Section B: Answer ALL questions. ~~**Parts marked with * involve knowledge of the extension component.**~~ **Write your answers in the spaces provided.**

1. (5 points) A student tries to find the thermal properties of a fluid with the following setup in figure 1.

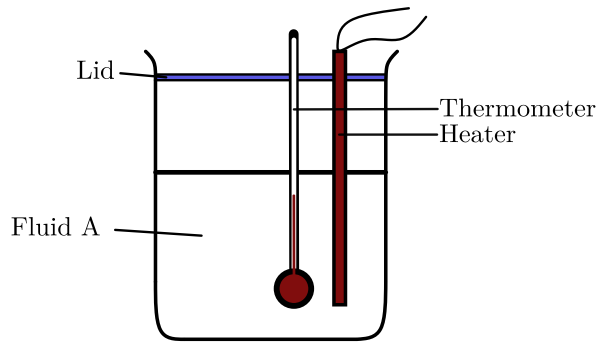

Figure 1: Experimental setup

(a) (2 points) The heater was switched on for 10 minutes, and the initial and final temperatures were recorded. Find the specific heat capacity for the liquid. You are given the following information:

- Initial temperature, $T_i = 25\,^{\circ}\mathrm{C}$.
- Final temperature, $T_f = 57\,^{\circ}\mathrm{C}$.
- Power of the heater, $P_H = 140\,\mathrm{W}$.
- Mass of fluid, $m = 1.5\,\mathrm{kg}$

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(b) (1 point) The student now wants to estimate the fluid's latent heat of vaporisation. To do so, the student wants to measure the decrease in mass in the liquid as the heater is turned on while the fluid is at its boiling point. Except for placing a mass balance at the bottom of the setup, name another procedure the student needs to do.

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(c) (2 points) The given value for the liquid's specific latent heat of vaporisation is $3.5{\cdot}10^5\mathrm{J\ Kg^{-1}}$. Assuming the power of the heat is the same as before. Estimate the rate of decrease in the mass of the fluid.

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2. (7 points) A car and a truck approach an intersection. As both drivers were driving under the influence of alcohol, they both run the red light and are about to crash. The situation is depicted in figure 2

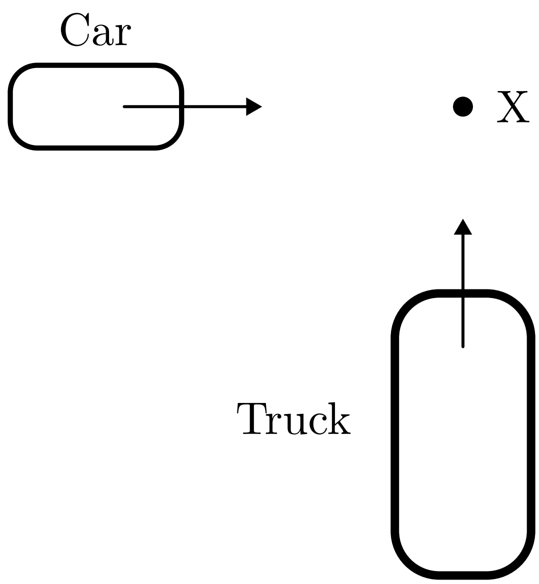

Figure 2: Car crash

(a) (4 points) The cars are set to crash at point X. The car weighs 1200 Kg and travels to the right at a speed of 14 $\mathrm{m\,s^{-1}}$. The truck has a mass of 2800 kg and is traveling upwards at 8 $\mathrm{m\,s^{-1}}$. The two vehicles stick together after the collision. Find the resulting **velocity** of the two cars.

(b) (2 points) Determine the amount of kinetic energy lost during the collision.

(c) (1 point) List one reason why kinetic energy is not conserved during the collision.

3. (6 points) A central pole (circle) is connected to an outer mass (hexagon) with a spring, as shown in figure 3.

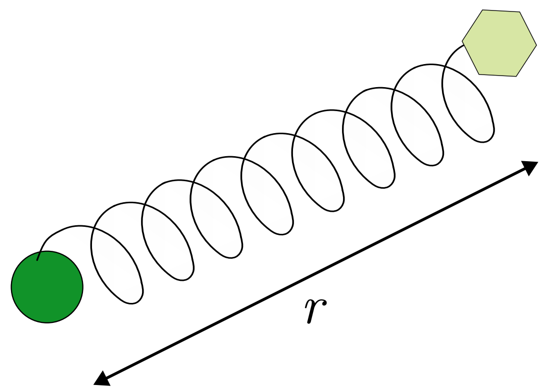

Figure 3: Mass connected to spring

(a) (2 points) A spring has a force with magnitude given by:

$$F = k(r - r_0)$$

where r_0 is the natural length of the spring, k is a constant and the direction of the force opposes the extension or compression of the spring. (e.g. The spring force pulls inward when the spring is stretched). Find the angular speed of the object in terms of rotation distance r, r_0 and k. You may assume the object undergoes uniform circular motion.

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(b) (1 point) What is the minimum length of r for the object to be able to rotate around the pole?

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(c) (1 point) Under what circumstances will the angular velocity no longer be dependent on the rotation radius?

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(d) (2 points) Virial Theorem states:

For an object subject to a force $F \propto r^n$, its kinetic energy K and potential energy U are related by:

$$K = \frac{n+1}{2}U$$

Taking $r_0 = 0$, find the potential energy of a spring system at some rotation radius r.

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4. (6 points) A student investigates the phenomenon of diffraction for waves.

   (a) (1 point) Sketch the waveform and crests of a water wave as it passes through a small slit in figure 4

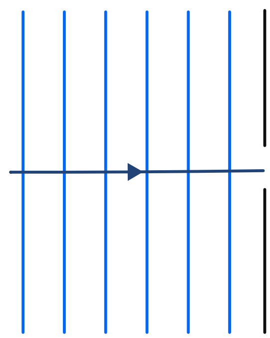

Figure 4: Water wave passing through a small slit

The student then uses a diffraction grating with 500 lines per mm in figure 5 to find the wavelength of a monochromatic light source. He uses a screen with rulings on it.

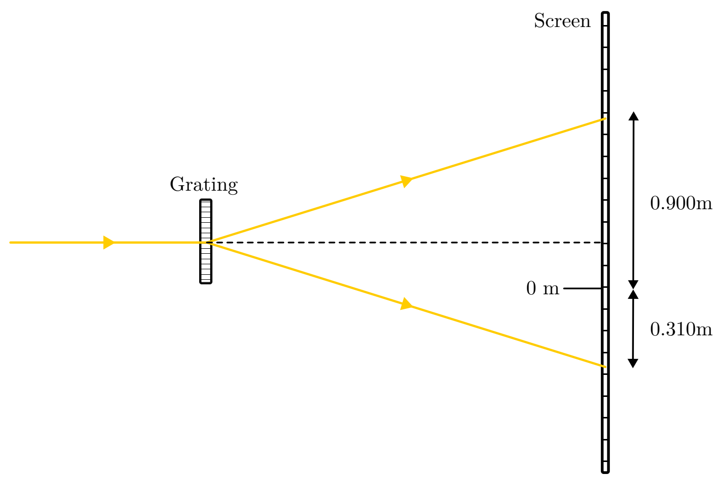

Figure 5: Diffraction grating setup

   (b) (3 points) However, he sets up the screen incorrectly and the 0m marking of the screen is off center, as seen in figure 5. He still measures the two first order maximums with the off-centered rulings. Find the wavelength of the monochromatic light source given that the grating-screen distance is 2 m

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The student once again modifies the setup to find the wavelength of an audible sound wave. The new setup is shown in figure 6.

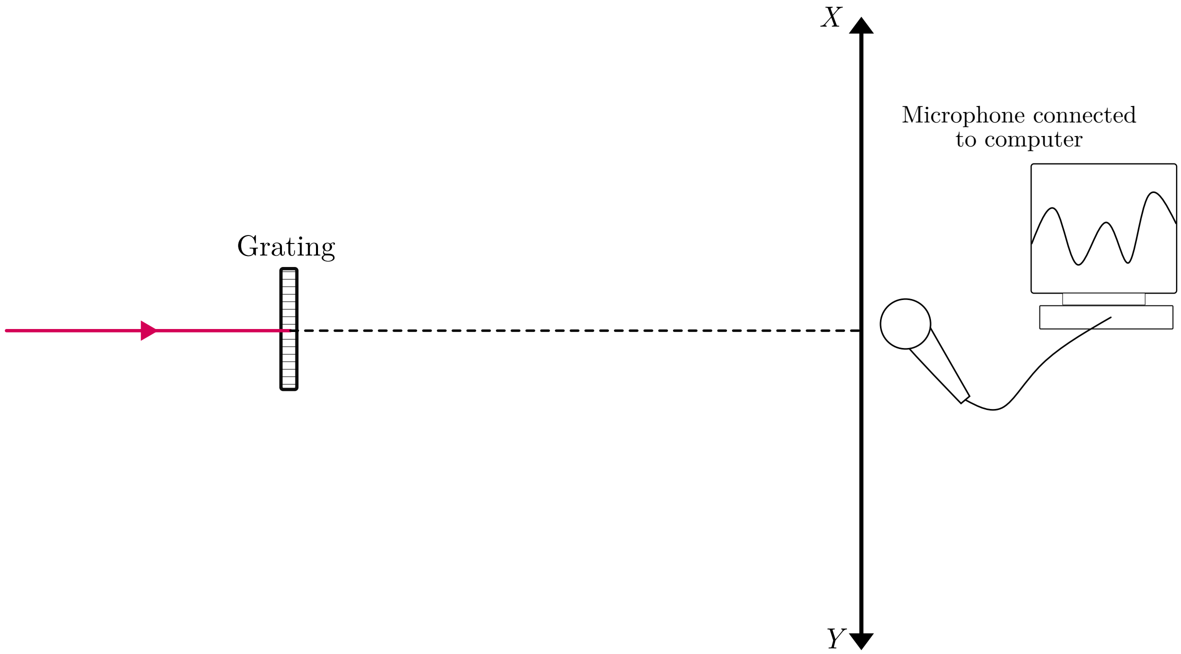

Figure 6: Diffraction grating setup for sound waves

(c) (2 points) Audible sound waves have wavelengths of around 0.01 m to 1 m. The student moves on the line XY, which is still 2 m away from the grating. The grating used is the same as that in part (b). Why is the student unable to find the wavelength with the above setup?

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5. (7 points) Read the following article on thin film interference and answer the questions.

> Sunlight that reflects off a thin film of oil floating on a puddle of water will exhibit thin film interference in an interesting manner which causes destructive interference for light of a certain wavelength.
>
> A critical reason behind this is that waves which reflect off new media can possibly experience a phase shift of π if they reflect off a medium in which the wave moves more slowly. As the phase difference between the two waves is the only factor that determines whether or not there is destructive interference, knowing whether or not each reflected wave has changed its phase by π is critical.
>
> A practical application of this effect are anti-glare films. When light strikes a thin film with air on both sides, if the film allows for no light to be reflected (i.e. all the reflected light destructively interferes), then conservation of energy requires that all of the light passes through the film to the other side.
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We now investigate the thin film interference phenomenon for sunglasses. A simplified diagram of thin film interference in shown in figure 7.

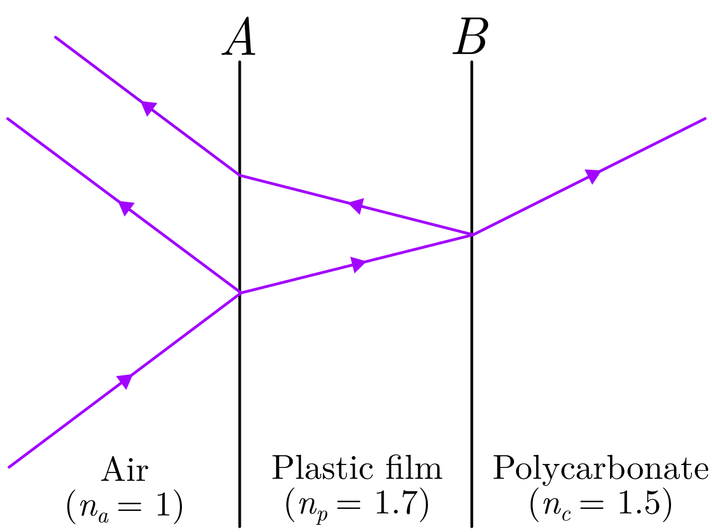

Figure 7: Thin film interference in sunglasses

(a) (1 point) On which boundary(ies) (A and/or B) will the reflected wave undergo a π phase shift?

Suppose the plastic film has a small thickness d, the optical path in the y-direction (vertically in figure 7) is negligible. Under this approximation, we sketch a new diagram, figure 8.

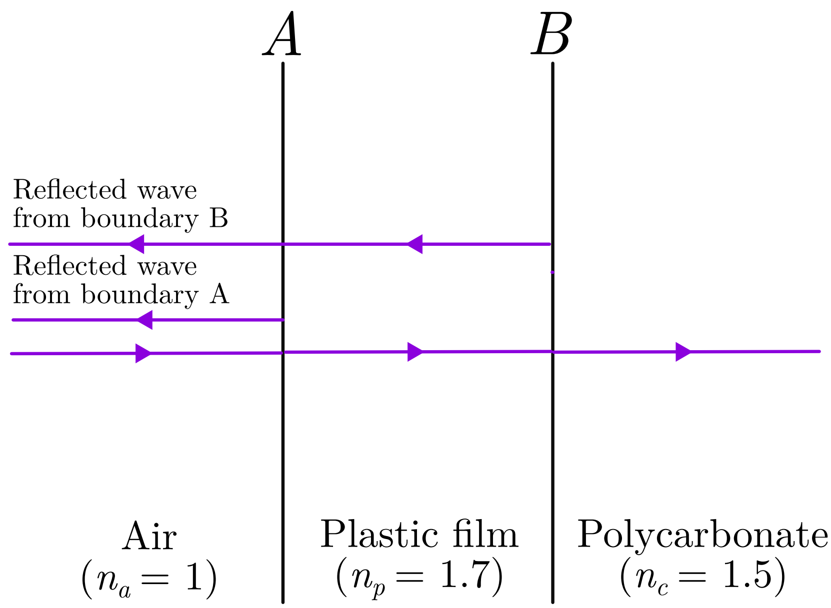

Figure 8: Approximated Thin film interference

(b) (2 points) Find the phase difference of the two reflected waves in terms of n_p and d

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(c) (2 points) Sunglasses mainly prevent violet light from passing through with their plastic coatings, find the thinnest coating thickness that can be used to block out light with a wavelength of 420 nm. This can show that our approximation is appropriate.

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(d) (2 points) We want to fully transmit green light across the boundaries, what would be the thinnest thickness of the film? In practice, this is used for anti-reflective coatings.

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6. (4 points) A charged oil droplet is held stationary inside an electric field set up by two parallel plates connected to a DC power source.

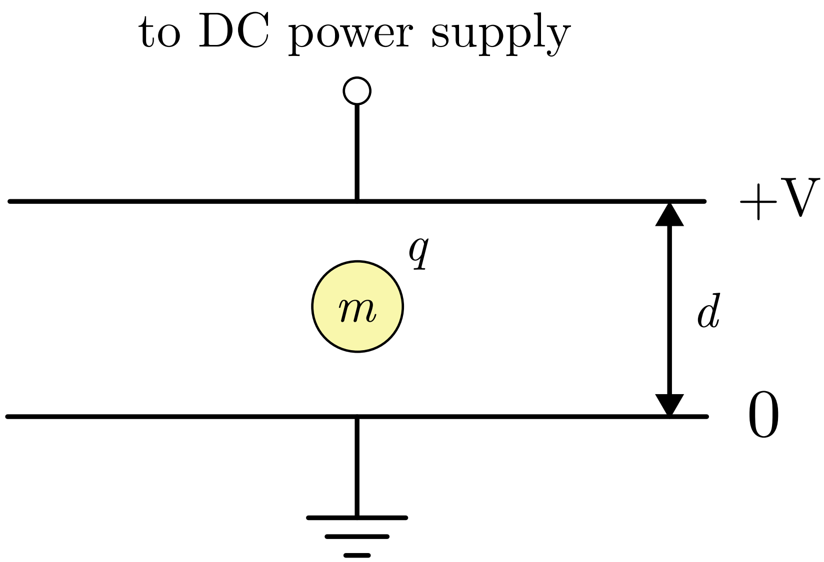

Figure 9: Charged oil drop held between parallel plates

(a) (2 points) Suppose the plates are at a distance $d = 0.10$m apart, with a potential $V = 22.0$V set across them. Find the charge to mass ratio of the oil droplet, include a unit for your answer and state the polarity of the charge.

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(b) (2 points) Can the oil droplet be held stationary in the same way with a magnetic field. If so, indicate the direction of the field. If not, explain why.

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7. (7 points) A technician tries to find the relationship between temperature and the unknown resistance (R_T) of a thermistor T. He uses the setup in figure 10

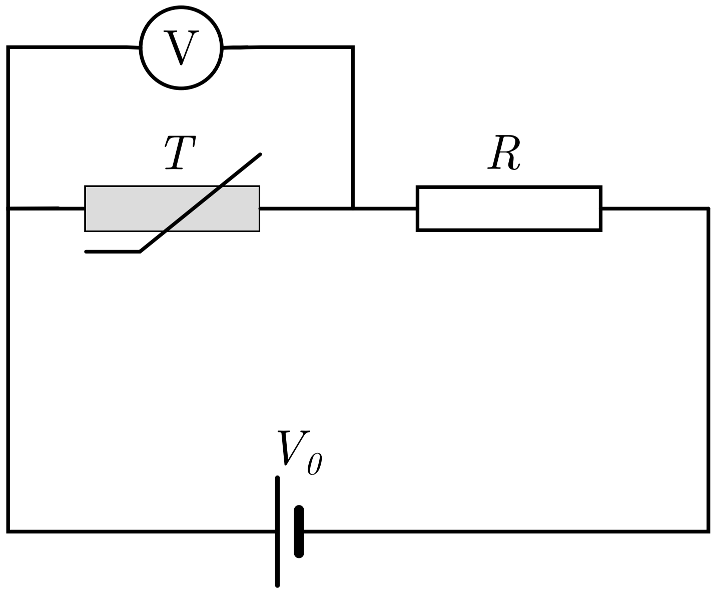

Figure 10: Circuit with thermistor T

(a) (1 point) In view of laboratory safety, why is the resistor R connected?

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(b) (2 points) At room temperature (298 K) the technician measures a potential difference of 8 V across thermistor T. Given that $R = 1\text{k}\Omega$, $V_0 = 12\text{V}$, find the resistance R_T of the thermistor at room temperature.

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(c) (3 points) A thermistor has a temperature value given by the following formula:

$$R_T = Ce^{\frac{\beta}{T_a}}$$

C and β are constants, while T_a is the temperature of the thermistor (in Kelvins).
The technician performs the experiment again, but this time with an ice pack attached to the thermistor such that its temperature drops to 15 °C. He measures a resistance of 3600 Ω this time. Find the values of β and C.

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(d) (1 point) Explain why the current in the circuit increases after the circuit is turned on for a while.

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8. (6 points) You are provided with the following apparatus to investigate a radioactive source at your school.

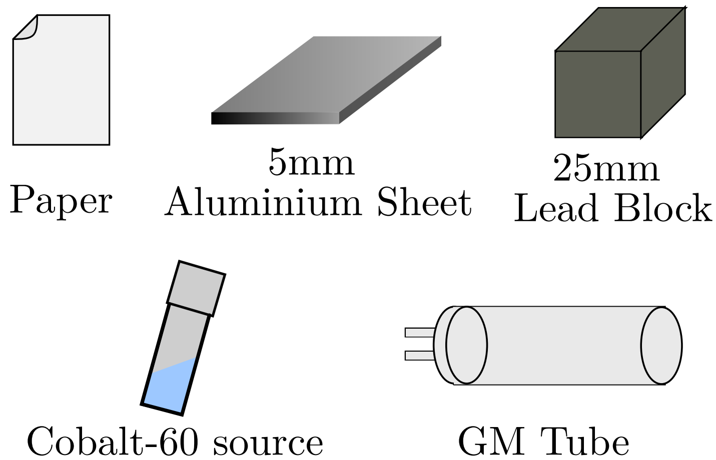

Figure 11: Investigating Cobalt-60 source

(a) (4 points) Outline a brief experiment to show that cobalt-60 only emits β-radiation and γ-radiation. Mention at least one experimental procedure to ensure accurate results.

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(b) (2 points) The source was determined to have an activity of 300 Bq. Given that the school records show the source had 420 Bq of activity 2.56 years ago, estimate the half life of cobalt-60.

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9. (8 points) The sun is primarily made up of hydrogen gas. Insider the sun's core, hydrogen undergoes fusion into helium gas.

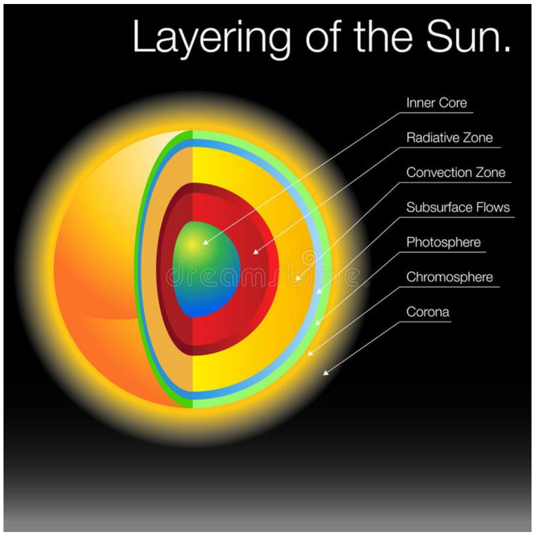

Figure 12: Anatomy of the sun

(a) (1 point) Why can we treat the hydrogen gas inside the sun as an ideal gas?

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(b) (3 points) The sun's core has a temperature of $15 \cdot 10^6$K and a density of $1.5 \cdot 10^5 \mathrm{kg\,m^{-3}}$. Estimate the gas pressure inside the sun's core. At such high temperatures, hydrogen becomes *plasma*, a gas of ions.

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(c) (1 point) Fill in the following equation for the fusion of hydrogen into helium.

$$^2_1\mathrm{H} +^3_1 \mathrm{H} \rightarrow \underline{\qquad\quad} +^4_2 \mathrm{He}$$

(d) (2 points) Later on in the Sun's life, it will consume all hydrogen and start to fuse helium into carbon. At this stage, the pressure of the sun is around 2000 times as before, while its volume is 1/600 times as before. Estimate the fusion temperature of helium.

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(e) (1 point) A student claims since the sun's core has decreased in size when it starts to fuse helium into carbon, the gravitational force on the Earth by the Sun will decrease in strength. Is he correct? Explain your answer.

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10. (11 points) A copper rod is connects two smooth conductive rails that are slanted at an angle θ to the surface. The circuit has a resistance R and a vertical magnetic field $\vec{B}$ passing through as shown in figure 13.

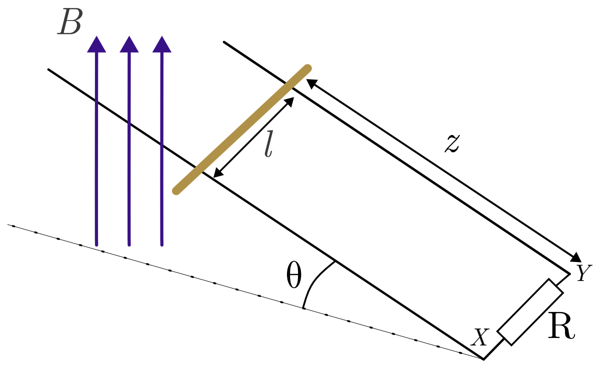

Figure 13: Experiment setup

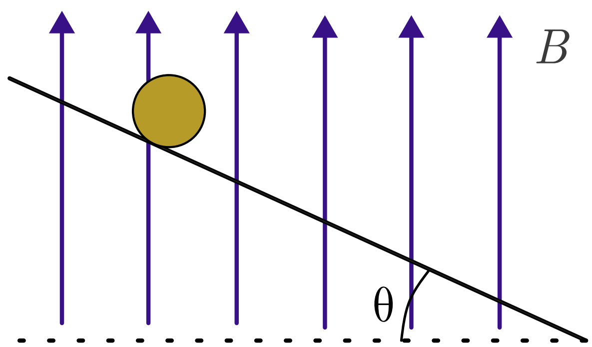

Figure 14: Experiment setup cross section

(a) (1 point) The copper rod is free to move along the rails. Assuming the copper rod was released from rest, state the direction of the induced current (from X to Y/ from Y to X)

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(b) (2 points) After the copper rod is released, explain, why after a while, the velocity of the rod becomes constant.

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(c) (1 point) Express the magnetic flux through the loop in terms of B, z, l, and θ.

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(d) (3 points) Indicate the forces acting on the rod on figure 14, find the magnitude of the terminal velocity of the rod. Assume the rod has a mass of m. Leave your answer in terms of all given parameters.

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(e) (2 points) Show that at terminal velocity, the current does not depend on the resistance of the resistor R.

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(f) (2 points) Further show that at terminal velocity, the rate of loss of gravitational potential energy of the rod is equal to the power dissipated in the resistor.

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11. (8 points) Object A is observed through an unknown lens. The thick horizontal line is the principal axis.

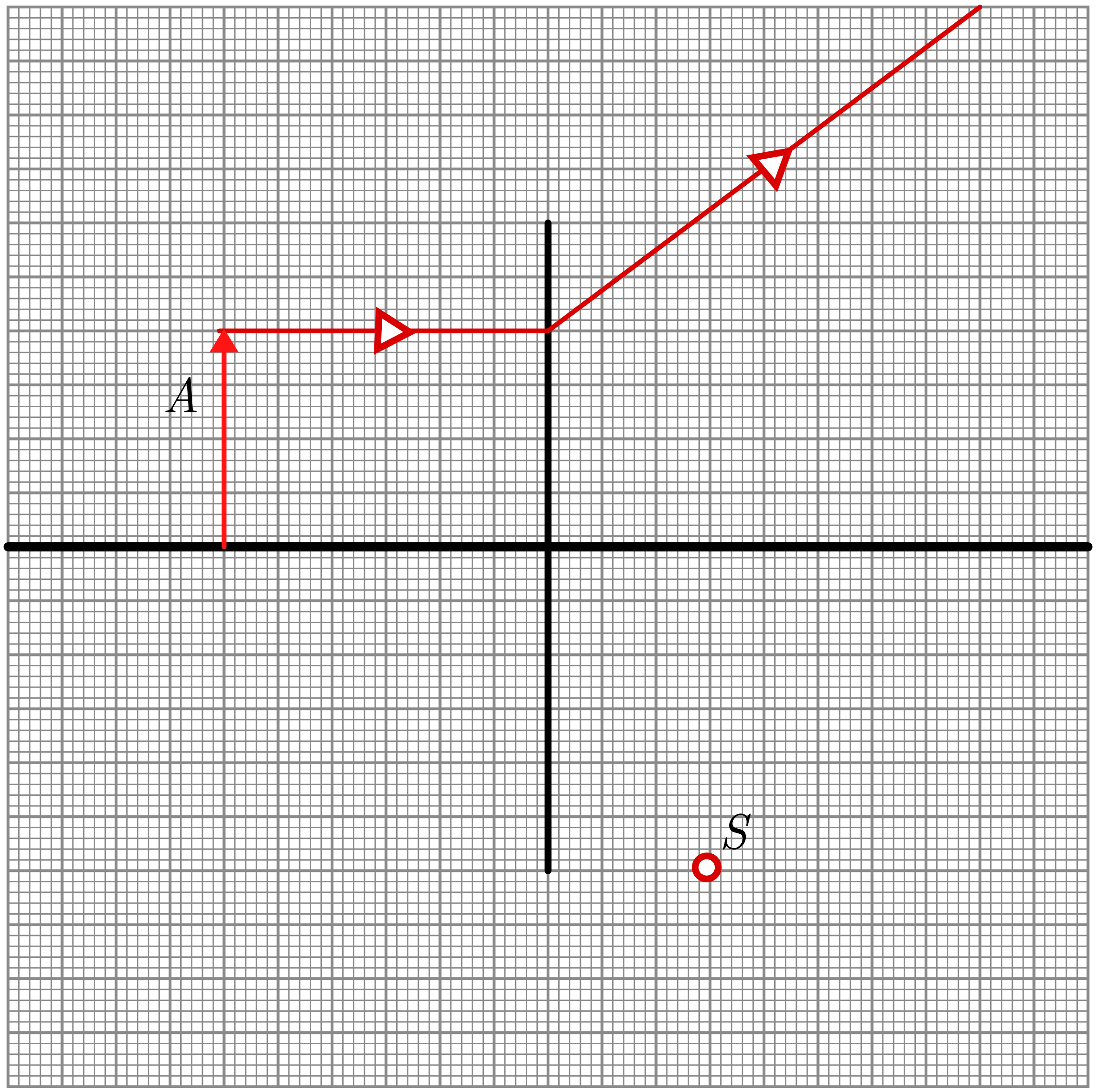

Figure 15: Object seen through a lens

(a) (1 point) Explain whether the lens is convex or concave.

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(b) i. (2 points) Find the image I for the object A by completing the ray diagram.

ii. (2 points) Draw a light ray to show how an observer (at S) can see the tip of the object A.

(c) (1 point) Given that one division is 5 cm in length, determine the focal length of the lens.

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(d) (2 points) Explain whether the magnification of the image increases or decreases as the object distance u is increased.

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12. (9 points) Mandy (at M) is throwing a ball to Nigel (at N), who is standing on a stage 2m tall. Mandy is at a horizontal distance of 10m away from the stage. The situation is shown in figure 16. Ignore all effects of air resistance.

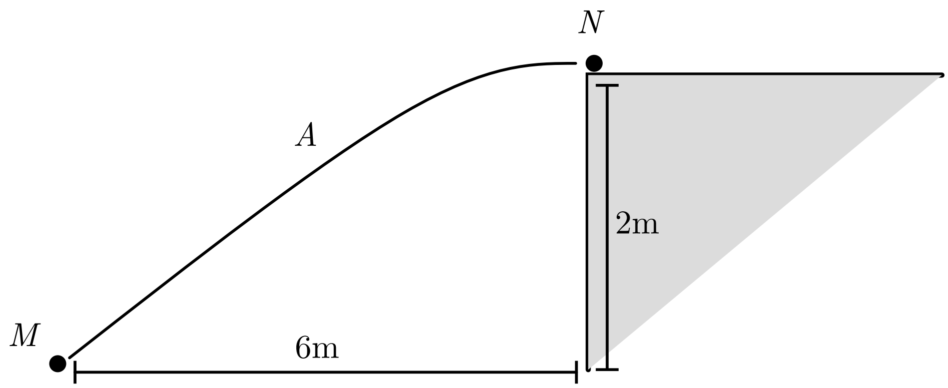

Figure 16: Mandy throws a ball

(a) (4 points) Mandy throws ball in a way such that it travels fully horizontally when Nigel catches it, see trajectory A in figure 16. Find the projection speed and angle of the ball.

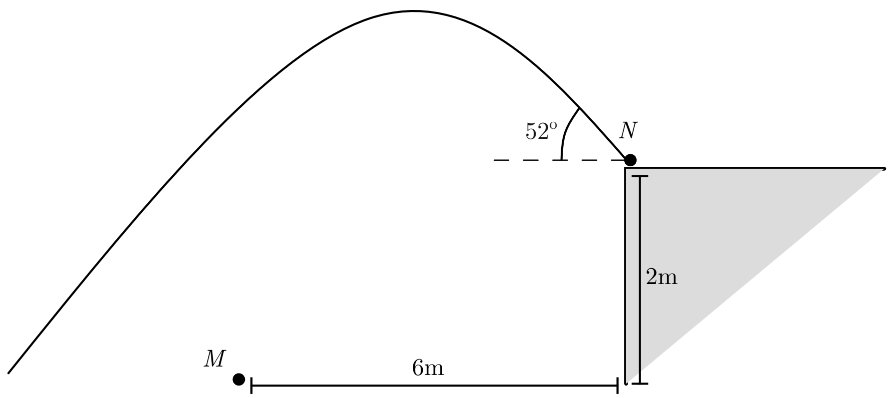

Figure 17: Nigel throws a ball

(b) Now, Nigel is throwing the ball at an angle of 52° above the horizontal at a speed of 10 $\mathrm{m\,s^{-1}}$.

i. (3 points) Mandy still stands at M, 6 m away from the stage. Mandy can run at 3 $\mathrm{m\,s^{-1}}$, will she be able to catch the ball. Assume the playground is large enough such that Mandy nor the ball collides with a wall.

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ii. (2 points) Now suppose Mandy stood in position to catch the ball initially. When the catches the ball, it takes her 0.2s to bring the ball to rest and the ball's mass is 0.4kg. Find the force acting on Mandy by the ball.

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END OF PAPER