two cars in the reference frame stationary with respect to the starting gate, including on your diagram a label for the event when the first car passes the starting gate, a label for the event where the second car passes the starting gate, and a label for the event of the second car passing the first car.
(b) Using the usual general form for the equation of a straight line ($y=mx+c$ where $y$ denotes the vertical axis variable, $m$ is the gradient, $x$ is the horizontal axis variable and $c$ is the vertical axis intercept), write $t$ in terms of $x$ and $v_1$ for the first car. Now write $t$ in terms of $x_2$ for the second car. In both cases, the equations should take the form $t=mx+c$, where $m$ is the slope of the world line of the car on the spacetime diagram, and $c$ is the time when it passes $x=0$.
(c) Solve the equations $t=mx+c$ for the two cars found above simultaneously, and determine the coordinates of the event where the second car passes the first car.
(d) Suppose instead that the second car had passed the starting gate travelling at 15 m/s, all other parameters remaining the same. At what time in the past did the first car overtake the second one?
PHY101 Tutorial Sheet 8

Please submit written answers to the Homework Questions to your Tutor at your tutorial in Week 10. Most tutors will accept tutorial homework up to the end of the week in fairness to all students since tutorial sessions are held throughout the week. The remaining questions will form the basis of your tutorial session. NB Assessed tutorial work counts 12.5% of your total semester work. Marks are shown as a guide in square brackets for your homework questions.

Homework Questions

Q1 A pulse travels along a string of mass M=1.3 kg and length L= 10 m. After a time t=0.7 s the pulse propagated 5 m down the string.
   a) Find the tension of the string. [2]
   b) Show that the expression for the velocity of the pulse \( v = \sqrt{\frac{T}{\mu}} \) is dimensionally correct. [3]

Q2 A block of mass m=0.1 kg is attached to a spring with spring constant k=100 Nm\(^{-1}\) and moves with a damping constant b=0.12 kg s\(^{-1}\). The block is initially pulled extending the spring by \( \Delta x=0.1 \) m and let go.
   a) Find the period T of the resulting oscillation and draw a graph of the displacement as a function of time. [1]
   b) Find the potential energy of the spring the moment after the block is pulled. [1]
   c) Derive an expression for the total energy of the spring \( E_n \) at time \( t=nT \), where \( n=0,1,2,3... \) and T is the period of the oscillation. [1]
   d) Evaluate the ratios \( E_1/E_0 \) and \( E_2/E_0 \). [2]
      (Hint: The total energy is equal to the potential energy for \( t=nT \))

Q3 For this question you are first required to watch the 35 minute movie at http://www.scivee.tv/node/2415

This movie is about an experiment to measure the lifetime distribution of muons at rest, and compare this with the lifetime distribution of muons moving at a fraction 0.995 of the speed of light in a vacuum with respect to an observer on Earth's surface.

(a) Muons in cosmic rays have a large range of velocities. What typically happens to muons entering the iron with velocities less than 0.9950c? What typically happens to muons entering the iron with velocities greater than 0.9954c?
(b) What are the two measured quantities resulting from the experiment at the top of the mountain, in two sentences?
(c) What is the one measured quantity resulting from the experiment at the bottom of the mountain, in one sentence?
(d) Why is the iron layer above the scintillator crystal thinner in the experiment at the bottom of the mountain than in the experiment at the top?
(e) How long in seconds does it take a muon travelling vertically with a speed of 0.995c to travel the 1920m from the top of the mountain to sea level?
(f) Given the radioactive decay law
   \[ N = N_0 e^{-\frac{t}{\tau}} \]
   where \( N \) is the number of undecayed remaining particles, \( N_0 \) is the original number of particles, \( t \) is the time over which the particles are given the opportunity to decay, and \( \tau \) is the inferred mean life of the particles, use the experimental results to determine \( \tau \) in microseconds for muons moving at 0.995c relative to the observer. Recall that an average of 564 muons are detected per hour at the top of the mountain, compared to an average of 412 muons per hour at sea level.
(g) What is the \( \gamma \) factor for a muon travelling at 0.995c?
(h) Taking into account time dilation, use your answers to (f) and (g) to estimate the lifetime of a muon at rest. How does this compare with our best estimate of 2.2\( \mu \)s?

**Tutorial Session Questions**

**Q4** A block of mass \( m \) is attached to a spring of spring constant \( k \) and has a damping coefficient \( b \).

a) Show that the function: \( x(t) = A e^{-\frac{t}{\tau}} \cos(\omega t + \phi) \) With \( \omega = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}} \) is a solution to the differential equation for a damped oscillator:
\[ m \frac{d^2x}{dt^2} + b \frac{dx}{dt} + kx = 0. \]

b) When an external force \( F_D = \cos(\omega_D t) \) is applied the block oscillates with angular frequency \( \omega_D \). Draw a graph of the amplitude of the oscillation as a function of the angular frequency of the driving force \( \omega_D \).

c) Discuss the phenomenon of resonance.

**Q5** Three particles have gamma factors of 10, \( 10^3 \) and \( 10^6 \) respectively. What are the differences in metres per second between their velocities and that of light in a vacuum?

**Q6** A simple pendulum is set into small-angle motion making a maximum angle with the vertical of 5\(^o\). Its period is 2.21 s. Determine (a) its length and (b) its average speed.
**Homework Questions**

**Question 1**

a) The end of a stretched string is forced to vibrate with a transverse displacement \( y(x = 0, t) = A \cos(\omega t) \) with \( A=0.3 \) m and \( \omega=9 \) rad \( \text{s}^{-1} \). If the tension of the string is \( T=4 \) N, and the mass per unit length is \( \mu=1250 \) kg \( \text{m}^{-3} \), calculate:

(i) the wave velocity,

(ii) the frequency of oscillation,

(iii) the wavelength and

(iv) the displacement of the string at \( x=2 \) m from the source at the time \( t=100 \) ms after the oscillation commences.

Assume that the wave is travelling from left to right.

**Question 2**

An astronaut on the Moon wishes to measure the value of \( g \) by timing pulses travelling down a 1.6 m long wire of mass \( m=4 \) g with a \( M=3 \) kg mass suspended from it. If a pulse takes 36.1 ms to traverse the total length of the string, calculate \( g \).

**Question 3**

The highest energy protons have gamma factors around \( 10^{12} \).

(a) Take our galaxy to have a disk diameter of 30 kpc, which is \( 9.3\times10^{20} \) m. If a photon and one of these high energy protons start traversing the galaxy at the same time, by how long will the arrival of the photon on the other side precede the arrival of the proton, in the reference frame stationary with respect to the galaxy? Give your answer in seconds.

(b) To an observer in the reference frame of the travelling proton, what is the measured diameter of the galaxy in kpc?

(c) To an observer in the reference frame of the travelling proton, how long does the journey across the galaxy take? Give your answer in seconds.

**Tutorial Session Questions**

**Question 4**

Two beams of hot plasma are ejected back-to-back from an active galactic nucleus at a speed relative to the nucleus of \( v=0.92 \) c. The nucleus is receding away from the Earth at a relative velocity of 0.8 c. The beams are aligned parallel to the line of sight between the active galactic nucleus and Earth.

(a) What are the velocities of the beams as measured by an observer in the reference frame of Earth?

(b) What is the velocity of recession of one plasma beam in the reference frame of an observer at rest with respect to the other plasma beam?
Question 5
A violin has a standard string length of 325 mm, whereas a viola typically has a string length of 375 mm. During a rehearsal, Pinchas, a viola player, breaks his “A” string and finds himself without a spare. However, Pinchas’ violin playing friend Itzhak is able to lend him a violin “A” string so that he can continue with the rehearsal.

(i) Calculate the tension in the violin string when it is fitted to the violin and tuned to correct pitch (A=440Hz). Assume the string is made from steel (density = 7700 kg m\(^{-3}\)) and has a diameter of 0.5 mm.

(ii) Calculate the tension when the same string is fitted to a viola and tuned to 440 Hz.

(iii) What do you answer tell you about violin and viola strings?

Question 6
A guitar string is vibrating in its fundamental mode with nodes at each end. The vibrating length of the string is 390 mm. The maximum transverse acceleration of a point halfway along the string is \(8.5 \times 10^3\) m s\(^{-2}\), and the maximum transverse velocity is 4 m s\(^{-1}\).

(i) Write down an expression for the y-displacement of the string \(y(x,t)\).

(ii) Write down expressions for the maximum transverse velocity and acceleration in terms of the angular frequency \(\omega\) and amplitude \(A\) at the anti-node.

(iii) Hence obtain values for \(\omega\) and \(A\).

(iv) Calculate the wave speed for the transverse waves on the string.
Homework Questions

Q1 A transverse wave is transmitted along a uniform string with mass per unit length of 0.15 kg m\(^{-1}\), under a tension of 59 N.
   i) Write down a general expression for the average power transmitted by the wave in terms of its frequency and amplitude and the linear density and tension of the string.
   [1]
   ii) Show that this expression is dimensionally correct.
   [2]
   iii) Calculate the average power transmitted for an amplitude of 42 mm and a frequency of 20 Hz.
   [1]
   iv) Calculate the sound intensity produced by the vibration at a distance of 5m from the string.
   [2]

Q2 A motorcycle is approaching a stationary pedestrian at a speed of 30 mph. The motorcyclist narrowly avoids a collision with a car travelling in the opposite direction at 45 mph. The motorcyclist and the driver, each naturally assuming that the other party is entirely at fault, angrily blast their horns at one another. If the frequency of the motorcycle horn is 650 Hz and the frequency of the car horn is 520 Hz calculate:
   i) the frequency of the motorcycle horn heard by the pedestrian.
   [2]
   ii) the frequency of the car horn heard by the pedestrian.
   [2]
   iii) the frequency of the car horn heard by the motorcyclist and
   [2]
   iv) the frequency of the motorcycle horn heard by the car driver.
   [2]

Q3 A pi meson has rest mass 131 MeV/c\(^2\) and total energy 1 GeV.
   (a) What is its momentum, expressed in MeV/c?
   [4]
   (b) By how much is its speed less than \(c\)? Give your answer in m s\(^{-1}\).
   [3]
   (c) A pi meson having the total energy 1 GeV decays in flight into two photons. The wavelength of each photon in the rest frame of the pi meson is 2.51 fm. What is the shortest possible wavelength for one of these photons in the reference frame where the pi meson has this total energy? What is the longest possible wavelength for one of these photons in the same rest frame?
   [4]