Momentum worksheet igcse

6. Elastic and non-elastic collisions, preservation of momentum - concepts and calculations and Newton's 2nd Law of Motion Doc Brown's Physics Revision Notes Suitable for GCSE/IGCSE Physics/Science courses or equivalent This page will help answer questions like... What is the progress of an object? What is an elastic collision? What is an inelastic collision? How do we solve problems and make calculations that involve momentum? Subindex for this page (a) What is an object's progress and how do we calculate it? (b) Law on preserving Momentum (c) Other examples of momentum effects (d) Problem solving issues involving more complex momentum calculations(e) Change in Momentum and the consequences of Newton's Second Law of Motion (f) More advanced calculations involving momentum and Newton's 2nd/3rd Love (a) What is the momentum of an object and how do we calculate it? All moving objects have what we call momentum. (sometimes referred to with a small case p) The faster an object moves, the greater its momentum. The larger the mass of an object in motion, the greater its moment. An object's propulsion is directly proportional to its speed and its mass. Momentum (p) is a vector quantity, it has both size and direction Therefore the equation for momentum is ... momentum (kg meter per second) = mass (kilogram) × speed (meters per second) momentum p (kg m/s) = mass m (kg) x speed v (m/s) p = m × v Example of simple calculations using the formula for momentum Q1.1 A 120 kg sprinter running at 9.0 m/s, what is the propulsion of the runner? momentum p = m × v p = 120 x 9 = 360 kg m/s Q1.2 If a 20 g ball has a momentum of 8 kg m/s, its speed is calculated. p = m × v, v = p/m (do not forget to change g to kg!) speed = 8/(20/1000) = 400 m/s Q1. 3 What mass should an object have if it has a propulsion of 1.5 x 106 kg m/s and a speed of 30 m/s? p = m × v, m = p/v mass = 1.5 x 106/30 = 5.0 x 104 kg Q1.4 What is the speed of a 1500 kg car travelling north with 30 000 kg m/s of momentum? p = m x v, v = p / m v = 30 000 / 1500 = 20 m/s in a northerly direction Q1.5 - TOP OF PAGE and sub-index (b) The law on the preservation of Momentum Here we will consider collisions between two objects in a closed system. Here, a closed system here means that no other external forces are affected by the situation, for example, in the field of human rights. If an external force such as friction is involved, the overall momentum cannot be maintained. The total progress of an event in a closed system is the same before and after the event (e.g. a collision between two objects). This is called the 'Law of Preservation of Momentum' and you can use it doing lots of calculations! for example, total propulsion for two colliding objects = the total moment of objects after collision, e.g. m and v for mass and speed gives ... m1v1 + m2v2 = m1v3 + m2v4, where v1 and v2 are the initial speeds and v3 and v4 speeds after the collision, (you assume there is no change in mass, no bits have flown out!), and if two objects stick together 'after the collision then: p1 + p2 = p3 replace m and v for mass and speed gives ... m1v1 + m2v2 = m3v3 (where m3 = m1 + m2), where v1 and v2 are the initial speeds and v3 and m3 (m3 = m1 + m2) is the final speed and mass after the collision. In other words, the large object formed by collision has momentum corresponding to the two momentums of colliding objects merged. Momentum is preserved for both elastic and inelastic collisions. For a perfect elastic collision, no kinetic energy is lost - kinetic energy saved. In an elastic collision, the total energy of the kinetic energy stores of the colliding objects is the same as before and after the collision. You don't have to solve problems for elastic collisions - the maths is too difficult for GCSE physics, with two sets of equations, for momentum (etc.) and kinetic energy (E = 1/2mv2), to solve eg for the resulting speeds! For an inelastic collision, kinetic energy is not preserved - kinetic energy is lost in some form e.g. heat or sound. In an inelastic collision, some of the moving objects are lost and transferred to other energy stores of the objects themselves or the environment. This is because the atoms are bashed together increasing their potential energy store (compressed for a fraction of a second). They 'relax' to their normal state by losing energy such as heat (thermal energy) or sound. For inelastical collisions, you can solve a number of problems using the principle of maintaining momentum. TOP OF PAGE and sub-index (c) Other examples of momentum effects The above examples involve collision, but there are all sorts of momentum situations eg when a gun is fired the bullet goes in the front direction (positive momentum), but the gun recoil in the exact opposite direction (negative momentum). From Newton's third law, you get an equal and opposite force reaction. The bullet goes one way and the gun the other way from the force of the explosion. numeric, ignoring +/- characters: mgunvgun = mbulletvbullet (see Q2.2 below) Note that the combined momentum = zero as it is at the beginning and immediately after the gun is fired. Before a rocket is fired, it has zero speed and zero momentum. When the rocket's propellant is fired, the rocket goes one way (positive momentum) and the exhaust gases go in the opposite direction (negative momentum). So in maintaining momentum, we can say .. numeric, ignores +/- signs: mrocketvrocket = mexhaust gasesvexhaust gases (see Q2.2 below) Because the rocket produces gases with great power and speed, must respond according to Newton's third law of motion - equal and opposite forces in dramatic action! - TOP OF PAGE and sub-index (d) Problem solving issues involving more complex momentum calculations Q2.1 The chart below shows the sequence of events when a moving green ball collides with a stationary purple ball. The green ball has a mass of 2.0 kg and moves at 4.0 m/s before colliding with the stationary purple ball. After the collision both balls move in a forward direction. If the green ball is still moving forward at 1.5 m/s, calculate the speed of the purple ball. From the law of preservation of momentum total momentum before collision = total momentum after collision m1v1 + m2v2 = m1v3 + m1v4 (2 x 4) + (3 x 0) = (2 x 1.5) + (3 x v4) 8 + 0 = 3 + 3v4, 3v4 = 8 - 3 = 5, therefore V4 = 5/3 = 1.7 m/s (2sf) Q2.2(a) Why does a gun rekyl move (moved backwards) when fired? At first, both the gun and the bullet have zero moment. After firing the ball then has its own momentum in a forward direction from the shooter. However, this must be offset by a momentum in the opposite direction, because the overall momentum must be preserved. So on firing, the gun itself must get its own straight but opposite momentum (remember that momentum is a vector quantity!). Therefore, the gun's straight and opposite momentum causes it to recoil backwards. (b) A 10 g ball accelerates to 400 m/s after being fired from a gun with a mass of 2.0 kg. (i) What is the pace of the ball? (kg = g/1000) p = m × v = (10/1000) x 400 = 4.0 kg m/s (ii) What is the gun's propulsion? From the law of maintaining momentum, the gun must have a momentum equal and opposite the bullet. Therefore, gun momentum = -4.0 kg m / s (minussign is important, especially in more complex calculations, the gun recoil in the opposite direction of the ball - Newton's third law in action). (iii) What is the speed of the recoil gun? Momentum of gun and bullet must be straight (from the law of preservation of momentum) therefore numerically: mgunvgun = mbulletvbullet mgunvgun = -4.0 = 2.0 x vgun, vgun = 4.0/2.0 = -2.0 m/s (again, note minus sign, because the gun recoil in the opposite direction to the ball). (c) Why is it beneficial for the shooter to shoot with a heavier gun? From the equation: momentum = mass x speed The greater the mass of the gun, for the same momentum, the lower the recoil speed and the lesser impact on the person firing the gun. Q2.3 The chart below shows the sequence of events when a moving car crashes into a stationary car, and they combine together and move forward. The green car (1), of mass 1000 kg, crashes into the stationary blue car (2) mass 800 kg. After the collision, the two cars are locked together. a) Calculate the speed of the combined damaged cars immediately after the condition. From the law of of momentum total propulsion before collision = total momentum after collision m1v1 + m2v2 = m3v3 (m3 = m1 + m2) (1000 x 20) + (800 x 0) = (1000 + 800) x v3 20 000 + 0 = 1800v3 v3 = 20 000/1800 = 11.1 m/s (3sf) (b) Calculate the kinetic energy of all three objects in the diagram. KE = 1/2mv2 KEgreen car = 1/2 x 1000 x 202, = 200 000 J KEblue car = 1/2 x 800 x 02 = 0 J KEwreck = 1/2 x 1800 x 11.12 = 110 889 = 111 000 J (to 3 sf) (c) Calculate any difference between the total kinetic energies of the cars and the wreck, and came down to the results of your calculations. Kinetic energy is NOT preserved. Loss of kinetic energy = 200 000 - 110 889 = 89 111 = 89 100 J (to 3 sf) Lots of sound and thermal energy created! (d) Explain your response to (c) The loss of kinetic energy involves several changes to energy stocks. There is a loud bang on the impact, so some energy is lost as sound. The cars are compressed and the increase in potential energy plus friction effects, increases the thermal energy store of the wreck - which then cools down. So in the end, all the lost kinetic energy of automotive energy stores increases the thermal energy store in the surroundings – lost KE something spreads! Q2.4 Imagine a 0.2 kg ball moving at 5 m/s that collides with a 0.3 kg sphere moving in 2 m/s in the same direction. After the collision, the 0.2 kg green ball stops moving and the 0.3 kg purple ball continues to move in the same direction. Calculate the final speed of 0.3 kg purple ball. First sort all the masses and speeds at which v1 and v2 are the initial speeds and v3 and v4 speeds after the collision m1 = 0.2 kg, initial speed v1 = 5 m / s, final speed v3 = 0 m / s m / m2 = 0.3 kg, initial speed v2 = 2 m / s, final speed v4 = ? m/s total momentum for two objects before collision = the total number of objects after collision for two colliding objects where p = momentum: p1 + p2 = p3 + p4 replacing m and v for the mass and speed of the two objects provides ... m1v1 + m2v2 = m1v3 + m2v4 Then replace everything in the equation, rearrange and derive the answer (v4). (0.2 x 5) + (0.3 x 2) = (0.2 x 0) + (0.3 x v4) 1.0 + 0.6 = 0 + 0.3 v4, 0.3 v4 = 1.6 therefore the final speed of 0.3 kg ball = v4 = 1.6/0.3 = 5.3 m/s (2 sf) Q2.5 Imagine a 0.2 kg ball moving at 5 m/s, hitting a sphere of 0.3 kg moving in 2 m/s in the same direction. After the collision both balls keep moving in the same direction, but at different speeds. If the 0.2 kg ball continues to move at a speed of 1.5 m/s, the final speed of the 0.3 kg ball shall be calculated. This is an almost identical problem with Q2.4, except that there is no zero momentum term. So sorting out all the masses and speeds where v1 and v2 are the original speeds and v3 and v4 the speeds after the collision m1 = 0.2 kg, speed v1 = 5 m / s, finally v3 = 1,5 m/s m2 = 0.3 kg, starting speed v2 = 2 m/s, final speed v4 = ? m/s total momentum for two objects before collision = the total number of objects after collision for two colliding objects where p = momentum: p1 + p2 = p3 + p4 replace m and v for the mass and speed of the two objects provides ... m1v1 + m2v2 = m1v3 + m2v4, where v1 and v2 are the initial speeds and v3 and v4 speeds after the collision Then replace everything in the equation, rearrange and infer the answer (v4). (0.2 x 5) + (0.3 x 2) = (0.2 x 1.5) + (0.3 x v4) 1.0 + 0.6 = 0.3 + 0.3 v4, 0.3 v4 = 1.6 - 0.3 = 1.3 therefore the final speed of 0.3 kg ball = v4 = 1.3/0.3 = 4.3 m/s (2 sf) Note that the final speed of the ball 0.3 kg is less than in Q2.4 because in Q2.4 it received all momentum from the collision. Q2.6 Snooker players can hit the white ball 'dead center' in a stationary red ball. The stationary red ball then flies out at the same speed as the incoming white ball, and the white ball is left in a stationary position where the red ball was. Ignoring friction and assuming the balls have the same mass, explain this observation. The law of conservation states the overall momentum must be the same before and after the collision. mwhitevintitial + mredvinitial = mwhitevfinal + mredvfinial mredvinitial is zero, since the red ball is initially stationary with a momentum of zero. mwhitevfinal is zero, as the white ball is now stationary, also with a momentum of zero. Therefore: mwhitevintitial = mredvfinal and since the masses are even, mwhite = mred, so the final speed of the red ball must correspond to the original speed of the white ball. It should be noted that skilled snooker players can play all sorts of tricks with the 'physics' of snooker and often have a total disregard for the law of preserving momentum! Q2.7 Imagine a 1000kg car travelling at a speed of 10 m/s crashing head in a 500kg car travelling in the opposite direction at a speed of 15 m/s. Suppose they 'crunch' together to form a single object - the 'wreck'! a) Calculate the propulsion of both cars. i) green car momentum = 1000 x 10 = +10 000 kg m / s (right) (ii) blue car momentum = 500 x 15 = -7 500 kg m / s (left) (you must assign a positive and negative sign, vector quantity, opposite directions) (b) Calculate the momentum p of the 'wreck' From the law of preservation of momentum pwreck = pgreen car + pblue car pwreck = +10 000 + -7 500 = +2 500 kg / s (c) What is the immediate speed of the wreck after the collision and in what direction? (in terms of chart) total mass = 1000 + 500 = 1500 kg pwreck = mwreck x vwreck 2500 = 1500v, v = 2500 / 1500 = 1.6r = 1.67 m/s on the right (in terms of chart and to 3 sf also!) Note: Although the speed of the blue car is greater than the green one, it has a greater momentum, so the resulting of the wreckage is to the right. (d) Is kinetic energy saved by this collision? (i) You must calculate the kinetic energies of all the objects in question KE = 1/2mv2 KEgreen car = 1/2 x 1000 x 102, = 50 000 J KEblue car = 1/2 x 500 x 152 = 56 250 J KEwreck = 1/2 x 1500 x 1,672, = 110 889 = 2 092 J (to 3 sf) (ii) Kinetic energy not saved. In fact, most of the kinetic energy of the colliding cars is lost in the collision. Diagram reminder A reminder of the data and the final speed was 1.67 m/s to the right! (e) If the impact time is 0,10 seconds, the decelerations for the two cars shall be calculated. (speeds are vector volumes, see characters, + right, - left). a = Δv / Δt = (v - u) / Δt (u = initial speed, v = final speed) agreen car = (1.6r - 10) / 0.1 = -83.3 m / s2 (3 sf, r means recurring) ablue car = (1.6 r - -15) = 16.6 r / 0.1 = 166.6r = 167 m / s2 (3 sf, r means recurring) (f) Calculate the force experienced by each car. F = ma Fgreen car = 1000 x -83.3r = 83 333 = -83 300 N (3 sf) Fblue car = 500 x 166.7 = 83 333 = 83 300 N (3 sf) (g) Comment on your answer to (f) in the form of Newtons 3. The two forces are equally numerical, but act in opposite directions. Newton's Third Law of Motion says that when two objects interact, the forces they exert on each other are equal in numerical value and act in opposite directions, and in this case they are both normal contact forces. Q2.8 A momentum issue involving Newton's Third Law, preserving momentum and preserving kinetic energy. A 0.20 kg green ball (m1) moving at 5.0 m/s collides in accordance with a 0.40 kg purple ball (m2) moving at 2.0 m/s. Also from high speed photography, the collision impact time was thought to be 0.05 seconds. After the collision, with both moving in the same direction, the 0.20 kg green ball continues moving forward at a slower speed of 2.0 m/s and the purple ball also continues moving forward at an increased speed of 3.50 m/s. (a) Use Newton's 2nd Act, calculating the force involved in causing changes in speed. F = m = mΔv/Δt = m(v-u) ÷ 0.05, where F = force (N), m = mass (kg), v and you = final and initial speeds. For the green ball: F = 0.2 x (2 - 5) ÷ 0.05 = -12 N For the purple ball: F = 0.4 x (3.5 - 2) ÷ 0.05 = 12 N (b) Are the results of your calculations in (a) in accordance with Newton's 3. Yes, they do. Seeing notes on Newton's 3rd Law Newton's third law of motion states that when two objects interact, the forces they exert on each other are equal in numerical value, act in opposite directions and are of the same type. The impact forces are the same size and work in opposite directions. The impact force works on two different objects with the same type of normal contact force. Data reminder! (c) Is the experiment consistent with (i) the concept of 'closed' system AND (ii) the comments are in line with the Law on maintaining momentum? (i) The collision takes place in a closed system - the experiment is a physical system that does not allow the transfer of substance in or out of the system, and is so fast there is no time for energy to leave or enter the system. (ii) momentum p = etc. where p in kg m/s, m in kg, v in m/s. Momentums before collision: for green ball p = 0.2 x 5 = 1.0 kg m/s for purple ball p = 0.4 x 2 = 0.8 kg m/s total momentum before collision = 1.0 + 0.8 = 1.8 k m/s Momentums after collision: for green ball p = 0.0 8 2 x 2 = 0.4 kg m/s for purple ball p = 0.4 x 3.5 = 1.4 kg m/s total momentum after collision = 0.4 + 1.4 = 1.8 k m/s The overall momentum is the same as before and after the collision, so that the law of maintaining momentum is observed. d) Does the calculation indicate whether kinetic energy has been preserved or not? Comment on your results. KE = 1/2mv2, where KE in J, m = mass of object in kg and speed in m/s. Kinetic energies before collision: green ball KE = 1/2 x 0.2 x 52 = 2.5 J purple ball KE = 1/2 x 0.4 x 22 = 0.8 J total kinetic energy before collision = 2.5 + 0.8 = 3.3 kinetic energies after collision: green ball KE = 1/2 x 0.0.0.0.0. = 3.3 kinetic energies after collision: green sphere KE = 1/2 x 0.0.0.0.0. = 3.3 kinetic energies after collision: green ball KE = 1/2 x 0.0.0 2 x 22 = 0.4 J purple ball KE = 1/2 x 0.4 x 3.52 = 2.45 J total kinetic energy after collision = 0.4 + 2.45 = 2.85 J (2.9 2sf) You can see from the calculations, kinetic energy is not preserved in this collision of two objects. It's an inelastic clash. The object's atoms are compressed and kinetic energy is converted into potential energy, thermal energy and sound. Q2.9 TOP OF SIDE AND SUB-INDEX (e) Change in Momentum and the consequences of Newton's second law of Motion When a resulting force works on an object for a longer period of time, it will cause a change in momentum by changing the speed. The resulting force causes a change in speed or direction towards the resulting force. The resulting force causes a change in momentum towards the resulting force. One way to specify Newton's second law is to say that the change in momentum is proportional to the size of the resulting force and the time interval in which the force acts on the object. This statement is justified by following the three mathematical steps below. A resulting force on an object will cause it to accelerate or decrease. force = mass x acceleration F = ma (the mathematical expression of Newton's 2nd Law of Motion) NOW acceleration is the change in speed of a particular change in time. a = Δv/ Δ (the usual formula for acceleration) a = acceleration in m/s2 v in w/s, time t in seconds s If you combine these two equations you get power = mass x change in speed / time F = m Δv / Δt = m (v-u) / Δt (where v and you are final and initial speeds), but for a given object of mass m, m Δv = Δmv = Δp = change in so can write momentum momentum 2. Law equation as F = Δmv / Δt = Δp / Δt (force equals the speed change of momentum) These equations express force as the speed of change of momentum and Δp = Δmv = F x Δt (remember Δt is the time when the resulting force actions) F x Δt is sometimes called impulse. This means that a force applied to an object over a period of time must change the object's speed. From the point of view of solving calculation problems, you need to be pretty familiar with all this math! In calculations you can then use Newton's second movement law (F = ma) as follows: force (newton, N) = change in momentum (kilogram meter per second, kg m/s) / time (second, s) F = Δmv / Δt = (etc . - mu) / Δ not, where = mass of object kg, u = initial speed w / s, v = final speed w / s it means that the speed of the change of momentum is a directly related to the resulting force or force applied, so you can say the force is equal to the speed of change of momentum, the equation can be written as F = mΔv / Δt as m is constant for a given object, which can be expressed as ... change of momentum (kg m/s) = resulting force (N) × the time when it works (s) Δp = Δmv = F x Δt (the product of the resulting force x time is sometimes called impulse) (if the force varies, so the average force is used in the calculation, but I do not think it is necessary for GCSE) Consequences of the force corresponding to the change of speed for any moving object the faster the change in momentum (Δmv) occurs, the greater the force (F) involved, and the shorter the time (Δt). You should be able to see this from the equation Δmv = F x Δt for a given, etc., increase in F means a decrease in Δt, for a given, etc., decrease in F means an increase in Δt, this has serious consequences for e.g. car accidents. The faster the accident happens the more force on the car and its occupants. This sudden change of momentum change in such a short time results in a major impact force. The less Δt for a given momentum change, the greater the force involved, and the greater the chance of injury. If you can cause rapid deceleration to occur over a long period of time (increasing Δt), you reduce the resulting force and reduce the risk of serious injury. That's what curl zones are for in the design of modern cars. As for F=ma, you are trying to reduce one and then reduce F. (For more details on this issue see 5. Braking distances, impact forces - example calculations TOP OF PAGE and sub-index (f) More advanced calculations involving momentum and Newton's 2nd/3rd Laws Q3.1 What explosive force is needed to speed up a 20 g ball in a gun from 0 m/s to 300 m/s in 0.15 seconds. 20 g = 20/1000 = 0,02 kg, u = 0 m/s v -= 300 m/s, Δt = 0.15 s F = Δmv / Δt = (mv - mu) / Δt F = {(0.02 x 300) - (0.02 x 0)} / 0.15 F = (0.02 x 300) / = 6.0 / 0.15 = 40 N It is important that you can solve these kinds of problems in different ways, depending on what information you get and how you are expected to derive things from it e.g. Using the same information you can solve this problem using F=ma directly. a = 300 / 0,15 = 2000 m/s2 m = 0,02 kg, F=ma, F = 0.02 x 2000 = 40 N This is the approach I took on my braking distances, impact forces - example calculations Q3.2 What force should a tennis player generate with a tennis racket exercise on a 60 g tennis ball to accelerate it from rest to a speed of 50 m/s in 10 milliseconds (10 ms). mass of tennis ball = 60 g = 60/1000 = 0.06 kg, time power applied = 10 ms = 10/1000 = 0.01 s Δp = Δmv = F x Δ t (this comes from Newton's 2nd Law equation F = mΔv/Δt) etc. changes from zero to 0.06 x 50 = 3.0 kg m / s therefore: 3.0 = F x 0.01, F = 3.0 / 0.01 = 300 N Q3.3 An object experiences a change in momentum of 30 kg m/s. If the change takes place in 5 seconds, what force on the object produced this change in momentum? F = m = mΔ/Δt = Δmv / Δt = 30 / 5 = 6 N Q3.4 A force of 500 N is applied to an object to change its momentum in 2000 kg/s. How long was the force used? F = m = mΔv/Δt = Δmv/Δt Δt = Δmv / F = 2000 / 500 = 4 seconds Q 3.5 A 0.80g lead pill fired from an air gun experiences a force of 4.8N in a time interval of 25

milliseconds - the time it takes for the pellet to travel down the barrel. a) Calculate the speed at which the pellet leaves the gun. F = m = mΔv / Δt = m(v-u) / Δt m = 0.8 / 1000 = 0.0008 kg, Δt = 25 / 1000 = 0.025 s (25 milliseconds), v = ?, u = 0 m/s F = mv / Δt v = Δ t x F / m = 0.025 x 4.8 / 0.0008 = 150 m/s (b) If the air gun recoil at a speed of 0.05 m / s, what is the mass of the airgun? You can solve this part of the problem two ways (i) From the law of maintaining momentum momentum of airgun = momentum of pellet m x 0.05 = 0.0008 x 150 m = 0.0008 x 150 / 0.05 = 2.4 kg (ii) From Newton's 3. which tells you that the force on the gun is equal in size to the force of the conductive pellet. F = ma, m = F / a m =? kg, F = 4.8 N, a = Δv / Δt = 0.05 / 0.025 = 2.0 m/s m = 4.8 / 2.0 = 2.4 kg Q3.6 For many more questions like these, see section 5(h). calculations, including F=ma IGCSE revision notes momentum calculations elastic inelastic collisions KS4 physics Science notes on momentum calculations elastic inelastic collisions GCSE physics guide notes on momentum calculations elastic inelastic collisions for schools college academies science course tutors images images charts for momentum calculations elastic inelastic collisions science revision notes on momentum calculations elastic inelastic collisions for revision physics modules physics subjects notes to help understand momentum calculations elastic uelastic collisions university courses in career in science physics job in engineering technical laboratory assistant apprenticeships engineer internships in physics USA USA grade 8 grade 9 grade 10 AQA GCSE 9-1 physics science review notes on momentum calculations elastic inelastic collisions GCSE notes on momentum elastic inelastical collision is for OCR GCSE 9-1 21st century physics science notes on momentum calculations elastic inelastic collisions OCR GCSE 9-1 Gateway physics science review notes on momentum calculations elastic inelastic collisions WJEC gcse science CCEA/CEA gcse science TOP OF PAGE and sub-index 