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Activity

Practice-for-exam questions

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Use the questions below either in class or for individual work after students have read the articles in the magazine. Although the questions state the values of constants required, some of the questions require additional data – students should either make reasonable estimates of quantities or look up values using a data book or website. Students should clearly communicate any assumptions made. Suggested outline answers to questions are provided in a separate document.

Dirigible planetary exploration

1 Consider a balloon with the cross-section shown in Figure 1, which consists of a cylindrical central section and two half spheres. This balloon is being designed to be used for exploration of the planet X such that it will be situated close to the sea level of the planet.

At standard temperature and pressure (STP) conditions, the density of air at sea level on planet X is known to be 15.0 times that of the density of air at sea level on Earth. The acceleration due to gravity on planet X is known to be half of that of Earth.

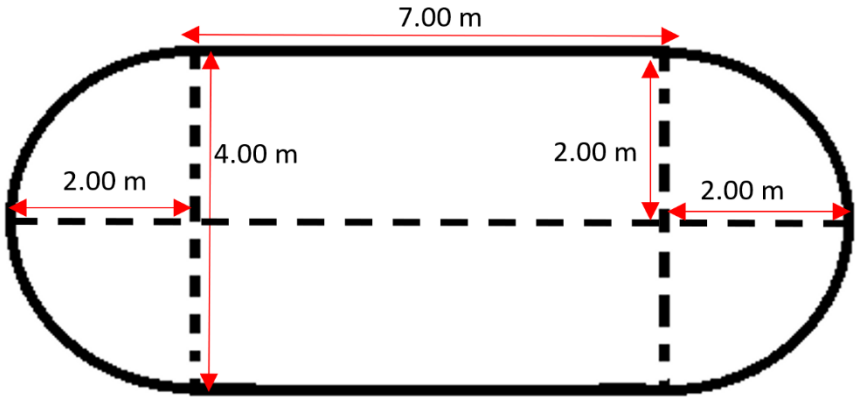

Figure 1: Balloon intended for exploration of planet X

a Calculate the volume of the balloon in m^3 by noting that the balloon is composed of two half-spheres and one cylinder.

b Determine the upward buoyancy force in kN acting on the balloon.

Acceleration due to gravity on Earth is 9.81 ms^{-2}.

Density of air at sea level on Earth (at STP) is 1.23 kg m^{-3}.

c The balloon will be equipped with hardware that includes several navigational instruments as well as some payload. Determine the maximum mass in kg of hardware permissible to

ensure the balloon will be able to rise in the planet's atmosphere. Assume the skin of the balloon has a weight of 1200 N.

2 A weather balloon contains 8.80 moles of helium at 1 atmospheric pressure (atm) and a temperature of 25 degrees Celsius at ground level. What is the volume of the balloon under these conditions?

Assume 1 atm is equal to 105 N m^{-2} and the molar gas constant to be 8.314 J mol^{-1} K^{-1}.

3 If a spherical hydrogen-filled balloon weighs 200 kg, what would the radius of the balloon need to be to allow it to lift off the ground on a hot summer day in the UK with a surface temperature of 27.0°C and atmospheric pressure of 1 atm? Assume the molar mass of air is 30.0 g mol^{-1}, 1 atm to equal 105 N m^{-2} and the molar gas constant to be 8.314 J mol^{-1} K^{-1}.

How cold is space?

1 Galactic 'red shift' is one piece of evidence that scientists base the 'Big Bang' theory on. Explain what is meant by 'red-shift' and how it evidences the Big Bang theory.

2 Cosmic microwave background (CMB) radiation was discovered by chance in 1965 by two radio astronomers (Penzias and Wilson) who registered a signal in their radio telescope that could not be attributed to any precise source in the universe. Explain what is meant by CMB.

3 Find the change in the wavelength of the light from a galaxy moving away from the Earth at 2.00×10^6 ms^{-1}. Assume the emitted wavelength is 600 nm and the speed of light in a vacuum is 3.00×10^8 ms^{-1}.

Supercapacitors

1 **a** What is the SI unit of capacitance? State three parameters that affect the capacitance of a capacitor.

b Capacitor A holds a charge of 10.0 μC when fully charged with a 5.00 V battery. Calculate the capacitance of Capacitor A.

c Calculate the energy stored in Capacitor A when the same capacitor is connected to a 9.00 V battery. State your answer in mJ.

2 Figure 2 shows a 370-pF capacitor consisting of two metal parallel plates that sandwich a thin sheet of polythene. This thin sheet completely fills the gap between the plates and has a relative permittivity of 2.30. Each metal plate (rectangular) has a length of 25.0 cm and width of 10.0 cm.

Figure 2: A 370-pF capacitor

a Calculate the area of each metal plate in m^2.

b Calculate the thickness of the polythene sheet in mm.

Note: permittivity of a material is given by $\varepsilon = \varepsilon_0\varepsilon_r$, where ε_0 is the permittivity of free space, which is 8.854×10^{-12} Fm^{-1}, and ε_r, which is the relative permittivity of the material.

c The capacitor is charged so that there is 35.0 V potential difference between the plates.

13.0 nC of charge is stored and the energy stored is 0.230 μJ. The supply is now disconnected, and the polythene sheet pulled out from between the plates without discharging or altering the separation of the plates. Show that the potential difference between the plates increases to about 80 V.

d Calculate the energy (in units of μJ) stored in the capacitor after the polythene dielectric was removed. Provide a reason for the change in energy compared with when the polythene was not removed.

3 **a** What is meant by the terms 'energy density' (ED) and 'power density' (PD)? State their SI units.

b Based on the information provided in the article, write down the correct range of ED and PD values in Table 1 below. Remember to state the SI unit of ED and PD in the respective column header.

Table 1: ED and PD comparison between a standard capacitor, a standard rechargeable li-ion battery, and an electrostatic double-layer (EDL) type supercapacitor

Component	Energy density (SI unit: _____)	Power density (SI unit: _____)
Standard capacitor	10^{-2} to 10^{-1}	
Rechargeable li-ion battery		
EDL supercapacitor		

c Looking at your completed table from part (b). What can you say about the ED and PD performance of a supercapacitor compared to that of a rechargeable li-ion battery of comparable size?

d Supercapacitors are well suited to any application that expects frequent charge and discharge cycles, extreme operating temperatures, or rapid discharge of high amounts of energy. State any two practical applications of supercapacitors that utilise some of these features.