WORKSHEET ON CATHODE RAY TUBES, OSCILLOSCOPES & CHARGED PARTICLES IN ELECTRIC & MAGNETIC FIELDS

1. **Explain why the cathode ray beam in the diagram below broadens along its path.**
2. **Deduce the sign of the charge on the cathode rays from the deflection of the rays shown in the following diagram.**
3. **If a very high voltage is applied across the ends of a Geissler tube and the air pressure inside the tube is gradually decreased, a pinkish/purplish glow appears in the tube and then this glow breaks up into a series of bright and dark bands called striations. See the diagram below.**

	1. **Account for the glow observed in the tube.**
	2. **Explain why striations appear.**
4. **Identify three properties of cathode rays.**
5. **An electron travelling at 3 m/s passes between the poles of a magnet as shown below.** 

**If the magnetic flux density is 0.5 T, determine the magnitude and direction of the force on the electron. Charge on electron = - 1.6 x 10-19 C.**
6. **Define the term “crossed fields” as it is usually applied in Physics.**
7. **A charged particle moves in a straight line through a region of space. Does this necessarily imply that there is no magnetic field present?**
8. **A boy stands in front of the screen of an old black and white television set while there is a picture on the screen. He places a bar magnet on top of the TV set so that the magnetic field is directed down the front of the screen. Describe what you would expect to happen to the picture on the screen. Explain this effect.**
9. **The diagram below shows an oscilloscope trace.** 

	1. **To which deflection plates (the x or y) is the time-base voltage applied in an oscilloscope?**
	2. **Determine the frequency of the voltage waveform being displayed.**
	3. **State the maximum positive voltage of the waveform.**
10. **A potential difference of 5000 V is applied to two parallel metal plates separated by a distance of 10 cm as shown in the following diagram.** 

	1. **Calculate the intensity of the electric field between the plates.**
	2. **Determine the size of the force on a charge of +2 C placed in the field.**
11. **Study the following situation.**

**A uniform electric field of strength 200 N/C exists between two charged parallel plates each of which is 0.1 m long. The separation between the plates is 0.1 m. An electron with a speed of 3 x 106 m/s enters the field perpendicular to the field lines.**
	1. **Calculate the acceleration of the electron whilst between the plates. Ignore the effects of gravity. Mass of electron = 9.11 x 10-31 kg.**
	2. **Determine the time the electron spends between the plates.**
	3. **Calculate the distance the electron moves vertically between the plates.**
12. **An antimatter electron, a positron, starts at rest in an electric field of strength 100 N/C. If the charge on the positron is +1.6 x 10-19 C and its mass is 9.11 x 10-31 kg, calculate its velocity after 50 ns. Remember 1 ns (nanosecond) = 1 x 10-9 s.**
13. **An electron enters a magnetic field of flux density 1 T with a velocity of 1 x 106 m/s at an angle of 45o to the field lines as shown below.**

**Determine the magnitude and direction of the force acting on the electron in the field.**
14. **At a particular instant, an electron is travelling in a vacuum at 2.4 x 104 ms-1, perpendicular to a uniform magnetic field of 5.20 mT, out of the page, as shown below.** 

**The electron is experiencing a magnetic force causing it to move into a uniform circular path.**
	1. **In which direction is the electron experiencing the magnetic force?**
	2. **What is the radius of the circular path followed by the electron?**
	3. **Explain why, even though the electron is in a vacuum, it will slowly lose energy as it moves in the circular path.**
15. **A simplified diagram of J J Thomson’s famous cathode ray tube is shown below.**

	1. **A high voltage power supply must be placed between P and Q. State whether P should be attached to the positive or negative terminal. Justify your answer.**
	2. **State why it is necessary to seal the glass tube in this experiment.**
	3. **Explain the purpose and importance of the Helmholtz coils at R.**
	4. **Outline the purpose of the tape measure at J.**
	5. **Identify two useful devices that were derived from this apparatus.**
16. **Briefly describe how Thomson measured the charge to mass ratio of the electron.**
17. **Derive Thomson’s expression for the charge to mass ratio of the electron:

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**ANSWERS TO WORKSHEET ON CATHODE RAY TUBES, OSCILLOSCOPES & CHARGED PARTICLES IN ELECTRIC & MAGNETIC FIELDS**

1. **Due to the Coulomb repulsive forces experienced by each electron in the beam due to the presence of other electrons.**
2. **Charge is negative by Fleming’s Left Hand Rule (or equivalent hand rule). For Fleming’s LHR, thumb of left hand points down in the observed direction of the force on the charges, index finger points into page in direction of magnetic field and therefore the second finger points to the left showing the direction of conventional current (positive charge) flow. Therefore, since the cathode ray beam moves to the right, it seems that it consists of negative charges.**
3. **(a) The glow in the tube is partly produced by light emitted from gas molecules and atoms when electrons within them de-excite by dropping back from high energy levels to lower levels. The glow is also partly due to the recombination of electrons and positive ions that occurs during collisions of these particles. The electrons are captured by the ions and de-excite by emitting light energy.

(b) Striations are caused by alternate ionizations and recombinations in the tube. The dark bands are positions where ionizations are occurring mainly due to collisions between ions and neutral atoms and molecules. The gas atoms and molecules absorb energy, which results in the excitation of electrons within them and in many cases the ionization of the atoms and molecules. Thus, no light is emitted. The bright bands are places where light is being emitted, either by the de-excitation of electrons during recombination with positive ions or by the de-excitation of electrons within excited atoms and molecules. (Note that the physics of gas discharge tubes is quite complex and that much more could be said here. However, it is probably true to say that for our present Syllabus the first sentence of this answer is sufficient to answer question 3 (b).**
4. **Any three of the following:**
	1. **They are always the same regardless of which metal is used as the cathode.**
	2. **Travel in straight lines perpendicular to the surface emitting them.**
	3. **Are deflected by magnetic fields as if they were negatively charged particles.**
	4. **Are deflected by electric fields.**
	5. **Cause glass to fluoresce.**
	6. **Carry energy and momentum.**
	7. **Produce some chemical reactions similar to the reactions produced by light – some silver salts change colour when struck by cathode rays.**
5. **From F = qvB, F = 2.4 x 10-19 N. Direction = up out of page (by Fleming’s LHR).**
6. **The term “crossed fields” refers to electric and magnetic fields at right angles to each other.**
7. **No. There may be a magnetic field present and the charge is travelling parallel to or anti-parallel to the direction of the field. Such a charge would experience no force due to the field. The other alternative is that the charge could be travelling in an area of crossed electric and magnetic fields, where the net force on the charge is zero.**
8. **The picture would be distorted because the electrons travelling to the screen would experience an extra force as they passed through the magnetic field of the bar magnet. This force would be to the left of the screen as seen by the boy standing in front of the screen and facing the screen. (WARNING: DO NOT experiment with this on your parents’ TV. External magnetic fields can change the settings of electronic components within the TV – eg colour settings – and also on occasions damage such components.)**
9. **(a) The time-base is applied to the X-deflection plates (the plates that are arranged vertically within the oscilloscope).

(b) From the trace, the period = 3.9 ms. Therefore, since the frequency is the reciprocal of the period, frequency = 256.4 Hz.

(c) 3.5 V or 3.6 V – either answer will do.**
10. **(a) From E = V/d, E = 50 000 V/m. (b) From F = qE, F = 100 000 N.**
11. **(a) Use F = qE to calculate the force on the electron and then use a = F/m to determine the acceleration. a = 3.51 x 1013 ms-2, up towards positive plate. Note also, some people worry as soon as they get an acceleration greater than 3 x 108 ms-2. Please don’t! Velocity and acceleration are different quantities. Although, according to Special Relativity Theory it is not possible for any physical object in the universe to exceed the speed of light (3 x 108ms-1), it is absolutely fine to have an acceleration whose magnitude is greater than 3 x 108 ms-2. You simply need to appreciate that no matter how long you apply the force that is producing such an acceleration, you can never exceed the velocity of light.

(b) Realise that there is no acceleration acting horizontally. The force on the electron due to the electric field is vertical in direction. So, the horizontal distance through the plates is 0.1 m and the speed of the electron is 3 x 106 ms-1. Use time = distance/speed and therefore, time = 3.33 x 10-8 s.

(c) Apply s = ut + 0.5at2 vertically. The electron has no initial vertical velocity and is between the plates for 3.33 x 10-8 s. The acceleration is as calculated in part (a) and so the distance moved vertically by the electron is 0.019 m or 1.9 cm.**
12. **Use the same method as in 11 (a) to determine the acceleration of the positron. Then apply v = u + at to obtain v = 8.8 x 105 ms-1 in the direction of the electric field.**
13. **Use F = q v B sin  to obtain F = 1.13 x 10-13 N, up out of page.**
14. **(a) Up the page (by Fleming’s LHR).

(b) The force on the electron due to the magnetic field is causing the electron to execute circular motion in the field. So this force can also be described by the centripetal force formula. Use mv2/r = qvB to obtain r = 2.63 x 10-5 m or 26.3 m.

(c) The electron is executing circular motion. It is therefore accelerating. Maxwell’s Theory of Electromagnetism tells us that an accelerating electric charge produces a changing electric field, which in turn produces a changing magnetic field, which in turn produces another changing electric field and so on. In short, the electron loses energy by emitting it as electromagnetic radiation.**
15. **(a) P must be attached to the negative terminal of the high voltage supply. P must be made the cathode so that electrons produced by ionisation of gas molecules due to the strong electric field between the cathode and anode (Q) can be accelerated down the tube in the direction from P to Q.

(b) The glass tube must be sealed so that it can be evacuated to low gas pressure thereby ensuring a relatively free path for the cathode rays (electrons) to travel all the way down to the other end of the tube.

(c) These coils produce a magnetic field transverse to the path of the cathode rays thereby allowing the experimenter to apply vertical magnetic forces to the cathode ray beam. This was an essential feature of Thomson’s experiment. He applied the magnetic field to the cathode rays, which caused them to move in a circular path as they passed through the field. By writing the force acting on the cathode rays as both a magnetic force and a centripetal force, he was able to derive a mathematical equation for the charge to mass ratio of the electron. He also noted the position of the beam on the end of the tube. From this the radius of curvature of the cathode rays in the field could be determined. Thomson then balanced this downwards magnetic force on the cathode rays with an upwards force produced by the electric field between the charged plates. This enabled him to determine the velocity of the cathode rays through the tube and then to calculate the charge to mass ratio of the electron from the equation for this that he had derived.

(d) The tape measure at J allowed Thomson to measure how far the cathode ray beam was displaced on the end of the tube when the magnetic field was turned on. This was then used to calculate the radius of curvature of the cathode rays in the magnetic field.

(e) The cathode ray oscilloscope and the television. (There are plenty of others.)**

**For answers to 16 & 17 – see your notes.**