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SUPERVISOR'S USE ONLY

SCHOLARSHIP EXEMPLAR

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

QUALIFY FOR THE FUTURE WORLD
KIA NOHO TAKATŪ KI TŌ ĀMUA AO!

Tick this box if you have NOT written in this booklet

Scholarship 2022
Physics

Time allowed: Three hours
Total score: 32

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should answer ALL the questions in this booklet.

For all 'describe' or 'explain' questions, the answers should be written or drawn clearly with all logic fully explained.

For all numerical answers, full working must be shown and the answer must be rounded to the correct number of significant figures and given with the correct SI unit.

Formulae you may find useful are given on page 3.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–20 in the correct order and that none of these pages is blank.

Do not write in any cross-hatched area. This area may be cut off when the booklet is marked.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

Question	Score
ONE	
TWO	
THREE	
FOUR	
TOTAL	

ASSESSOR'S USE ONLY

This page has been deliberately left blank.
The examination starts on page 4.

The formulae below may be of use to you.

$v_f = v_i + at$ $d = v_i t + \frac{1}{2}at^2$ $d = \frac{v_i + v_f}{2}t$ $v_f^2 = v_i^2 + 2ad$ $F_g = \frac{GMm}{r^2}$ $F_c = \frac{mv^2}{r}$ $\Delta p = F\Delta t$ $\omega = 2\pi f$ $d = r\theta$ $v = r\omega$ $a = r\alpha$ $W = Fd$ $F_{net} = ma$ $p = mv$ $x_{COM} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$ $\omega = \frac{\Delta\theta}{\Delta t}$ $\alpha = \frac{\Delta\omega}{\Delta t}$ $L = I\omega$ $L = mvr$ $\tau = I\alpha$ $\tau = Fr$ $E_{K(ROT)} = \frac{1}{2}I\omega^2$ $E_{K(LIN)} = \frac{1}{2}mv^2$ $\Delta E_p = mg\Delta h$ $\omega_f = \omega_i + \alpha t$ $\omega_f^2 = \omega_i^2 + 2\alpha\theta$ $\theta = \frac{(\omega_i + \omega_f)}{2}t$ $\theta = \omega_i t + \frac{1}{2}\alpha t^2$	$T = 2\pi\sqrt{\frac{l}{g}}$ $T = 2\pi\sqrt{\frac{m}{k}}$ $E_p = \frac{1}{2}ky^2$ $F = -ky$ $a = -\omega^2 y$ $y = A\sin\omega t$ $\quad y = A\cos\omega t$ $v = A\omega\cos\omega t$ $\quad v = -A\omega\sin\omega t$ $a = -A\omega^2\sin\omega t$ $\quad a = -A\omega^2\cos\omega t$ $\Delta E = Vq$ $P = VI$ $V = Ed$ $Q = CV$ $C_T = C_1 + C_2$ $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$ $E = \frac{1}{2}QV$ $C = \frac{\varepsilon_0 \varepsilon_r A}{d}$ $\tau = RC$ $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ $R_T = R_1 + R_2$ $V = IR$	$F = BIL$ $V = BvL$ $\phi = BA$ $\varepsilon = -\frac{\Delta\phi}{\Delta t}$ $\varepsilon = -L\frac{\Delta I}{\Delta t}$ $\frac{N_p}{N_s} = \frac{V_p}{V_s}$ $E = \frac{1}{2}LI^2$ $\tau = \frac{L}{R}$ $I = I_{MAX}\sin\omega t$ $V = V_{MAX}\sin\omega t$ $I_{MAX} = \sqrt{2}I_{rms}$ $V_{MAX} = \sqrt{2}V_{rms}$ $X_C = \frac{1}{\omega C}$ $X_L = \omega L$ $V = IZ$ $f_0 = \frac{1}{2\pi\sqrt{LC}}$ $v = f\lambda$ $f = \frac{1}{T}$ $n\lambda = \frac{dx}{L}$ $n\lambda = d\sin\theta$ $f' = f\frac{V_W}{V_W \pm V_S}$ $E = hf$ $hf = \phi + E_K$ $E = \Delta mc^2$ $\frac{1}{\lambda} = R\left(\frac{1}{S^2} - \frac{1}{L^2}\right)$ $E_n = -\frac{hcR}{n^2}$

QUESTION ONE: PHOTONS

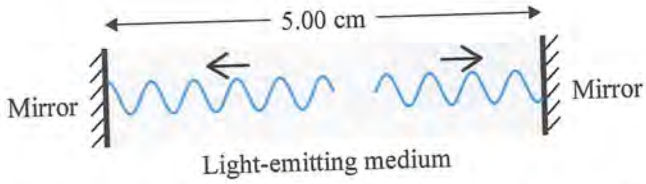
Radius of Earth	$= 6.37 \times 10^{6}$ m	Mean Earth-Sun distance	$= 1.50 \times 10^{11}$ m
Mass of Earth	$= 5.98 \times 10^{24}$ kg	Mass of Sun	$= 1.99 \times 10^{30}$ kg
Speed of light	$= 3.00 \times 10^{8}$ m s^{-1}	Planck's constant	$= 6.63 \times 10^{-34}$ J s
Surface area of a sphere	$= 4\pi r^2$		

(a) The description of the photoelectric effect and the Bohr model of the atom both involve the concept of the quantisation of energy. There are similarities and differences in how this concept is applied in these contexts.

Describe ONE difference in the use of the concept of the quantisation of energy between the photoelectric effect and the Bohr model of the atom. (wavelength of light)

Both concepts involve absorption of specific energy by an electron to be excited to a certain energy level. All electrons in same subshell occupies the same energy level in Bohr model whereas electrons from different atoms have distinct energy level in photoelectric effect even if they occupy same subshell.

4 (b) A laser typically consists of a medium that emits light placed between two mirrors that form a cavity, as illustrated on the right. The cavity is similar to a closed box for the emitted light waves.



The light-emitting medium can emit a continuous spectrum of light within a narrow range of wavelengths. The minimum wavelength of emitted light is 480 nm (4.80×10^{-7} m), and the maximum wavelength is 490 nm (4.90×10^{-7} m). The cavity is 5.00 cm long.

Some wavelengths within this range are able to form standing waves within the cavity. These are called standing wave modes.

Calculate the total number of standing wave modes possible in the cavity within the emitted 480–490 nm range.

path difference between emitted & reflected wavelength has to be n.

5×10^{-2} m $\quad \frac{5 \times 10^{-2}}{\lambda \times 10^{-7}} \Rightarrow$ ~~[illegible]~~ rational number.

480nm / 485nm / 490nm

$\hookrightarrow$ 3 standing waves will form.

(c) The process of nuclear fusion in the Sun releases energy which spreads through space in the form of electromagnetic radiation. The photons that make up this radiation carry momentum as well as energy, with the momentum per photon given by:

$$p = \frac{h}{\lambda}$$

where h is Planck's constant, and λ is the photon wavelength.

The Sun loses 4.30×10^9 kg of mass each second due to nuclear reactions.

Estimate the force exerted on the Earth by the photons it receives from the Sun.

Assume each photon has a wavelength of 550 nm (5.50×10^{-7} m), and that every photon that reaches Earth is absorbed.

$E = mc^2 \qquad E = 4.30\times10^9 \times (3\times10^8)^2 = 3.87\times10^{26}$ J.

E of each photon $= \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^8}{5.5\times10^{-7}} = 3.62\times10^{-19}$ J.

number of photon $= \frac{3.87\times10^{26}}{3.62\times10^{-19}} = 1.069\times10^{45}$

number of photons reaching the earth $= 1.069\times10^{45} \times \frac{2(6.37\times10^6)^2\pi}{4(1.5\times10^{11})^2\pi}$

~~force~~ $P = \frac{6.63\times10^{-34}}{5.5\times10^{-7}} = 1.21\times10^{-27}$ | $= 9.64\times10^{35}\ s^{-1}$

$1.21\times10^{-27} \times 9.64\times10^{35} = 1.16\times10^9$ N

(d) (i) Comment on the significance of the size of the force exerted on the Earth by the photons.

$1.16\times10^9 = 5.98\times10^{24}\ v \qquad v = 1.94\times10^{-16}.$

absorption of force only creates a very small velocity so the force is not significant.

(ii) If the Earth were covered by ice it would be more reflective.

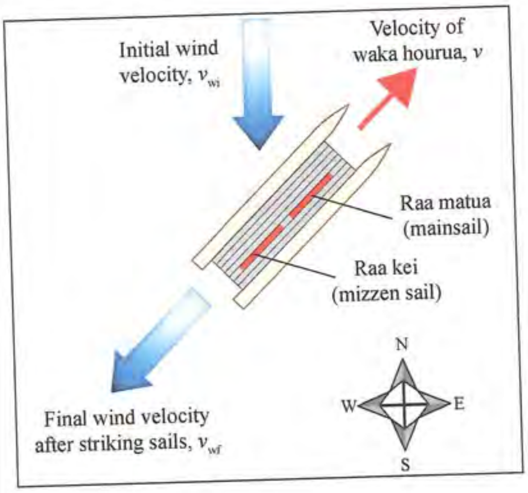
Explain how this would affect your answer to part (c).

Some photons will be reflected carrying some amount of energy and momentum.

The change in momentum is greater so the force exerted on the Earth will increase.

QUESTION TWO: WAKA HOURUA

The history of sailing in New Zealand goes right back to the original settlement by ancestors of Māori, more than 700 years ago. The ancestors, from Polynesia, designed double-hulled boats with triangular sails, called waka hourua, that were strong, stable, and most importantly, able to sail into the wind. This allowed them to carry out exploratory voyages. From such exploration, they were able to plan and carry out their migration to Aotearoa. Waka hourua are able to sail against the wind by heading at an angle to the wind, as shown in the simplified diagram below right.

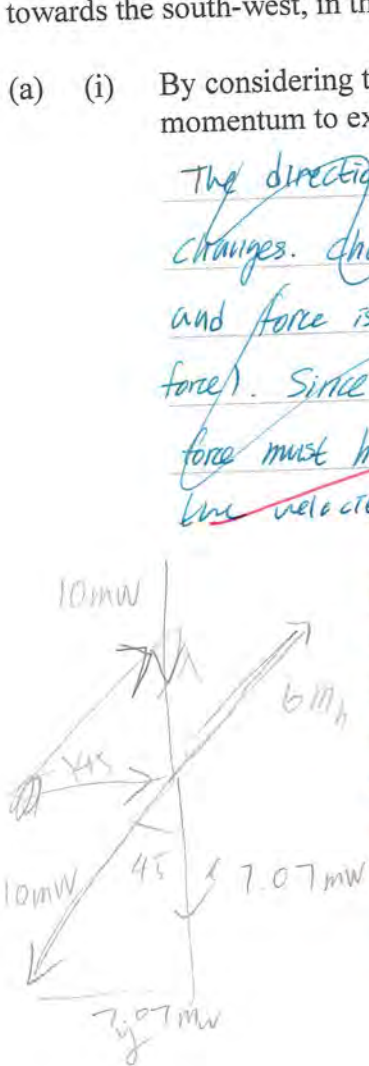


Adapted from: www.sciencelearn.org.nz/images/701-te-aurere

As measured by a stationary observer, the initial wind velocity is 10.0 m s^{-1} from the north, the velocity of the waka hourua is 6.00 m s^{-1} to the north-east, and the final wind velocity is 10.0 m s^{-1} towards the south-west, in the opposite direction to the velocity of the waka hourua.

(a) (i) By considering the wind direction before and after striking the sails, use impulse and momentum to explain how the wind produces a force on the sail.

The direction of the wind changes therefore the velocity changes. change in velocity means that momentum changes and force is exerted in the opposite direction (Equal and opposite force). Since the final ~~moment~~ velocity is towards south west force must have been exerted towards North East, the direction of the velocity of waka hourua.



change in wind direction is 45° from the south
let mass of wind as m_w and mass of boat as m_h
momentum of vertical component changes from $10m_w$ to 7.07mW. Momentum of horizontal component changes from 0 to 7.07mW. Impulse is change in momentum over time, so this will create a force in opposite direction. (North and east). due to the angle, 45° the components will add up to create a resultant force towards north east.

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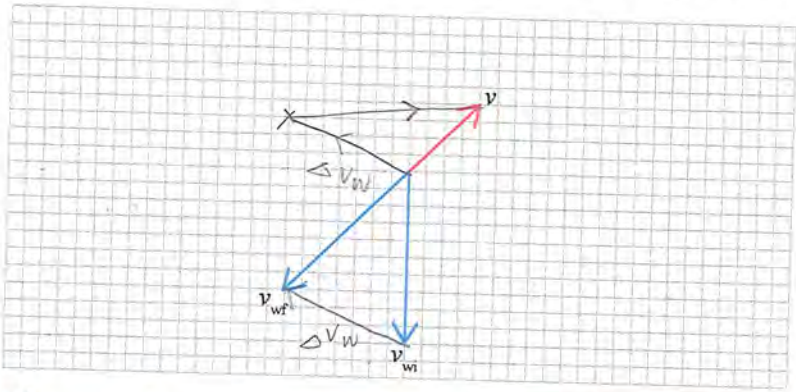
(ii) Explain how the wind produces a force on the waka hourua that has a component in the direction that the waka hourua is travelling.

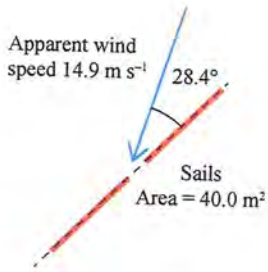
Use the grid below to draw a vector diagram to help your explanation. The vectors for the initial wind velocity v_{wi}, the final wind velocity v_{wf}, and the velocity v of the waka hourua are drawn on the grid to help you.
Start your answer by finding the vector for the change Δv_w in the velocity of the wind.



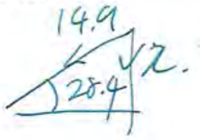
If you need to redraw your response, use the diagram on page 14.

ΔV_W adds both vertical and horizontal components to the velocity v
The wind will eventually push the boat both forward and towards the East.

(b) The motion of the waka hourua combined with the motion of the wind changes both the apparent speed and direction of the wind hitting the sails. On board the moving waka hourua, the wind appears to have a higher speed, and to come from a direction further towards the front of the waka hourua. The captain measures the wind velocity as 14.9 m s^{-1} that hits the sails at an angle of 28.4°, as shown in the diagram on the right. The sails have a combined area of 40.0 m^2. The density of air is 1.23 kg m^{-3}.



Calculate the mass of air that hits the sails each second.



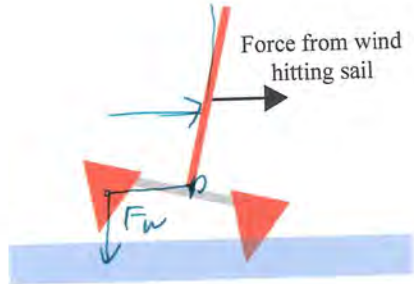
$x = \sin 28.4 \times 14.9 = 7.087 \text{ ms}^{-1}$.

$7.087 \times 40.0 = 283.5 \text{ m}^3 \text{ s}^{-1}$

$283.5 \times 1.23 = 348.7 \text{ kg s}^{-1}$

$\approx 349 \text{ kg s}^{-1}$ (3sf).

(c) The sideways force of the wind on the sails causes the waka hourua to tilt over sideways. In strong winds, the upwind side of the hiwi (hull) may lift out of the water altogether.



(i) Explain how the double-hulled design of the waka hourua helps it stay upright in strong winds.

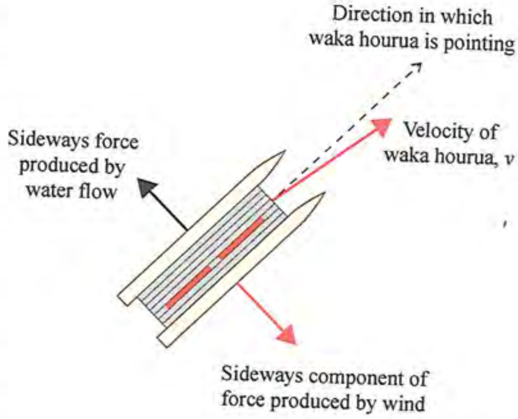
You may wish to add information to the diagram to illustrate your answer.

Heavy mass concentrated on both side of the waka will create a moment about the midpoint (torque) as ~~gravity~~ the weight force acts downwards. Up to a certain angle of tilt the waka will return to its equilibrium as torque constantly acts to balance the boat.

(ii) Explain how the tilting of the waka hourua will affect the force produced by the wind hitting the sails.

Assuming the wind is blowing horizontally the tilting of waka will make the wind stike the sail non- ~~per~~ perpendicularly. This will reduce the change in momentum as the wind will reflect off in an angle, reducing the force exerted on the sail. (This will make the balancing easier)

(d) Due to the sideways component of the force from the wind, the velocity of the waka hourua is in a slightly different direction to the direction that the hull is pointing. This slight difference in directions creates an asymmetrical flow of water around the sides of the hull, which produces a sideways force on the hull of the waka hourua, as shown in the diagram on the right.

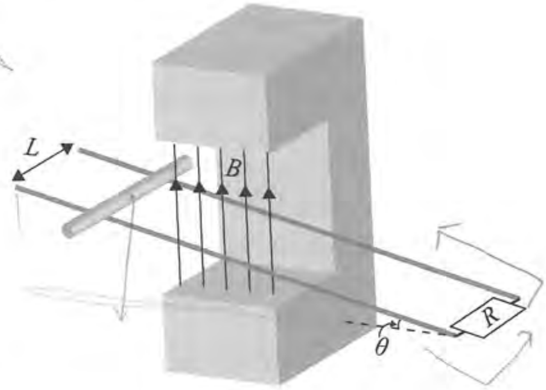


Explain the effect the sideways force produced by water flow around the hull will have on the direction of motion, and on the ability of the waka hourua to stay upright in strong winds.

Ignoring the push by water the sideways component of force produced by the wind will cause the boat to rotate. As the boat tilts the surface area for water to strike on the boat increases, exerting a force in opposite direction to the force exerted by the wind. This will reduce the effect of the boat rotating by cancelling out the force. If balanced correctly the boat will rotate ~~a~~ anticlockwise to reestablish the direction before.

QUESTION THREE: MAGNET SLIDER

Acceleration due to gravity = 9.81 m s^{-2}



A metal roller of mass m slides without friction down parallel conducting rails of negligible electrical resistance. The rails are separated by a distance L, and are connected to each other at the bottom by a resistance R, forming a closed rectangular conducting loop with the rails and the roller. The plane of the rails makes an angle θ with the horizontal, and a uniform vertical magnetic field B exists throughout the region.

As the metal roller slides down the rails through the magnetic field, it reaches a constant velocity v.

(a) (i) Show that the constant velocity achieved by the roller through the magnetic field is given by the relationship:

$$v = \frac{mgR\tan\theta}{B^2L^2\cos\theta} \qquad \textbf{Equation \#1}$$

$\boxed{\text{See Pg 14 and 15 :)}}$

~~$F_1 = mg\sin\theta$~~

~~$F_2 = \frac{BIL}{\cos\theta}$~~ ~~$V = BvL\cos\theta$~~

~~$I = \frac{V}{R}$~~ ~~so $IR = BvL\cos\theta \rightarrow I = \frac{BvL}{R}$~~

~~$F_2 = \frac{BvL}{R\cos\theta}$~~ ~~$F_2 = F_1$ as constant velocity reached~~

~~$mg\sin\theta = \frac{BIL}{\cos\theta}$~~ ~~$\frac{mg\sin\theta\cos\theta}{BL} = I$~~

~~$\frac{mg\sin\theta\cos\theta}{BL} = \frac{BvL\cos\theta}{R}$~~

~~$v = \frac{mgR\sin\theta}{B^2L^2}$~~

(ii) Explain what difference, if any, it makes to the constant velocity v, if the magnetic field is in the opposite direction.

Induced current will flow in opposite direction with the same magnitude as the rate of change in ~~number of~~ magnetic flux linkage ~~change~~ is equal.

Both directions of current and magnetic field is opposite so the resulting magnetic force will be equal in magnitude and direction.

The final velocity will therefore stay constant.

For small values of θ, Equation #1 may be approximated as:

$$v = \frac{mgR}{B^2L^2} \times \left(\theta + \frac{5\theta^3}{6}\right) \qquad 0.4905 \qquad \textbf{Equation \#2}$$

(b) An experiment is set up with $B = 2.00$ T, $L = 0.500$ m, $m = 5.00 \times 10^{-3}$ kg, and $R = 10.0\ \Omega$.

Determine the accuracy of **Equation #2**, compared with **Equation #1**, at $\theta = 25.0°$ (0.436 radians).

Eq 1: $\frac{5\times10^{-3}\times9.81\times10}{2^2\times0.5^2} \times \frac{\tan 0.436}{\cos 0.436} = \cancel{0.50422}\ 0.25211$

Eq 2: $\frac{5\times10^{3}\times9.81\times10}{2^2\times0.5^2} \times \left(0.436 + \frac{5\times0.436^3}{6}\right) = 0.24774$

$\frac{0.25211 - 0.24774}{0.25211} \times 100 = 1.73\%$ difference $< 10\%$

so accurate.

(c) By calculating the velocity at the high angle of $\theta = 85.0°$, explain if this equipment would be suitable for testing whether **Equation #1** is accurate at high angles of θ.

$\frac{85\times2\pi}{360} = 1.484$. $\left(\theta + \frac{5\theta^3}{6}\right) = 4.204$

$\frac{\tan\theta}{\cos\theta} = 133$.

~~Eq1~~: $V = \frac{133\,mgR}{B^2L^2}$ using Eq 1

$= 65.24\,ms^{-1}$

$V = \cancel{20}\ 2.062\ ms^{-1}$ using Eq 2

The difference is significant / too large to ~~...~~ claim whether eq 1 is suitable at 85.0° using the equipments.

(d) Explain whether **Equation #1** remains valid if the roller rolls rather than slides down the slope.

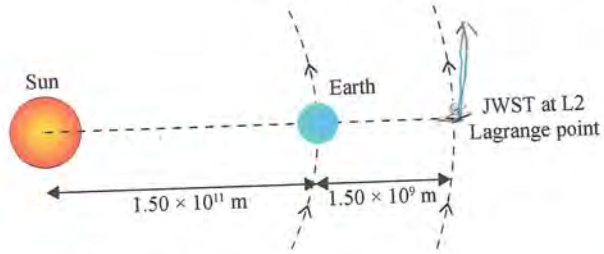
rolling roller will have rotational energy. some of the magnetic force Force will ~~...~~ be put in in ~~...~~ stopping rotational acceleration.
Since the amount of magnetic force that opposes the linear motion of the roller, ~~it~~ the equation will not be valid.
(max V will be higher than value calculated using the equation)

QUESTION FOUR: ORBITAL DYNAMICS

Universal Gravitational Constant $= 6.67 \times 10^{-11}$ N m^2 kg^{-2}
Period of Earth's orbit $= 365.25$ days

Mass of Sun $= 1.99 \times 10^{30}$ kg
Mass of Earth $= 5.98 \times 10^{24}$ kg

The James Webb Space Telescope (JWST) has a mass of 6.16×10^3 kg. It was launched on Christmas Day 2021 and is now orbiting at a point called the L2 Lagrange point, where it will remain in a direct line with the Sun and Earth as shown right.



(a) (i) State the period of the orbit of the JWST around the Sun.

~~365 days~~ 365.25 days

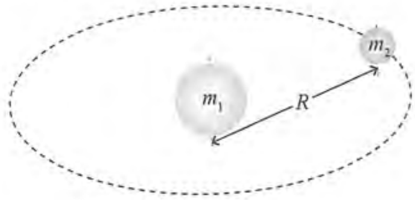
(ii) Calculate the net force acting on the JWST at the L2 point.

$$\frac{6.67\times10^{-11}\times 6.16\times10^{3}\times 5.98\times10^{24}}{(1.50\times10^{9})^2} + \frac{6.67\times10^{-11}\times 6.16\times10^{3}\times 1.99\times10^{30}}{(1.5\times10^{11}+1.5\times10^{9})^2}$$

$= 1.092 + 34.01 = 35.1\text{ N}$ (3sf)

An approximation for two bodies in orbit around each other is that the period T of the orbit can be determined using the relationship:

$$T^2 = \frac{4\pi^2 R^3}{Gm_1}$$



where R is the distance between the centre of masses of the two objects, and m_1 is the mass of the more massive body.

(b) One assumption of the relationship above is that m_1 is much greater than m_2.

(i) Explain why it is necessary to assume that m_1 is much greater than m_2 to derive this relationship.

So that the gravitational force between m_1 and m_2 ~~does~~ is not large enough to significantly move m_1 (cause circular motion). We assume that m_1 stays stationary so that the orbit of m_2 is constant.

(ii) State another key assumption of this relationship.

m_2 orbits around m_1 in perfect circular path.

(c) In the case that m_1 is **not** much larger than m_2, show that the period of the orbit is given by the relationship:

$$T^2 = \frac{4\pi^2 R^3}{G(m_1 + m_2)}$$

$\frac{GM}{r^2} = \frac{4\pi^2}{T^2}$ $\frac{4\pi^2 R^3}{Gm_1 + Gm_2}$

Any other assumptions made for the relationship given on page 12 are still valid.

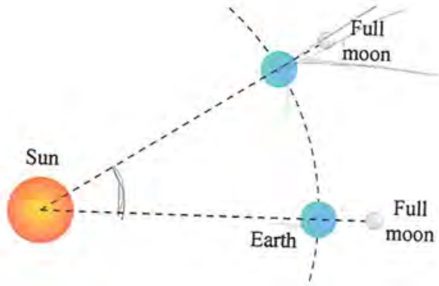
On m_1: $\frac{Gm_1 m_2}{r^2} = m_1 r \left(\frac{2\pi}{T_1}\right)^2$ | On m_2 $\frac{Gm_1 m_2}{r^2} = m_2 r \left(\frac{2\pi}{T}\right)^2$

$\frac{Gm_2}{r^2} = \frac{4\pi^2 r}{T_1^2}$ $\frac{Gm_1}{r^2} = \frac{4\pi^2 r}{T_2^2}$

$\frac{Gm_2}{r^2} + \frac{Gm_1}{r_2} = \frac{4\pi^2 r}{T^2}$

$\frac{G(m_1 + m_2)}{r^2} = \frac{4\pi^2 r}{T^2}$ $T^2 = \frac{4\pi^2 r^3}{G(m_1+m_2)}$

(d) The phases of the Moon are caused by the relative positions of the Sun, Earth, and Moon. A full moon occurs when the Sun, Earth, and Moon are directly aligned. The Moon takes 27.3 days to complete one 360° orbit around the Earth. However, because the Moon must orbit more than 360° to return to a direct alignment with the Sun and Earth (as shown in the diagram on the right), the time between one full moon and the next is more than 27.3 days.



Show that the time between one full moon and the next is 29.5 days.

period of the earth = 365.25 days. $\frac{360}{365.25} = 0.986°\ \text{day}^{-1}$

period of the moon = 27.3 $\frac{360}{27.3} = 13.19°\ \text{day}^{-1}$

time between full moon $= x$.

$\frac{0.986 \times x + 360}{13.19} = x$

$0.986x + 360 = 13.19x$ $12.204x = 360$

$x = \underline{29.5 \text{ days (3sf)}}$

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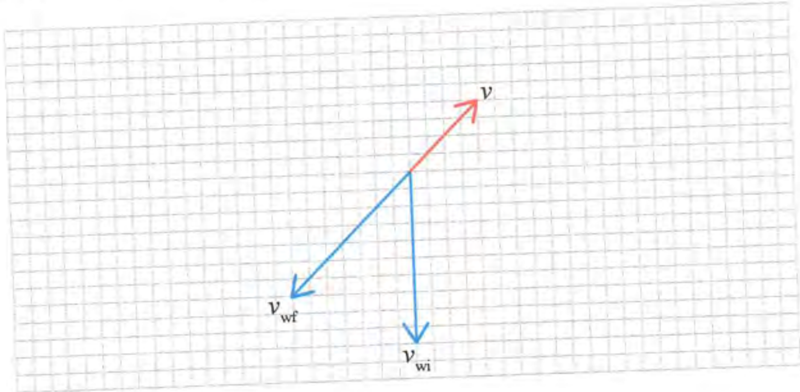
SPARE DIAGRAMS

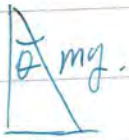
If you need to redraw your response to Question Two (a)(ii), use the diagram below. Make sure it is clear which answer you want marked.



Extra space if required.
Write the question number(s) if applicable.

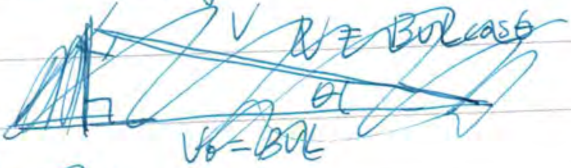
QUESTION NUMBER

Q3 a (i)

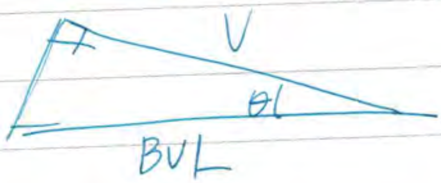


$F_1 = mg\sin\theta$

The roller will cut the magnetic field linkage inducing a current/ emf. $V_0 = BvL$



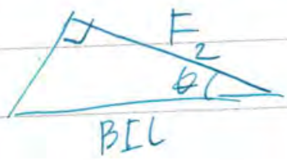
$\cancel{\cos\theta = \frac{BvL}{V_0}}$ $\cancel{V = \frac{BvL}{\cos\theta}}$



$\cos\theta = \frac{V}{BvL}$ $V = BvL\cos\theta$

$V = IR \therefore IR = BvL\cos\theta.$ $I = \frac{BvL\cos\theta}{R}$

current flowing so magnetic force will be generated.



$F_2 = BIL\cos\theta.$

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

$F_1 = F_2$ as constant v reached

$mg\sin\theta = BIL\cos\theta$ $\qquad I = \dfrac{BvL\cos\theta}{R}$

$\therefore \; mg\sin\theta = \dfrac{B^2L^2\cos^2\theta\, v}{R}$

$$V = \frac{mgR\sin\theta}{B^2L^2\cos^2\theta} = \frac{mgR\,\frac{\sin\theta}{\cos\theta}}{B^2L^2\frac{\cos^2\theta}{\cos\theta}} = \frac{mgR\tan\theta}{B^2L^2\cos\theta}$$

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

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Write the question number(s) if applicable.

QUESTION NUMBER

93103

Scholarship exemplar 2022

Subject:	Physics	NZS standard:	93103	Total score:	21

Q	Score	Annotation
1	5	Shows an adequate grasp of quantisation without being clear in the detail. Does not recognise the difference in scale between the laser cavity and the wavelength of visible radiation. Shows a scholarship level grasp of a multi-level calculation marred only by a minor error and shows a clear understanding of aspects of momentum change despite some apparent confusion in terminology.
2	4	Failed to realise that only information about the wind’s change of momentum is supplied while only managing a rudimentary vector subtraction without advancing to the consequences. However the candidate did show understanding in stability arguments, calculations and the effects of tipping.
3	6	Shows scholarship level grasp of components, induction and calculation skills. Misreading of part of the question led to errors and a final disappointment in failing to recognise the significance of constant rotational velocity.
4	6	Scholarship levels performance throughout this question marred only by an arithmetic slip and a failure to grasp the significance of a displaced centre of mass.