11-14 Momentum

Prerequisites

Students should have already completed the **Calculating Speed, Weight** and **Forces** sheets. While not essential, it will help if they have also studied the **Force & Motion** sheet. A momentum approach can be a simpler approach to understanding how force affects motion than the conventionally taught F=ma, and therefore the students do not need to have prior knowledge of acceleration.

The Main Points

- **Momentum** is the modern scientific name for what Newton [more helpfully] called 'motion'.
- Momentum depends on the mass and the velocity (speed and direction of motion)
  - A 6kg dog at 3m/s has more momentum than a 3kg cat.
  - A 3kg cat at 6m/s has more momentum than a 3kg rabbit at 2m/s.
  - A mouse running East has a very different kind of motion to a mouse running West even if they are going at the same speed. They will end up in different places!
- In mathematical terms: momentum = mass x velocity
- Momentum is measured in kg m/s.
- The more momentum something has, the harder it is to stop it.
- Momentum as a number tells you the size of [resultant] force (in newtons) needed to stop the object in one second.
- If there is **no force** on an object (or balanced forces) the **momentum does not change**
- If an **unbalanced force** pushes an object, the **momentum will change**.
- A 14N force (for example) will change an object's momentum by 14 units every second.
- As an equation: Force x Time = Momentum change
  - Force needed = Momentum change / Time taken
  - Time taken = Momentum change / Force
  - If there is more than one force, then the 'Force' in these equations is the Resultant Force (see the Force and Motion sheet for an explanation).

Teacher Quarter Briefing

- Introduction: https://youtu.be/v9u6RwXVYbM
- Practice: https://isaacphysics.org/gameboards#itsp_teach_momentum
- Review: https://youtu.be/-ZOzxBKdSwQ
- If you want to go further: use the Momentum and Force lesson materials

Rationale

You may be surprised to see a worksheet on momentum in a set of resources for Year 7-8 students. This concept used to be reserved for Year 13, and then more recently it was introduced to GCSE. A body of educational research suggests that students find the concept of 'momentum' more intuitive than force or acceleration (and certainly more intuitive than the link between the two). Once students understand momentum, they more easily understand that forces change momentum, and this leads to an excellent understanding of dynamics (without F=ma or 'metres per second squared' ever being mentioned). In fact Newton originally wrote his first two laws in terms of momentum. We therefore encourage you to try using a momentum approach when explaining motion to your students. Of course, you may prefer not to (it is never required for KS3), and this sheet is optional. The resources for Acceleration on Isaac Physics can be used completely independently of this sheet.

Class Question Notes

The worksheet can be printed either in full, or in cloze text form (where the red text is missing, and students can complete these blank spaces after class discussion). The online version of the notes requires the appropriate text to be dragged to the right place in the sentences.

Shallow learning gradient online assignment - q1,2,3,4,5,6,7,9,11,13
Steeper learning gradient online assignment - q5,6,7,8,10,12,13,14,15,16

1. In Q1-4, students calculate momentum using the formula mass x velocity, with scaffolded support.
5. As a precursor to Q6-7, students calculate the momentum of an apple, a rabbit and a cat.
6. Here students fill in sentences to describe the link between momentum and how hard it is to stop a moving object. The more momentum something has, the harder it is to stop. This could be because it has more mass, or more velocity.
7. Students calculate the force needed to stop a running cat in one second. The force needed to stop an object in one second is numerically equal to its momentum, so we want them to calculate the momentum of the cat = 3.1kg x 6.0m/s.
8. In this question, students calculate the momentum for a pair of objects and see which is larger. This is the harder object to stop.
9. In this question, students are told that a school trolley needs 4.5N to stop it moving on one second. So the momentum is 4.5 kg m/s. They are then given the mass and asked to work out the velocity (with scaffolded support). This then leads them to an equation for velocity in terms of momentum (=momentum / mass).
10. In the first part of the question, students work out velocity from momentum (if 3kg x velocity = 30 kg m/s, then velocity must be 10m/s). They use the momentum as the force needed to stop the brick in one second. Finally, they comment on why it would actually take a larger force than this to stop a brick. To answer this, they need to remember that the brick is falling, and they have to support it (balance its weight) as well as stop it moving. For students who have already studied the Force and Motion sheet, and have come across the idea of resultant force, please explain that the answer to (b) [30N] is the resultant force, but the brick weighs 30N too, so an upwards force of 60N is going to be needed to give it the upwards 30N resultant force needed to stop the brick in one second.
11. This question is similar to Q9, but here the student works towards an equation for mass in terms of momentum (=momentum / velocity).
12. Here students write down the equations involving momentum using symbols. Momentum is usually given the symbol p, which is strange, but it is what everyone does.
13. In this question, a wheelchair and rider are stopping, but not in one second. The force to stop something in 9s (as in part b) will be one ninth of the force needed to stop it in one second.
14. The go-kart in this question is accelerating (speeding up) from rest to 25m/s. It starts with no momentum. After it is moving at 25m/s, its momentum is 150kg x 25m/s = 3750 kg m/s. Getting it to this speed in 1s would require a 3750N force (the momentum change), so speeding it up in five seconds requires a force one fifth of this = 3750/5 = 750N. Notice that this is the same answer you would get if you used F=ma with an acceleration of 5m/s^2.
15. In this question, after an example, we work the other way. We multiply the force by the time to get 8N x 0.3s to get the momentum change (2.4 kg m/s). As we know the mass, we can work out the velocity and hence the speed: 2.4 kg m/s = 0.08kg x velocity, so velocity = 2.4 / 0.08 = 30 m/s.
16. In this question, after an example, we work out the time needed to stop a train. The momentum of the train (the momentum which needs to be lost when the train stops) is numerically equal to the force needed to stop the train in one second. If we divide this by the actual force from the brakes, we get the number of seconds taken to stop the train.

Homework Question Notes

These questions have a very similar form to the questions in the class task, so students can refer back to their earlier answers to help

Shallow learning gradient online assignment - q1,2,3,4,5,7,9,10,11,12
Steeper learning gradient online assignment - q1,6,8,11,12,13,14,15,16,17

1. Students choose words to explain momentum, how to calculate it and what it means in terms of the force needed to stop a moving object.
2. This question is similar to class Q2 - students calculate momentum from mass and velocity.
3. This question is similar to class Q4 - students calculate momentum from mass and velocity but without scaffolding.
4. This question is similar to class Q5 - students calculate momenta for use in Q5.
5. As in class Q6, students state which person is harder to stop and give a reason in terms of mass or velocity.
6. As in class Q8, students work out which animal or object is harder to stop.
7. As in class Q9, students work out a velocity from momentum and mass with support.
8. Students work out velocity from momentum and mass without support.
9. As in class Q11, students work out a mass from momentum and velocity with support.
10. Students write word equations linking momentum, mass and velocity.
11. Students need to use their working from class Q13 to write the equation for force in terms of momentum change and time. Given that the momentum change is the force needed to make the change in 1s, and that half the force would require twice the time, the force = momentum change / time taken.
12. Here a student works out the momentum of a tram passenger (75 kg x 6 m/s = 450 kg m/s). The force needed to stop them in one second will be 450N. The force needed to stop them in two seconds is half of this.
13. This question involves more than one force (just like class q5).
14. As in class q6, the students calculate the force needed to stop a van in different amounts of time.
15. This question is similar to the previous one, except that the race car is speeding up (compared to the van slowing down). The idea is the same. The momentum (800 kg x 125 m/s = 1000 000 kg m/s) means that the car would need a 1000 000N force to speed it up in one second. Actually it takes 6s, so the force will be 6 times smaller. The answer should be rounded to a suitable level (we would suggest 2 significant figures, but the website will allow other rounded answers too).
16. In this question, the student multiplies force by time to get the momentum change (3N x 0.12s gives 0.36 kg m/s of momentum to the dart). The speed is then calculated by dividing this momentum by the dart's mass.
17. In this question, the momentum of the tanker ship is calculated (40 000 000kg x 8.5 m/s). This number is then divided by the force of 4000 000N to find out how much time it will take for the force to stop the ship.

Extension questions from 'Step Up to GCSE Physics':
https://isaacphysics.org/gameboards#step_up_phys_13_b1
https://isaacphysics.org/gameboards#step_up_phys_14_b1
https://isaacphysics.org/gameboards#step_up_phys_15_b1