BOSWELL-BÈTA

James Boswell Exam

physics vwo

Date:	example exam 2
Time:	3 hours
Number of questions:	5
Number of subquestions:	24
Number of appendices:	2 (for questions 1 and 2)
Total number of points:	71

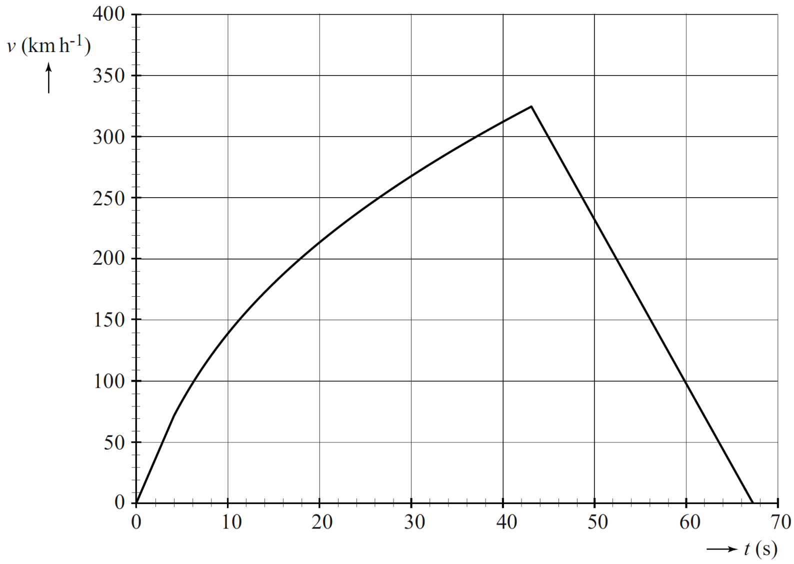
- Write your name on each sheet.
- Answer each question on a separate sheet.
- For every question, show how you obtained your answer by means of a calculation or motivation.
- No points will be awarded to an answer without an explanation.
- Answers with an error in the significance of more than 1 digit in the quantities or units or a combination thereof will result in deduction of one point per separate question.
- Write legibly and in ink. Use of tipp-ex and such or writing in pencil is not allowed.
- Only use a pencil for making drawings.
- Possible additional data can be found in BINAS.

QUESTION 1 REJECTED TAKE-OFF

Airplanes are frequently subjected to intensive tests. An example of such a test is the Rejected Take-Off (RTO).

During an RTO, the plane accelerates to the velocity it needs to achieve take-off. The pilot then brakes as hard as possible. During this emergency stop the brakes can heat up so much that they catch fire. See the picture.

The figure below shows the (v,t)-diagram of an RTO test. This diagram has also been given in the appendix.



The acceleration of the plane is constant during the first four seconds.

a. (3p) Determine this acceleration, using the (v,t)-diagram in the appendix.

The test is carried out on a landing strip with a length of 4.00 km.

b. (3p) Using the (v,t)-diagram in the appendix, explain that this strip is long enough for this test.

The plane has a mass of $5.9 \cdot 10^5$ kg. The motors use kerosene for fuel.
During combustion, 1.0 m^3 of kerosene provides $35.5 \cdot 10^9$ J. The efficiency of the engines is 40%.

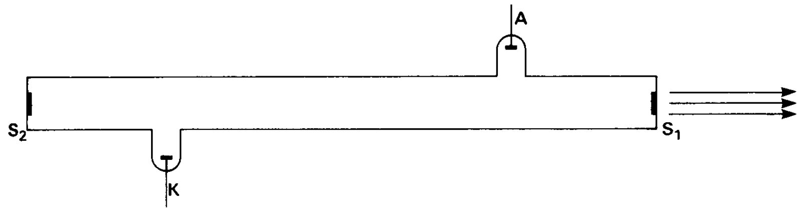
c. (4p) Determine the minimum number of liters of kerosene that are needed to give the plane the maximum velocity.

The plane has 20 wheels; each wheel has one brake.

d. (3p) Using the (v,t)-diagram in the appendix, determine the brake force that a single wheel exerts while braking.

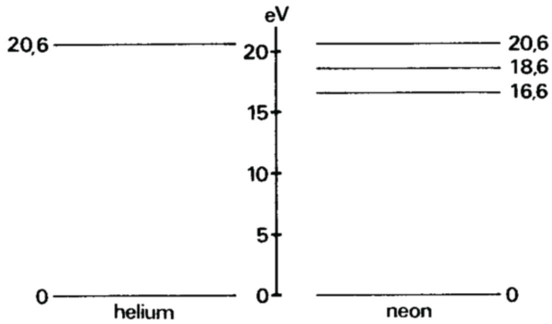
QUESTION 2 Lasers in health care

A helium-neon gas laser consists of a cylindrical glass tube with two flat, parallel mirrors, S_1 and S_2, one at each end.
See the figure on the right.



A cathode K and an anode A, which are connected to a high-voltage direct current, have been inserted into protrusions of the tube. This creates a gas discharge in the tube filled with helium and neon.

The figure on the right shows a simplified version of the energy level diagram of helium and neon. The state 0 eV is the ground state. During the gas discharge, accelerated electrons collide with neon and helium atoms. Many of these atoms are thus brought into their first excited state: neon into the 16.6 eV state and helium into the 20.6 eV state.



energy level diagram

In the middle of the tube the electric field strength is $5.0 \cdot 10^3$ V/m and is directed approximately along the axis of the tube from S_1 to S_2.

a. (3p) Calculate over what distance in this field an electron needs to be accelerated from standstill, to be able to excite a stationary neon atom from its ground state to energy level 16.6 eV.

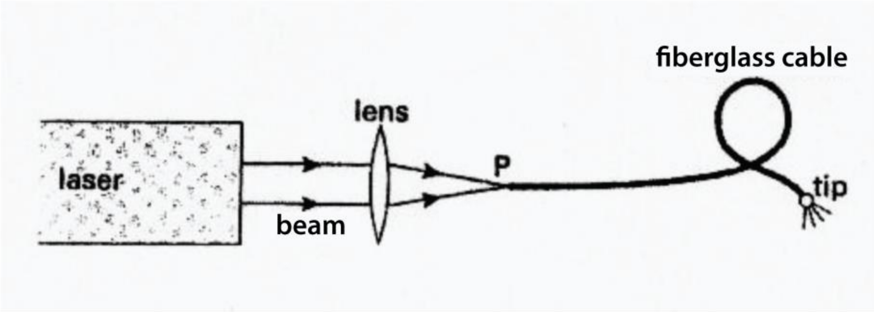
In a gas discharge relatively few neon atoms are excited to the higher state of 20.6 eV through collisions with electrons. In order for the laser to function well, it is nevertheless necessary to bring many neon atoms into this excited state of 20.6 eV. This is achieved by the abundant presence of helium atoms in the tube. A helium atom in the excited state of 20.6 eV can, by means of a collision with a neon atom in its ground state, completely transfer its internal energy of 20.6 eV to the neon atom which is thus brought into the desired energy state of 20.6 eV.
When this excited neon atom subsequently returns to the 18.6 eV state, a photon is released which causes the characteristic red light of a helium-neon laser.

b. (3p) Determine the wavelength of this red light.

To enable light to exit the laser, mirror S_1 is given a permeability of 1.0%, while mirror S_2 reflects all the photons. The laser beam exiting through S_1 has a power of 0.50 mW.

c. (3p) Determine the number of photons of 2.0 eV that reaches S_1 per second.

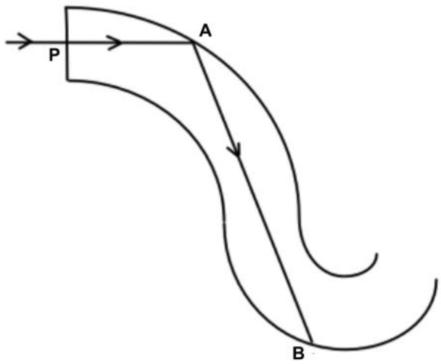
High-power lasers can be used as surgery knives. The laser light then has to be guided from the laser to the skin of the patient.
To achieve this, the setup in the figure below is used.



The parallel beam of laser light converges in point P with the help of a lens.

Point P is located in the middle of a fiberglass cable which guides the light to the so-called tip. This tip is placed close to the patient's skin.

A fiberglass cable is made of glass with a high refractive index because total reflection must occur within the cable. The figure below shows a beam of light which enters the fiberglass cable at P. At A total reflection occurs.
The figure has also been given in the appendix.



d. (4p) Using the figure in the appendix, determine the minimum value of the refractive index of the glass for total reflection also to occur at point B.

When the tip is held close to the patient's skin, the skin will be heated to a high temperature in that spot. The tip can thus be used to cut into the patient's skin.

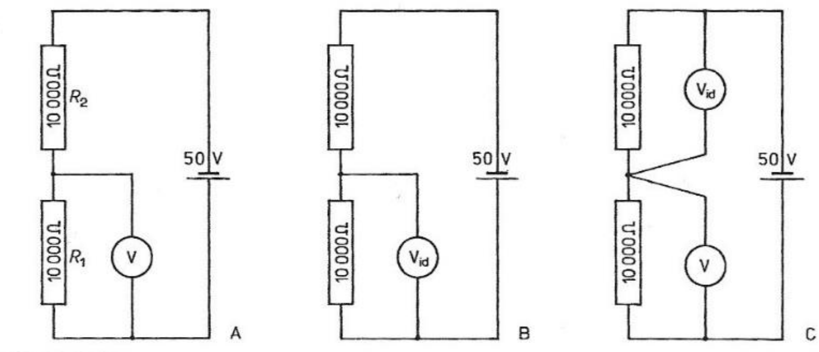
The beam of light exiting the tip has a power of 48 W.
The beam is aimed at the skin. The piece of skin that absorbs this laser light has a mass of 0.013 grams. The specific heat capacity of skin is $3.7 \cdot 10^3$ J/kgK. Assume that all of the laser light is absorbed by this piece of skin.

e. (3p) Calculate the rise in temperature of this piece of skin during 95 ms.

QUESTION 3 The voltmeter

In the figure below V_{id} represents an ideal voltmeter. This means that the resistance of the voltmeter is so large that the strength of the current through the meter can be neglected. V is a non-ideal voltmeter.

The voltmeter in circuit A indicates 20 Volts.



a. (4p) In circuit A, calculate the resistance of the voltmeter V.

b. (2p) In circuit B, calculate the voltage that the ideal voltmeter indicates.

c. (2p) In circuit C, calculate the voltages that the voltmeters indicate.

d. (2p) Explain whether the voltage source in circuit A delivers more, less, or an equal amount of power compared to the power delivered in circuit B.

QUESTION 4 Wear in a steel bearing

To determine the wear in a steel ball bearing, the following procedure is followed: the steel bearing with a mass of 140 grams is exposed to neutron radiation in a nuclear reactor for a certain amount of time. As a result of this irradiation, nuclear reactions occur in the material during which the isotopes ^{56}Mn and ^{59}Fe are formed.

Both isotopes are distributed homogeneously over the bearing.
Both isotopes are radioactive and decay by the process of beta emission (β^-). The half-life of ^{56}Mn is 2.57 hours, and that of ^{59}Fe is 45 days.

a. (3p) Give the decay equation of ^{59}Fe.

Directly following the neutron irradiation, the total activity in the bearing of the ^{56}Mn and ^{59}Fe formed is $4.2366 \cdot 10^{10}$ Bq.

After 54 hours the activity is measured again: the activity of ^{59}Fe is then $5.467 \cdot 10^{8}$ Bq.

b. (2p) Why can it be assumed that after 54 hours only ^{59}Fe decay will be measured?

c. (3p) Calculate the initial activity of ^{56}Mn directly after irradiation.

After being irradiated, the bearing was installed in a machine and 48 hours after ending irradiation, the machine was used for six hours. During use, the bearing is subjected to wear; small metal particles become dislodged from the bearing and end up in the bearing grease.

After being used, the bearing is disassembled. The bearing grease is dissolved and after filtration, the particle dust is collected. The dust is applied to the window of a Geiger-Müller tube which is connected to the corresponding counting equipment. Of all the particles emitted during the radioactive decay process, 40% is counted in this measuring setup.

Without the specimen, the counter indicates 112 pulses during a measuring period of 10.0 minutes. After applying the particle dust, the counter indicates 1410 pulses during a period of 10.0 minutes.

d. (2p) Explain why the counting equipment detects radiation even when there is no radioactive material present.

e. (3p) Show that the activity of the particle dust is 5.41 Bq.

f. (4p) Calculate the amount of bearing material in μg that becomes dislodged due to wear in the bearing per hour of being in use.

QUESTION 5 Exoplanet

On 3 February 2009 the ESA (European Space Agency) reported the discovery of the exoplanet Corot-exo-7b. An exoplanet is a planet that does not orbit the sun but another star, a planet in another solar system. The table below gives some details about this planet and its 'sun'.

Name star	Corot-exo-7	**Name planet**	Corot-exo-7b
distance	140 pc	discovered in	2009
type	K0V	mass	5 to $10M_{\text{earth}}$
apparent visual brightness	11.7	radius planet	$1.8R_{\text{earth}}$
age	$1.17 \cdot 10^9$ years	radius planet orbit	$2.54 \cdot 10^9$ m
apparent temperature	5300 K	period of orbit	0.83 days

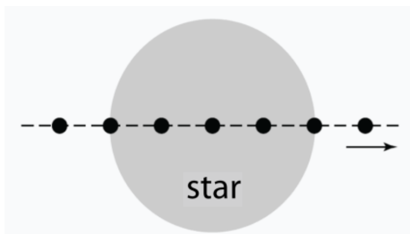
Corot-exo-7b is the smallest exoplanet observed thus far. Its radius is only 1.8 times as big as the earth's radius. The volume of a sphere with radius r is $V = \frac{4}{3}\pi r^3$.

Much is still unknown about the mass of the planet. See the table.

Assume that the exoplanet is 'earth-like', which means that the density of the planet is (roughly) equal to that of the earth.

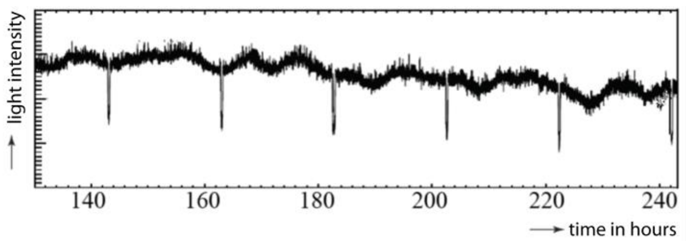
a. (3p) For this scenario, calculate the planet's mass, expressed in the earth's mass.

figure 1



Corot-exo-7b was discovered using the transit method. Every time the planet travels in front of the star (see figure 1), it covers a small portion of the star. This causes the light intensity of the star to change periodically. See figure 2.

figure 2



A 'year' is very short on this planet.

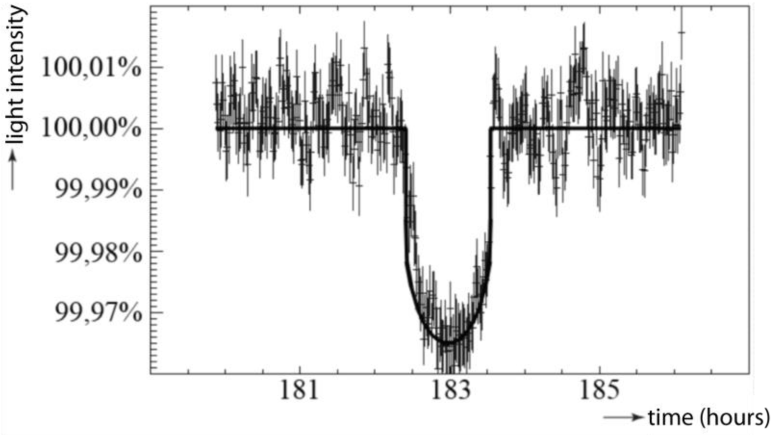
b. (3p) Using figure 2, determine the length of a 'year' on this planet. Check whether your answer corresponds to the value given in the table.

Using the data in the table, the orbital velocity of the exoplanet can be calculated.

c. (3p) Show that the orbital velocity of the exoplanet is $2.2 \cdot 10^2$ km/s.

Figure 3 shows an enlarged part of figure 2. The thick line is the trend line through the measurement points.

figure 3



d. (3p) Using figure 3, determine the star's diameter. To do this, assume that the planet's diameter can be neglected in comparison to the star's diameter.

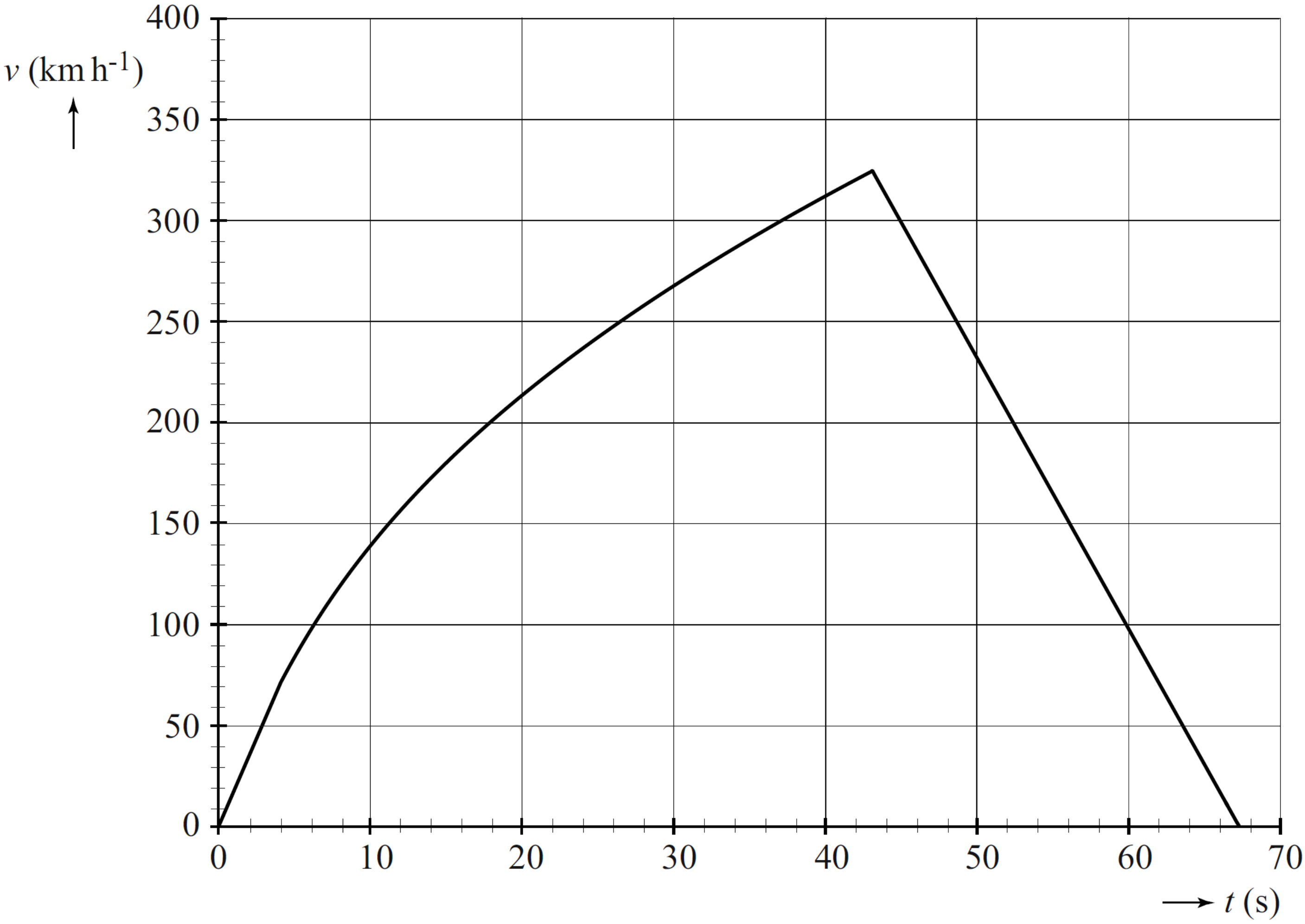
The table contains the apparent temperature (surface temperature) of the star around which the planet orbits.

e. (3p) Explain whether the color of this star is more red or more blue than that of the sun.

THE END

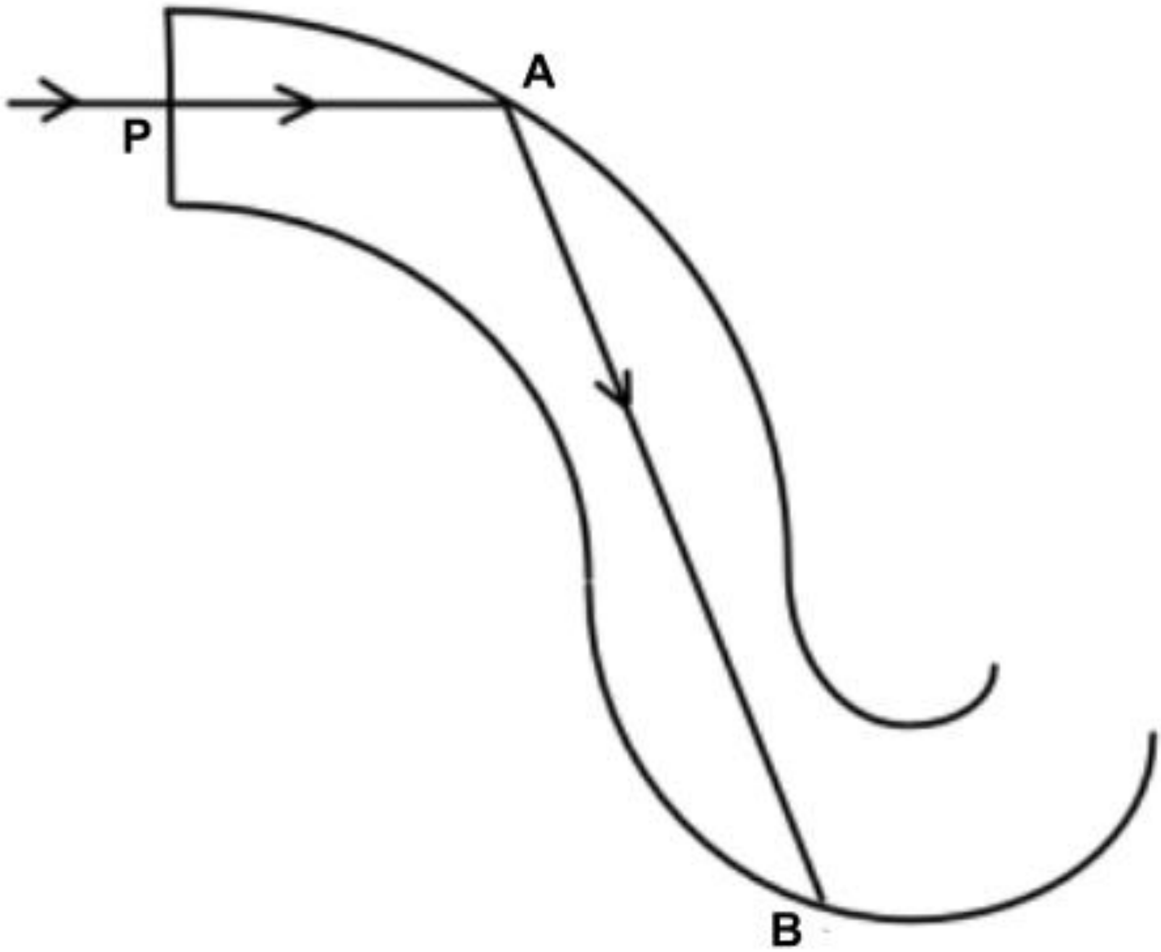
Appendix for question 1

Name

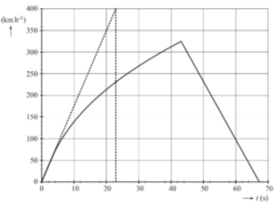


Appendix for question 2

Name

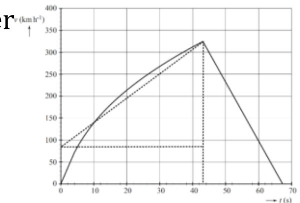


Question 1 Rejected Take Off



a. The acceleration corresponds to the slope of the graph: $\frac{400/3.6}{23} = 4.8\ \mathrm{m/s^2}$

b. The braking distance corresponds to the area under the graph: (for example) $(85/3.6) \times 43 + ½ \times (240/3.6) \times 43 + ½ \times (325/3.6) \times 24 = 353\ \mathrm{m}$



c. The maximum kinetic energy is $E_\mathrm{k} = \frac{1}{2}mv^2 = \frac{1}{2} \times 5.9 \cdot 10^5 \times (235/3.6)^2 = 2.40 \cdot 10^9\ \mathrm{J}$.
1 $\mathrm{m^3}$ fuel provides $35.5 \cdot 10^9 \times 0.40 = 14.2 \cdot 10^9\ \mathrm{J}$, so the number of litres needed is $\frac{2.40 \cdot 10^9}{14.2 \cdot 10^9} \times 1000 = 1.7 \cdot 10^2\ \mathrm{L}$.

d. The deceleration is $\frac{325/3.6}{67-43} = 3.76\ \mathrm{m/s^2}$
Therefore the braking force is $F_\mathrm{res} = ma = 5.9 \cdot 10^5 \times 3.76 = 2.2 \cdot 10^6\ \mathrm{N}$
For a single wheel: $\frac{2.2 \cdot 10^6}{20} = 1.1 \cdot 10^5\ \mathrm{N}$

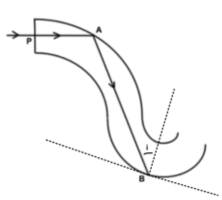
Question 2 Lasers in health care

a. $W_\mathrm{el} = F_\mathrm{el} = q\mathrm{E}s \Rightarrow s = \frac{W_\mathrm{el}}{qE} = \frac{16.6 \times 1.6 \cdot 10^{-19}}{1.6 \cdot 10^{-19} \times 5 \cdot 10^3} = 3.32 \cdot 10^{-3}\ \mathrm{m} = 3.32\ \mathrm{mm}$

b. $E_\mathrm{ph} = 20.6 - 18.6 = 2.0\ \mathrm{eV}$, $E_\mathrm{ph} = hf = \frac{hc}{\lambda}$
$\Rightarrow \lambda = \frac{hc}{E} = \frac{6.63 \cdot 10^{-34} \times 3.00 \cdot 10^8}{2.0 \times 1.6 \cdot 10^{-19}} = 6.2 \cdot 10^{-7}\ \mathrm{m} = 620\ \mathrm{nm}$

c. Every second the total energy of the photons reaching S_1 is $0.5 \cdot 10^3 \times 100 = 0.05$ J. The energy of 1 photon is $2.0\ \mathrm{eV} = 2.0 \times 1.6 \cdot 10^{-19} = 3.2 \cdot 10^{-19}$ J, so the number of photons reaching S_1 is $\frac{0.05}{3.2 \cdot 10^{-19}} = 1.6 \cdot 10^{17}$.

d. The angle of incidence $i = 39°$ (draw a normal and measure). This angle has to be larger than the critical angle g, so the critical angle should be at least 39:
$n = \frac{1}{\sin(39°)} = 1.6$.



e. $Q = cm\Delta T \Rightarrow \Delta T = \frac{Q}{cm} = \frac{48 \times 95 \cdot 10^{-3}}{3.7 \cdot 10^3 \times 0.013 \cdot 10^{-3}} = 95\ °$

Question 3 The voltmeter

a. The total current follows from the upper part of the circuit: $I_2 = \frac{U_2}{R_2} = \frac{50-20}{10000} = 3$ mA. The combined resistance of the lower part is therefore $R_\mathrm{v} = \frac{20}{3 \cdot 10^{-3}} = 6.67 \cdot 10^3\ \Omega. \Rightarrow \frac{1}{R_\mathrm{v}} = \frac{1}{10000} + \frac{1}{R_\mathrm{voltmeter}}$
$\Rightarrow R_\mathrm{voltmeter} = 2.0 \cdot 10^4\ \Omega$

b. No current flows through the voltmeter, so the potential difference is $\frac{50}{2} = 25$ V.

c. This circuit is the same as circuit A, so the voltmeter at the bottom indicates 20 V and the voltmeter at the top indicates 30 V.

d. The total resistance in circuit A is smaller than in B, so the total current in A is larger than in B, so the power $P = UI$ is also larger in A.

Question 4 Wear in a steel bearing

a. ${}^{59}_{26}\mathrm{Fe} \rightarrow {}^{59}_{27}\mathrm{Co} + {}^{0}_{-1}\mathrm{e}$

b. 54 hour corresponds to $\frac{54}{2.57} = 21$ half-lives, so all Mn has decayed.

c. $A(t) = A(0) \cdot \left(\frac{1}{2}\right)^{t/t_h} \Rightarrow A(0) = A(t)/\left(\frac{1}{2}\right)^{t/t_h}$
$= 5.467 \cdot 10^8/\left(\frac{1}{2}\right)^{\frac{54}{45}} = 1.256 \cdot 10^9$ Bq, so the activity of the Mn is $4.2366 \cdot 10^{10} - 1.256 \cdot 10^9 = 4.111 \cdot 10^{10}$ Bq.

d. The counting equipment detects the background radiation.

e. $A = \frac{1410-112}{10 \times 60}/0.40 = 5.41$ Bq

f. The total activity of 140 g bearing is $5.467 \cdot 10^8$ Bq, the measured activity of 5.41 Bq corresponds to a wear of $\frac{5{,}41}{5.467 \cdot 10^8} \times 140 = 1.4\ \mu\mathrm{g}$.
Per hour: $\frac{1.4}{6} = 0.23\ \mu\mathrm{g}$.

Question 5 Exoplanet

a. The mass is directly proportional to the volume, so to R^3, so $M = 1.8^3 \times M_\mathrm{earth} = 5.8 \times M_\mathrm{earth}$

b. The time between 5 'dips' is $242 - 143 = 99$ hour, so the orbital period is $\frac{99}{5} = 19.8$ hour. The table gives $0.83 \times 24 = 19.9$ hour so it does agree.

c. $v = \frac{2\pi r}{T} = \frac{2\pi \times 2.54 \cdot 10^9}{0.83 \times 24 \times 3600} = 2.2 \cdot 10^5\ \mathrm{m/s} = 2.2 \cdot 10^2\ \mathrm{km/s}$

d. The total time of the 'dip' is $183.5 - 182.4 = 1.1$ hour, so $d = 2.2 \cdot 10^2 \times (1.1 \times 3600) = 8.7 \cdot 10^5$ km

e. The temperature of the sun is 5800 K (see BINAS), so the star has a lower temperature. From Wien's law, $\lambda_\mathrm{max} T = k_\mathrm{W}$, it follows that λ_max of the star is longer than the peak wavelength of the sun. Therefore the star is more red than the sun.