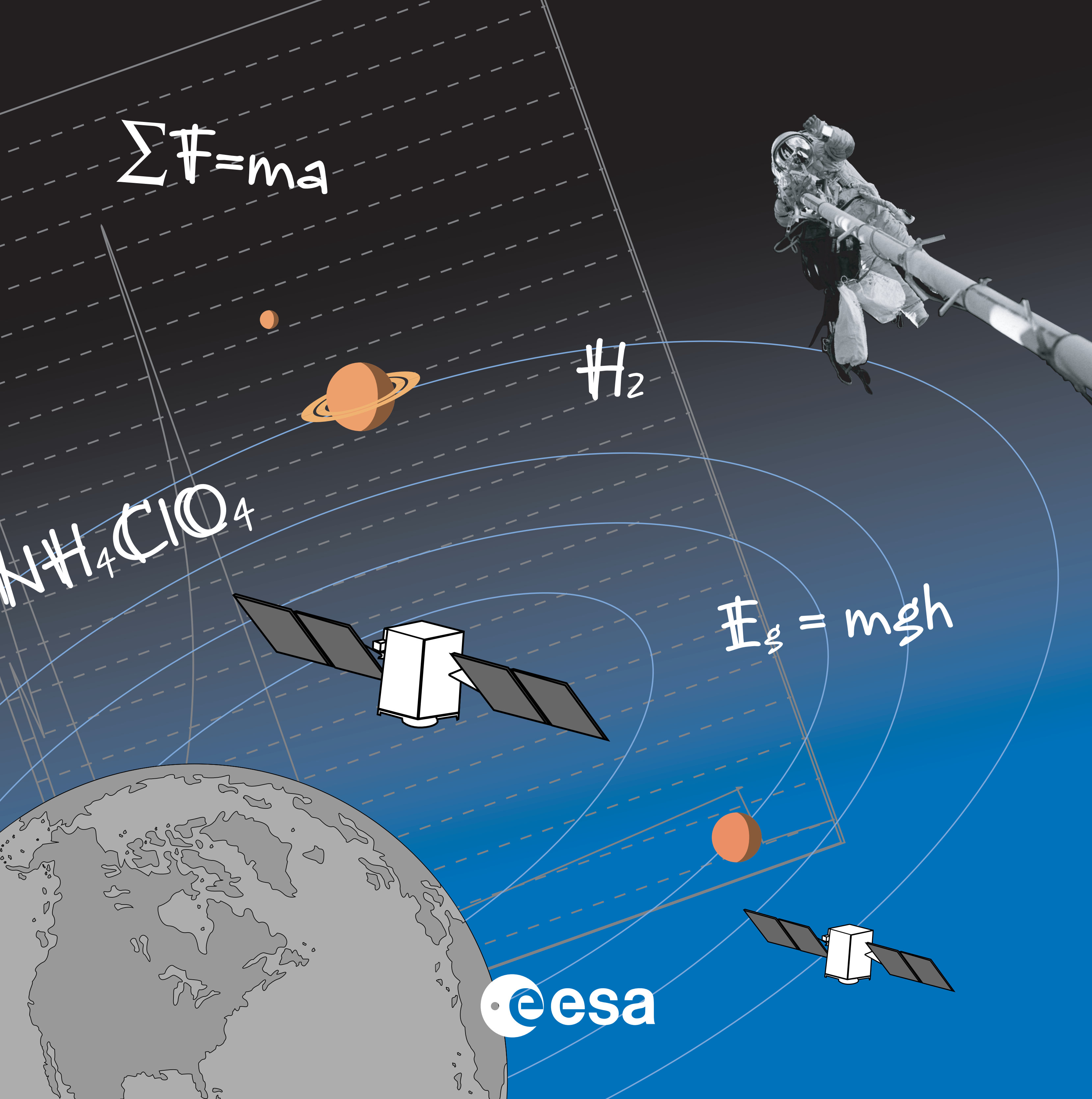
BR-223

English version

Lift-off

European Space Agency physics and chemistry exercises based on real space data for secondary schools



esa

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May 2004

Lift-off!

European Space Agency physics and chemistry exercises based on real space data for secondary schools

European Space Agency
Agence spatiale européenne

Every schoolgirl and boy is interested in space – astronauts, rockets and satellites, parabolic flights, everything – and we have to make sure that we provide a knowledge base so that we do not find ourselves without a skilled workforce in 20 years!

Jean-Jacques Dordain
Director General
European Space Agency

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Introduction

Space is a very attractive topic for everybody – also for students. Unfortunately, at school space-related subjects such as physics and chemistry are often regarded as difficult and abstract with little connection to reality.

With space as a reference, the Education Department of the European Space Agency (ESA) has created a new educational tool to be used in secondary schools. It consists of a series of physics, chemistry and technology exercises based on real ESA space data aimed at students between 15 and 18 years of age.

The purpose is to demonstrate them that all concepts, magnitudes, formulas and theories that are studied in class are the same ones used in everyday life in the space business. Students will calculate the orbit of a real satellite, deal with typical space chemistry reactions, handle the problems of a rendezvous in space, find out what forces are at work at a launch and on a launcher, understand the lifetime of real batteries, propose correct timing for missions and much more.

The exercises and the exercise data have been developed working closely together with ESA scientists and engineers[1], who checked numbers and accuracy of the exercises. Without their collaboration this project could not have been carried out. I am very grateful of their support.

Each exercise consists of a **questions page** that can be photocopied easily. These questions sheets also include necessary data, some hints and illustrations. On an extra page the teacher is provided with the **solution** of the exercises and possible further information. Some technical concepts, marked by *italics*, can be found in the glossary, and if you want more information please visit www.esa.int/education/exercises.

I hope students will enjoy finding out how a satellite works!

Samuel T. Buisán
ESA Education Department

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What is ESA?

The European Space Agency is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the people of Europe. ESA has 15 Member States. By coordinating the financial and intellectual resources of its members, it can undertake programmes and activities far beyond the scope of any single European country.

What does ESA do?
ESA's job is to draw up the European space plan and carry it through. The Agency's projects are designed to find out more about the Earth, its immediate space environment, the solar system and the Universe, as well as to develop satellite-based technologies and promote European industries. ESA also works closely with space organisations outside Europe to share the benefits of space with the whole of mankind.

Who belongs to ESA?
ESA's 15 Member States are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. In addition Canada and Hungary participate in some projects under cooperation agreements and Greece and Luxembourg will join in 2004. ESA is an entirely independent organisation although it maintains close ties with the EU with whom it shares a joint space strategy.

Where is ESA located?
ESA has its headquarters in Paris and it is here that future projects are decided upon. However, ESA also has centres in Europe, each of which has different responsibilities. **ESTEC**, the European Space Research and Technology Centre, is the design hub for most ESA spacecraft and is situated in Noordwijk, the Netherlands. **ESOC**, the European Space Operations Centre, is responsible for controlling ESA satellites in orbit and is situated in Darmstadt, Germany. **EAC**, the European Astronauts Centre, trains astronauts for future missions and is situated in Cologne, Germany. **ESRIN**, the European Space Research Institute, is based in Frascati, near Rome in Italy. Its responsibilities include collecting, storing and distributing satellite data to ESA's partners, and acting as the Agency's information technology centre. In addition, ESA has liaison offices in the United States, Russia and Belgium, a launch base in French Guiana, and ground and tracking stations in various areas of the world.

How many people work for ESA?
In 2002 the total number of staff working for ESA numbered 1898. These highly qualified people come from all the Member States and include scientists, engineers, information technology specialists and administrative personnel.

Where do ESA's funds come from?
ESA's mandatory activities (space science programmes and the general budget) are funded by a financial contribution from all the Agency's Member States, calculated in accordance with each country's gross national product. In addition, ESA conducts a number of optional programmes. Each country decides in which optional programme it wishes to participate and the amount of its contribution.

How does ESA benefit European citizens?
The benefits of space exploration are not confined to scientists, engineers and astronauts. Space exploration also helps to improve daily lives. Below are just some of the ways in which ESA's programmes benefit Europe and its citizens.

- ***Strengthening and promoting European Science*** Europe's space programme has helped to keep Europe at the forefront of scientific discovery on our solar system and the Universe. This research has also led to breakthroughs in other scientific areas.
- ***Improving medical science*** Many of the scientific discoveries that are making our lives healthier and longer originated in space research. Just two examples: recent advances in detecting cancers and new treatments for heart disease.
- ***Generating new technology*** Developments in space technology can also be adapted for other uses. One example being the flame-resistant textiles used for protective clothing which are the result of research to protect electric circuits in rockets.
- ***Strengthening European industry*** The space industry benefits from the award of ESA contracts and also puts the technical experience gained from taking part in ESA's programmes to other uses.
- ***Promoting industrial development*** Satellites are used to discover new mineral or oil deposits.
- ***Protecting the Earth*** Earth observation satellites provide the data which is used to safeguard the environment and to monitor environmental change and damage.
- ***Assisting agriculture*** Remote sensing provides information for geographical information systems (GIS). This is used to improve land cultivation and elaborate agricultural statistics at both European and national levels.
- ***Developing more accurate weather forecasts*** This benefits agriculture as well as navigation and leisure activities.
- ***Improving communications*** Television broadcasts can now be beamed all over the world. Satellites are also used for cellular phones, and for intercontinental voice and data exchange.
- ***Creating accurate maps*** One of the many benefits this has brought is improved town planning.
- ***Improving navigation*** Satellites are used to provide the navigation systems increasingly used in cars, trains, planes and ships
- ***Increasing employment*** The European space industry employs 40 000 people directly and 250 000 indirectly.
- ***Preventing the brain drain*** The innovative science being carried out by ESA helps to keep top scientists in Europe.

Last, but certainly not least, ESA ensures that Europe is at the forefront of the most exciting adventure of the 21st century - space exploration

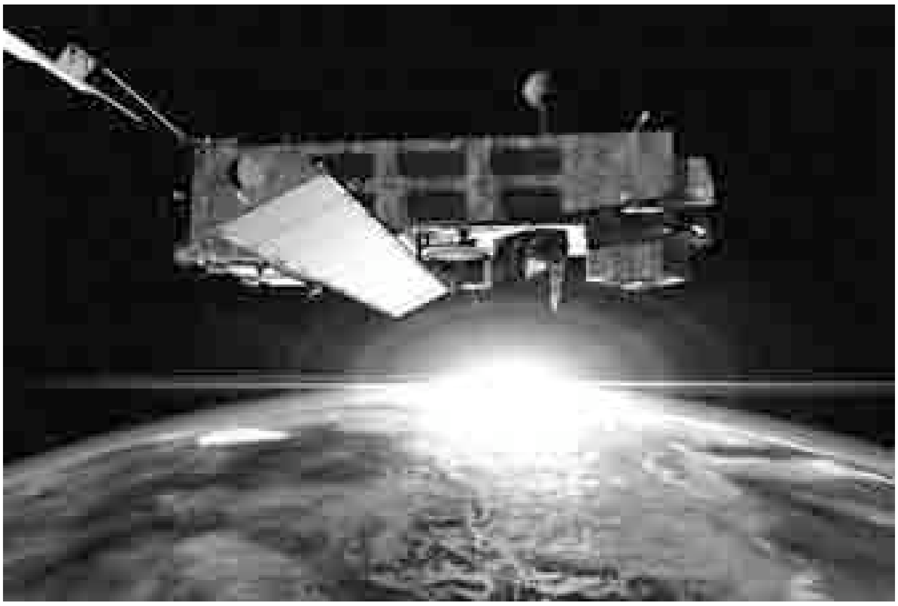
Index of Exercises

1 - Spacecraft thermal control

In space, the temperature of a spacecraft is the result of the balance between the energy that it receives from the Sun and the Earth, the energy that the spacecraft produces and the energy that it loses through *radiation*.

In general a spacecraft in a low orbit around the Earth receives energy from three different sources:

Direct solar radiation	= 1367 W/m^2
The rate of solar energy reflected by the Earth (albedo)	= 0.30
Infrared radiation emitted by the Earth	= 240 W/m^2



Artist's impression of Envisat

a) Calculate the energy (W/m^2) received at low-orbit altitude.

b) Calculate the energy received by Envisat during 20 s, assuming that a quarter of the spacecraft is facing the Sun and another quarter facing Earth.

Hydrazine (N_2H_4) is the *propellant* of Envisat. The temperature tolerance is between 9ºC and 40ºC.

c) If we assume that the energy radiated does not change with the temperature and that the energy produced does not change either, how long would it take to raise the temperature 50 kg of this propellant by 32ºC?

Data: Consider Envisat's surface = 160 m^2
Hydrazine's specific heat capacity = 98.9 J/molK

If you want to know more: http://www.esa.int/envisat

Solution "Spacecraft thermal control"

a) $Q_{received} = 1367\ \text{W/m}^2 + 0.3 \cdot 1367\ \text{W/m}^2 + 240\ \text{W/m}^2 = 2017.1\ \text{W/m}^2$

b) $Q_{20s} = \left(\frac{1}{4} \cdot 160\ \text{m}^2 \cdot 1367\ \text{W/m}^2 + \frac{1}{4} \cdot 160\ \text{m}^2 \cdot (240\ \text{W/m}^2 + 0.3 \cdot 1367\ \text{W/m}^2) \right) \cdot 20\ \text{s} = 1613680\ \text{J}$

c) First we have to calculate the moles of Hydrazine

$$n = \frac{50000\ \text{g}}{32\ \text{g/mol}} = 1562.5\ \text{moles}$$

$$Q_{Hydrazine} = nc_p \Delta T = 1562.5\ \text{mol} \cdot 98.9\ \text{J/molK} \cdot 32\ \text{K} = 4945000\ \text{J}$$

$$\Delta t = \frac{Q_{Hydrazine}}{Q_{20s}} = \frac{4945000\ \text{J}}{1613680\ \text{J}} = 3.06 \approx 1\ \text{min}$$

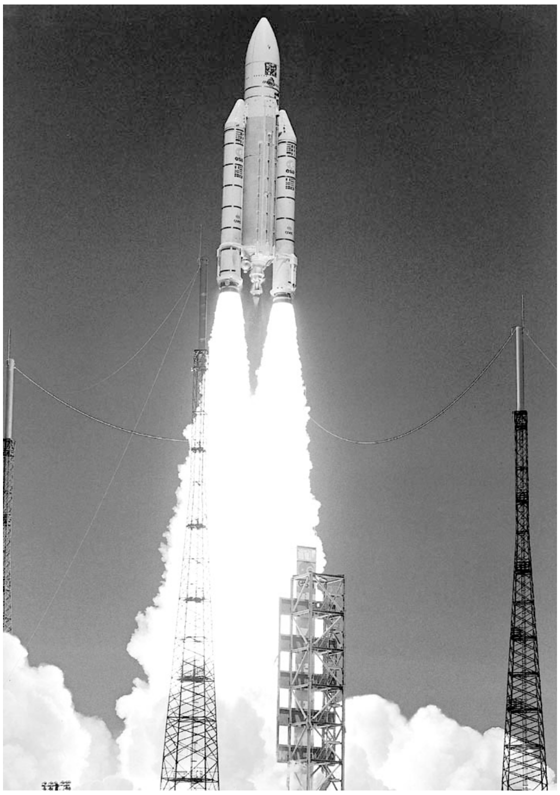
Fortunately there are control techniques onboard satellites that maintain their temperature between certain operating limits, allowing the instruments to work properly.

2 - ARIANE 5 Lift-off

Ariane 5 is a European rocket. It launches satellites from Europe's spaceport in Kourou (French Guiana, South America). To escape from the Earth's gravity, tremendously powerful engines are needed to ensure lift-off.

At lift-off two solid *booste*r stages deliver 6713 kN (kilonewton) each and the main *cryogenic stage* (central tank) delivers 1167 kN. The mass of Ariane 5 at lift-off is 725 tonnes.

Calculate the vertical acceleration of Ariane 5 and the percentage of contribution of each of the stages.



Launch of an Ariane 5

If you want to know more: http://www.esa.int/launchers

Solution “Ariane 5 lift-off”

$$\sum F = m \cdot a$$

$F_4 = 725000 \text{ kg} \times 9.8 \text{ m/s}^2 = 7105000 \text{ N}$ This is Ariane’s weight.

$$a = \frac{F_1 + F_2 + F_3 - F_4}{m} = \frac{6713000 \text{ N} + 6713000 \text{ N} + 1167000 \text{ N} - 7105000 \text{ N}}{725000 \text{ kg}} = 10.3 \text{ m/s}^2$$

The two boosters deliver a combined thrust of 92% at liftoff.

They work for only 130 seconds – this is enough to reach a height of about 60 km. At that moment the fuel is used up, the two boosters separate and fall back into the sea.

3 - Europe's comet chaser

The European "comet chaser" Rosetta will encounter and study the comet 67P/Churyumov-Gerasimenko after it has travelled through space for ten years. It will also release a lander onto the nucleus of the comet.

Rosetta will be the first space mission to journey beyond the main asteroid belt using *solar cells* for power generation. Big solar panels are required to produce enough power to balance power consumption in deep space.

Note: The power P produced from a given area A of a *solar array* is given by:

$P = \phi_{Sun} A\eta$ where ϕ_{Sun} is the flux of sunlight and η is a factor including cell efficiency and the angle to the Sun, in this example constant with a value of 0.124

The flux of sunlight decreases with the inverse square of the distance from the Sun, d (in *astronomical units*):

$$\phi_{Sun} = \left(\frac{1367}{d^2}\right) \text{W/m}^2 \qquad d_{Earth} = 1 \text{ U.A.} = 1.49597870 \times 10^{11} \text{ m}$$

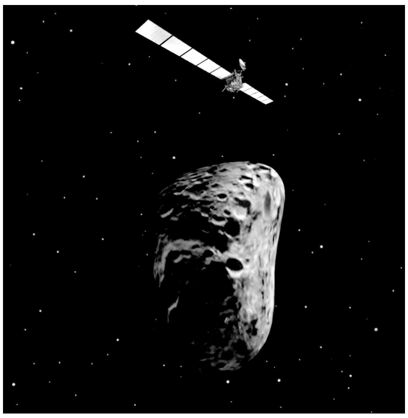
A power of 395 W is required when the spacecraft is at a distance of $7.853888175 \times 10^{11}$ m from the Sun.

a) Calculate the area of the solar panels needed to fit with the objectives of the mission.

b) Calculate the power that Rosetta would deliver in orbit around Earth.

For a correct design two "solar panel wings", each 2.3 m wide, must be attached to both sides of the main body (a box of $2.8 \times 2.1 \times 2.0$ m).

c) Calculate the length of the "wings" and draw the Rosetta spacecraft in scale.



Rosetta approaching the comet

If you want to know more: http://www.esa.int/rosetta

Solution "Europe's comet chaser"

a) $d = \dfrac{7.853888175 \times 10^{11}\ \text{m}}{1.49597870 \times 10^{11}\ \text{m}} = 5.25\ \text{U.A.}$

Note: Jupiter is at a distance of 5.2 U.A.

$$A = \frac{P}{\phi_{Sun} \cdot \eta} = \frac{395\ \text{W}}{\left(\dfrac{1367}{(5.25)^2}\right)\text{W/m}^2 \times (0.124)} = 64.2\ \text{m}^2 \cong 64\ \text{m}^2$$

b) $P = \left(\dfrac{1367}{1^2}\right)\text{W/m}^2 \times 64\ \text{m}^2 \times 0.124 = 10848.5\ \text{W}$

c) $l = \dfrac{64\ \text{m}^2 / 2}{2.3\ \text{m}} = 13.91\ \text{m} \cong 14\ \text{m}$

4 - How noisy is a rocket?

At lift-off, the noise produced by the powerful engines of Ariane-5 reach intensity levels of 180 dB. This is one of the reasons why there is a security perimeter of 10 km around the launch pad. Other reasons are, for example, toxic gases or the possibility of a launcher failure.

Calculate:

a) **What is the intensity of the sound waves in W/m^2?**

b) **How many people would have to talk at the same time to deliver the same energy?**

c) **Consider a sound propagating from the launcher without any obstacles. What is the energy received in the limit of the security perimeter?**

Decibel Scale

Intensity level (dB)	Intensity (W/m^2)	Sound
0	10^{-12}	Threshold of hearing
10	10^{-11}	Breathing
20	10^{-10}	Rustling leaves
30	10^{-9}	Quiet house
40	10^{-8}	Library
50	10^{-7}	Normal office
60	10^{-6}	Normal Conversation (2 people)
70	10^{-5}	Normal traffic
80	10^{-4}	Vacuum cleaner
90	10^{-3}	Factory
100	10^{-2}	Subway train
120	10	Commercial plane at takeoff (threshold of pain)
140	10^{2}	Military jet at takeoff (at 30m)

Data: $I_o = 10^{-12}$ W/m^2 threshold of hearing

$I_{dB} = 10\log\frac{I}{I_o}$ formula for decibel

If you want to know more: http://www.esa.int/launchers

Solution "How noisy is a rocket?"

a) $I_{dB} = 10\log\frac{I}{I_o}$

$$180 = 10\log\frac{I}{10^{-12}\ \text{W/m}^2}$$
$$180 = 10(\log I + 12)$$
$$6 = \log I$$
$$I = 10^6\ \text{W/m}^2$$

b) Normal conversation 2 people 10^{-6} W/m^2 so

Number of people $= \frac{10^6}{10^{-6}} \times 2 = 2\times10^{12}$ people talking at the same time.

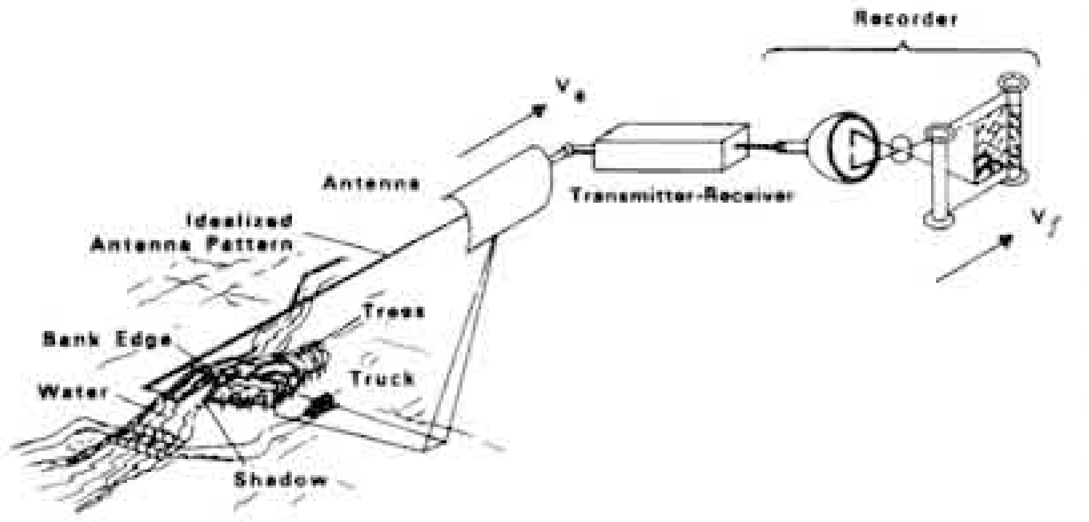
Approximately 300 times the world's population.

c) The wave front of propagation is a sphere centred in Ariane 5. As the surface area of this sphere increases with distance the sound energy within a given area decreases.

$$I = \frac{Power}{4\pi R^2} = \frac{10^6\ \text{W}}{4\times3.14\times(10000\ \text{m})^2} = 8\times10^{-4}\ \text{W/m}^2$$

5 - When the ground moves

An "Imaging Radar", like the one onboard the ESA satellites Envisat and ERS, is a type of radar that operates in a side-looking direction to Earth's surface. The transmitted signal $A\sin(kr + wt)$ is reflected back from the Earth's terrain and received onboard the satellite.
The image is produced by motion of the satellite and the time delay associated with this received signal that gives the distance between target and radar. (See picture)

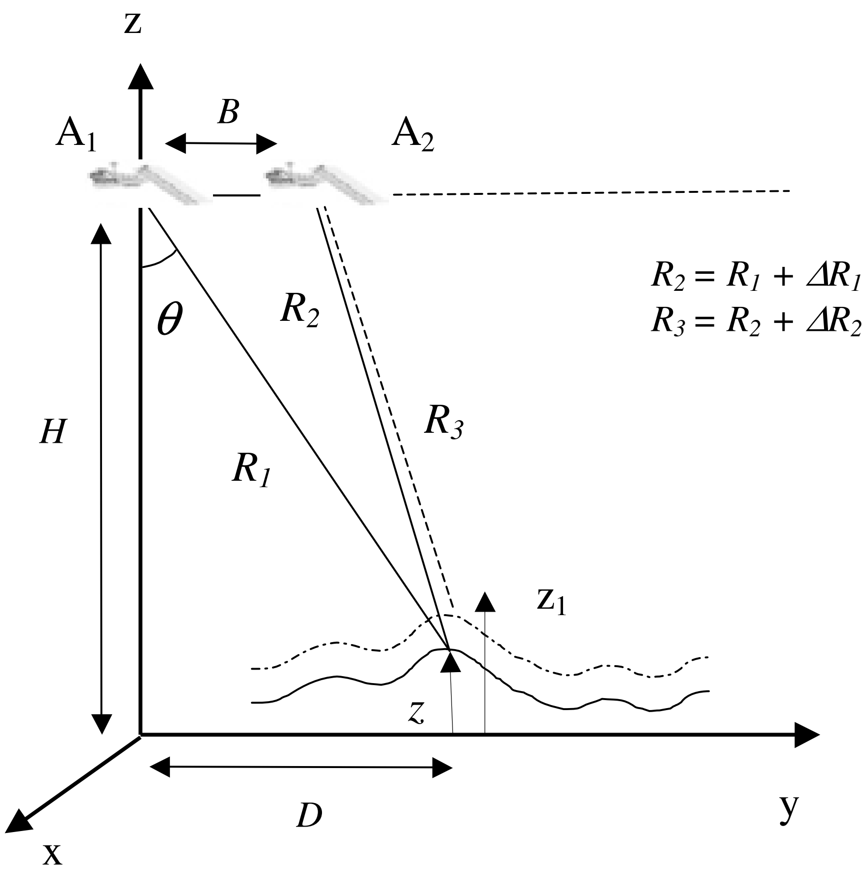


Description of the method for one single point:

<u>Satellite pass 1 (height calculation[1])</u>
Point A$_1$: The satellite sends the signal and receives the reflected signal at the same point, recording the phase $\phi_1 = k(2R_1)$ where $k = \dfrac{2\pi}{\lambda}$
Point A$_2$: The satellite sends the signal and receives the reflected signal at the same point, recording the phase $\phi_2 = k(2R_2)$ where $k = \dfrac{2\pi}{\lambda}$
<u>Satellite pass 2 (surface deformation)</u>
Point A$_2$: After a certain time, the satellite passes again over the same point in space and records a different phase in this point due to a surface deformation R_3

Note:
Due to the speed of the signal we can consider that the point does not change during each round-trip of the emitted signal.
Radars can take pictures of large areas of land day and night under all weather conditions.

[1] See note in the solution



a) **Calculate ΔR_1 as a function of the phase difference, $\Delta\phi_{21} = \phi_2 - \phi_1$ detected by the antenna.**

Changes of height on the surface can be related to volcano eruptions, land subsidence, earthquakes, sea waves, oil spills etc.

A deformation is detected. This formula $\Delta z = z_1 - z = \Delta\phi_{31} \dfrac{\lambda}{4\pi} \cos\theta$ gives the deformation range comparing phases taking at different satellite passes.

b) **The phase difference of each fringe is between 0 and 2π. If the C-band is used ($\lambda = 6\,\text{cm}$) and the viewing angle is 20°, what is the maximum deformation that can be detected for each fringe?**

c) **How would you improve the accuracy of the data?**

If you want to know more: http://www.esa.int/envisat

Solution: "When the ground moves"

a) Round trip signal $R_2 = R_1 + \Delta R_1$ so

$$\Delta\phi_{21} = \phi_2 - \phi_1 = \frac{2\pi[2(R_1 + \Delta R_1)]}{\lambda} - \frac{2\pi(2R_1)}{\lambda} = \frac{4\pi\Delta R_1}{\lambda}$$

$$\Delta R_1 = \frac{\Delta\phi_{21}\lambda}{4\pi}$$

Note

To calculate the height z:

The parameters $\phi, \lambda, B, H, \theta$ are known for the satellite and using the cosines rule:

$$\sin\theta = \frac{R_1{}^2 + B^2 - (R_1 + \Delta R_1)^2}{2RB}$$

$$z = H - R_1\cos\theta$$

These formulas are used for all points on the surface. Software manipulates the data and generates the image with the height of each point.

b) $\Delta z = 2\pi \times \frac{6\,\text{cm}}{4\pi} \times \cos 20° = 2.8\,\text{cm}$. So deformations can be detected at intervals of 2.8 cm.

c) By repeating passes of the satellites over the same area.

6 - The Universe in different wavelengths

All ESA science satellites observe the Universe at different wavelengths. This means that they can be used to study a variety of different phenomena – the most violent processes in the universe (such as *supernovae* and *black holes*), normal activity of the stars and even the most ancient *radiation* in the Universe. Below is a list of four ESA satellites and the typical wavelengths their instruments can detect.

Calculate the frequency for each wavelength. Sort them in descending order of energy of the radiation that they are used to study.

Artist's impression of the Integral satellite

Hubble $\lambda = 50\ \mu m$

Planck $\lambda = 5\ mm$

Integral $\lambda = 0.0001\ nm$

XMM-Newton $\lambda = 0.1\ nm$

Data: Speed of light $c = 3 \times 10^{8}\ m/s$

If you want to know more: http://www.esa.int/science

Solution "The Universe in different wavelengths"

Thanks to Planck's law we know the relationship between energy and frequency

$E = hf$ Where h is Planck's constant

Frequency and wavelength are related by $f = \frac{c}{\lambda}$ where c is the speed of light in the vacuum

Hubble $f = \frac{3\times10^{8}\text{ m/s}}{50\times10^{-6}\text{ m}} = 6\times10^{12}\text{ s}^{-1}$

Planck $f = \frac{3\times10^{8}\text{ m/s}}{5\times10^{-3}\text{ m}} = 6\times10^{10}\text{ s}^{-1}$

Integral $f = \frac{3\times10^{8}\text{ m/s}}{0.0001\times10^{-9}\text{ m}} = 3\times10^{21}\text{ s}^{-1}$

XMM-Newton $f = \frac{3\times10^{8}\text{ m/s}}{0.1\times10^{-9}\text{ m}} = 3\times10^{18}\text{ s}^{-1}$

The higher the frequency the higher the energy.

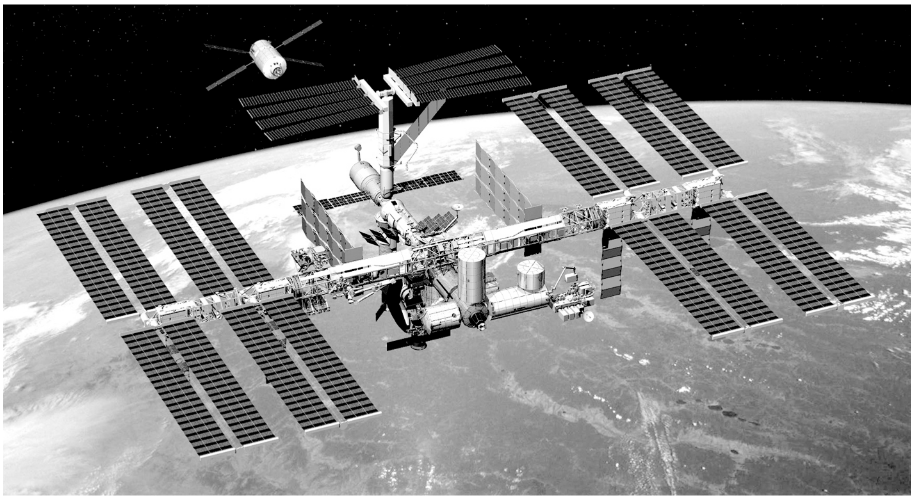
The solution is:

Integral (Gamma ray)
XMM-Newton (X-Ray)
Hubble (Near Ultraviolet, Visible and near infrared)
Planck (launch planned for 2007) (microwave)

7 - Living on board the ISS

In partnership with the United States, Russia, Japan and Canada, Europe is taking part in the greatest international project of all time – the International Space Station (ISS). Once completed, the 450-tonne International Space Station will have more than 1200 cubic metres of pressurised space - enough room for a crew of seven and a vast array of scientific experiments.

The ISS orbits the Earth at a height of 400 km above the surface.



The International Space Station

How many times do astronauts on the ISS see the Sun rise each Earth day?

Mass of Earth:	$M = 6 \times 10^{24}$ kg
Radius of Earth:	6378 km
Gravitational constant:	$G = 6.67 \times 10^{-11}\ \mathrm{m^3/kg \cdot s^2}$

If you want to know more : http://www.esa.int/esaHS

Solution "Living on board the ISS"

In a circular orbit the gravitational force acts as the centripetal force:

So… $$\frac{G \cdot M \cdot m}{r^2} = \frac{m \cdot v^2}{r}$$

Simplify… $$v^2 = \frac{G \cdot M}{r}$$

Substitute… $$v^2 = \frac{6.67 \times 10^{-11}\ \mathrm{m^3/kg \cdot s^2} \times 6 \times 10^{24}\ \mathrm{kg}}{(400000\ \mathrm{m} + 6378000\ \mathrm{m})}$$

Velocity $v = 7.68\ \mathrm{km/s} = 27648\ \mathrm{km/h}$

Time to make one orbit:

$$t = \frac{e}{v} = \frac{2\pi R}{v} = \frac{2 \times 3.14 \times 6778\ \mathrm{km}}{27648\ \mathrm{km/h}} \cong 1.5\ \mathrm{h} = 90\ \mathrm{min}$$

24 h means one sunrise on Earth. The ISS concludes one orbit every 90 min =1.5h.

The number of sunrises in the ISS = $\frac{24\ \mathrm{h}}{1.5\ \mathrm{h}} = 16$

8 - Why is Ariane 5 so big?

For the propulsion of the main *cryogenic stage* of Ariane-5 (the central tank in the picture), 132 tonnes of liquid oxygen and 25 tonnes of liquid hydrogen are stored in the launcher's giant core. The core consists of two main compartments: one for liquid oxygen and one for liquid hydrogen.

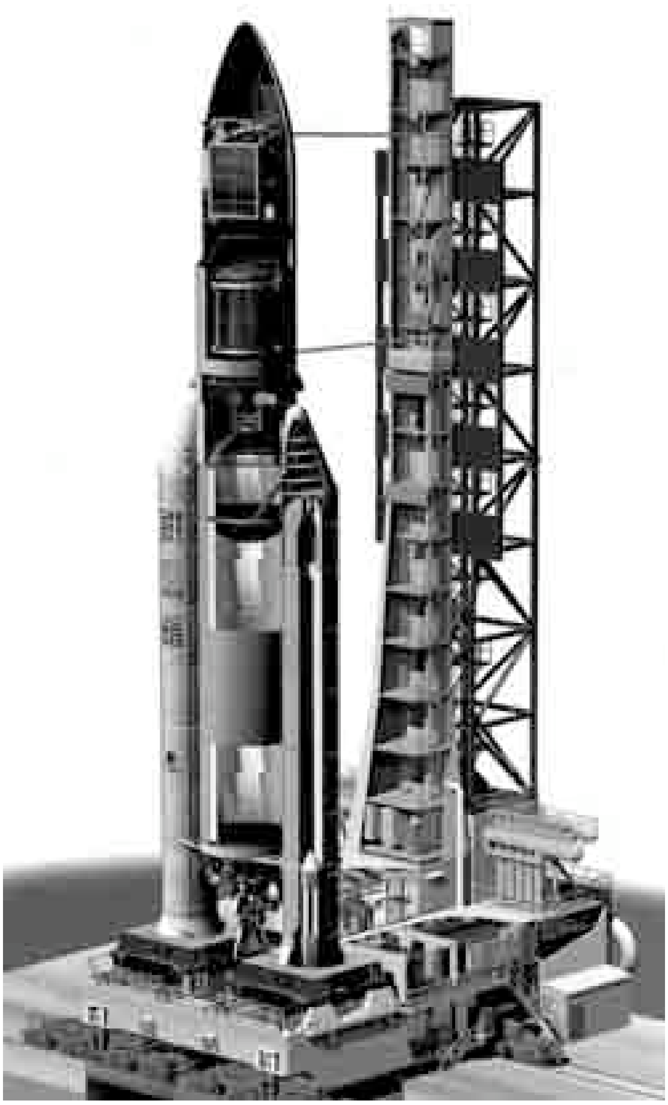
a) Which of these compartments must be bigger?

b) Calculate the number of hydrogen and oxygen molecules.

Assume you have a cylinder of 2.7 m radius (the same of that of Ariane 5).

c) How tall must this cylinder be to contain these quantities of liquid oxygen and liquid hydrogen?

Data:
Liquid hydrogen density: 0.07 g/cm^3
Liquid oxygen density: 1.14 g/cm^3
Avogadro's number:
6.022×10^{23} particules/mol



If you want to know more: http://www.esa.int/launchers

Solution "Why is Ariane 5 so big?"

a)

Hydrogen compartment $V = \frac{m}{d} = \frac{25000\,\text{kg}}{70\,\text{kg/m}^3} = 357.1\,\text{m}^3$

Oxygen compartment $V = \frac{m}{d} = \frac{132000\,\text{kg}}{1140\,\text{kg/m}^3} = 115.7\,\text{m}^3$

b) Hydrogen, H_2

$25\ \text{tonnes} = 25 \times 10^6\,\text{g}$

$\frac{25 \times 10^6\,\text{g}}{2\,\text{g/mol}} = 1.25 \times 10^7\,\text{mol}$

$\text{Molecules} = 1.25 \times 10^7\ \text{mol} \times 6.022 \times 10^{23}\ \text{molecules/mol} = 7.5275 \times 10^{30}\ \text{molecules}$

Oxygen, O_2

$132\ \text{tonnes} = 132 \times 10^6\ \text{g}$

$\frac{132 \times 10^6\,\text{g}}{32\,\text{g/mol}} = 4.125 \times 10^6\ \text{mol}$

$\text{Molecules} = 4.125 \times 10^6\,\text{mol} \times 6.022 \times 10^{23}\,\text{molecules/mol} = 2.484 \times 10^{30}\ \text{molecules}$

c) If we add the two quantities we will have a combined volume of 472.8 m^3

Cylinder volume= (Basis Area) $\times$ (height)

$$h = \frac{V}{\pi R^2} = \frac{472.8\,\text{m}^3}{3.14 \times (2.7\,\text{m})^2} = 20.65\,\text{m}$$

This is one of the main reasons of the size of Ariane 5.

Together with the boosters, engines, payload fairing, the third stage propulsion and some more compartments Ariane 5 reaches a height of more than 50 metres.

9 - Space Debris – danger in space

ESOC, the European Space Operations Centre in Darmstadt, Germany, is responsible for controlling ESA satellites in orbit. One of its tasks is to track man-made *space debris* that could damage the satellites.

Control Centre at ESOC

Approximately 110 000 objects estimated to be between 1 cm and 10 cm in size have been observed in low Earth orbits (between 400 km and 1000 km). A typical orbital velocity of objects at these altitudes is around 7.5 km/s.

a) **Suppose an aluminium sphere of 4 cm diameter collides with a satellite in orbit and calculate the loss of kinetic energy.**

b) **How fast would a car (1 t) have to go to produce the same energy in a crash on Earth?**

Data: Aluminium density: 2.70 g/cm^3

If you want to know more: http://www.esoc.esa.de

Solution "Space Debris – danger in space"

Mass

$$m = Vd = \frac{4}{3}\pi R^3 d = \frac{4}{3} \times 3.14 \times (2\ \text{cm})^3 \times 2.70\ \text{g/cm}^3 = 90.43\ \text{g} \cong 0.0904\ \text{kg}$$

Kinetic Energy

$$E = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.0904\ \text{kg} \times (7500\ \text{m/s})^2 = 2542500\ \text{J}$$

Car crash

$$v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2 \times 2542500\ \text{J}}{1000\ \text{kg}}} = 71.31\ \text{m/s} = 256.7\ \text{km/h}$$

There is enough energy to penetrate and damage the spacecraft, resulting in a loss of the spacecraft.

10 - XMM–Newton discovering the secrets of the Universe

XMM-Newton, with a mass of 3.8 tonnes, is the biggest science satellite ever built in Europe. It studies the violent universe by detecting the emitted X-rays – from what happens in and around *black holes* to the formation of *galaxies* in the early Universe.

XMM-Newton was launched on 10 December 1999 by the launcher Ariane 5 from Kourou (French Guiana). XMM-Newton has a 48-hour elliptical orbit. The orbit's apogee is 114 000 km above the Earth and the orbit's perigee is 7000 km above the Earth, where it passes the Earth at a speed of 24 120 km/h.

a) **Find the speed of XMM-Newton at the apogee of its orbit.**

b) **In which part of the orbit is XMM-Newton at its slowest?**

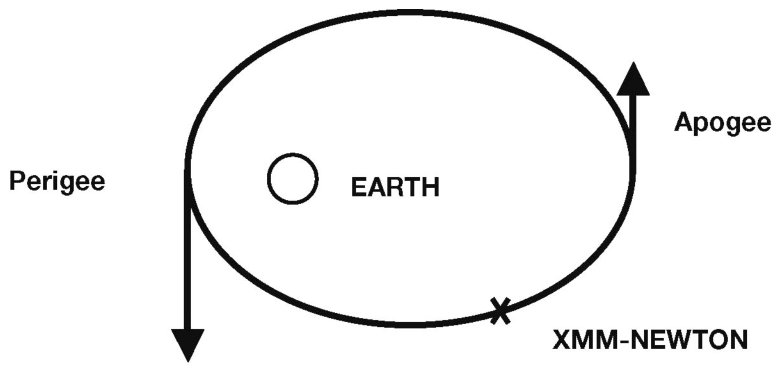
The elliptical orbit of XMM-Newton is inclined 40 degrees to the Earth's equator, with its long arm on the southern side.

c) **Why does the European Space Agency have a *tracking station* in Perth, Australia?**

In the radiation belts that can extend to about 40 000 km above the Earth there are zones of high-energy particles that can give false readings in the satellite detectors.

d) **How does XMM-Newton avoid these false readings most of the time during its orbit?**

Data: Radius of Earth = 6378 km



If you want to know more: http://www.esa.int/science/xmmnewton

Solution “XMM–Newton discovering the secrets of the Universe”

a) The angular momentum of the satellite remains constant because it moves under a central force.

$$L_{apogee} = L_{perigee}$$
$$m_{XMM} v_a r_a \sin 90° = m_{XMM} v_p r_p \sin 90°$$

$$v_a = \frac{v_p r_p}{r_a} = \frac{24120\ \text{km/h} \times 13378\ \text{km/h}}{120378\ \text{km}} = 2680.5\ \text{km/h}$$

b) According to Kepler’s second law, XMM-Newton must sweep out equal areas in equal time intervals. The area is bigger in the long arm. Thus the time is longer and the velocity smaller with the minimum velocity at the apogee as we saw in section a).
This means that XMM-Newton spends most of the time orbiting in the long arm.

c) As the long arm of XMM-Newton’s orbit is on the side of Earth’s southern hemisphere, a tracking station in this hemisphere is needed to remain in contact with the satellite.

d) By having a very elongated orbit. The advantage is that most of the time is spent outside the radiation belts with an apogee of 120 378 km. In fact, XMM-Newton spends almost 40 hours out of the 48 hours of its total orbit time in space beyond the radiation belts, where uninterrupted astronomy can proceed.

11 - Earth rotation speed and Kourou

Launches into a geostationary orbit can profit from additional velocity due to the rotation of the Earth.

a) In what direction should a launcher take off to take advantage of this effect?

b) Find the additional velocity given by the rotation of the Earth on the equator and on the North Pole.

Kourou, the European spaceport, lies at latitude of 5.2°, just over 500 km north of the equator.

c) Calculate the additional velocity given by the rotation of the Earth to an Ariane-5 launched from there.

Baikonur, the Russian spaceport, is located at latitude of 51.6° and Cape Canaveral lies at a latitude of 28.5°.

d) Calculate the additional velocity given to their launchers and compare the result with the additional velocity at Kourou.

e) What is the main advantage of this effect regarding the launcher and the satellite?

f) If you were to choose the best place to build a spaceport in Australia for placing satellites in geostationary orbits, would you choose northern or southern Australia? Why?

Ariane 5 on its way to the launch pad in Kourou

Data: Radius of Earth = 6378 km

If you want to know more: www.esa.int/launchers

Solution "Earth rotation speed and Kourou"

a) The same as the velocity of the rotation of the Earth, towards the east.

b) Equator

$$v = \frac{2\pi R}{t} = \frac{2 \times 3.14 \times 6378\ \text{km}}{24\ \text{h}} = 1668.91\ \text{km/h} = 463.5\ \text{m/s}$$

Pole

$v = 0$ m/s As it is placed in the Earth's rotational axis

c) Kourou

$$v = \frac{2\pi R \cos 5.2°}{t} = \frac{2 \times 3.14 \times 6378\ \text{km} \times \cos 5.2°}{24\ \text{h}} = 1662\ \text{km/h} = 461.6\ \text{m/s}$$

d) Baikonour

$$v = \frac{2\pi R \cos 51.6°}{t} = \frac{2 \times 3.14 \times 6378\ \text{km} \times \cos 51.6°}{24\ \text{h}} = 1036.6\ \text{km/h} = 287.9\ \text{m/s}$$

Cape Canaveral

$$v = \frac{2\pi R \cos 28.5°}{t} = \frac{2 \times 3.14 \times 6378\ \text{km} \times \cos 28.5°}{24\ \text{h}} = 1466.6\ \text{km/h} = 407.3\ \text{m/s}$$

It is clear that launches from Kourou need less initial additional speed thanks to its proximity to the equator.

e) The effect saves fuel and money, thus more massive satellites can be launched.
From Kourou an Ariane 5 can launch more than 6 tonnes into geostationary orbit, from Baikonour 3.5 tonnes and 5 tonnes from Cape Canaveral.

f) Northern Australia, near to the equator, to benefit from maximum additional velocity due to the rotation of the Earth.

12 - Removing gas contaminants in space

In a space habitat where astronauts work, CO_2, a product of human respiration, must be controlled and removed before it becomes toxic.

In space suits, LiOH is used to chemically adsorb the CO_2, producing Li_2CO_3 and H_2O.

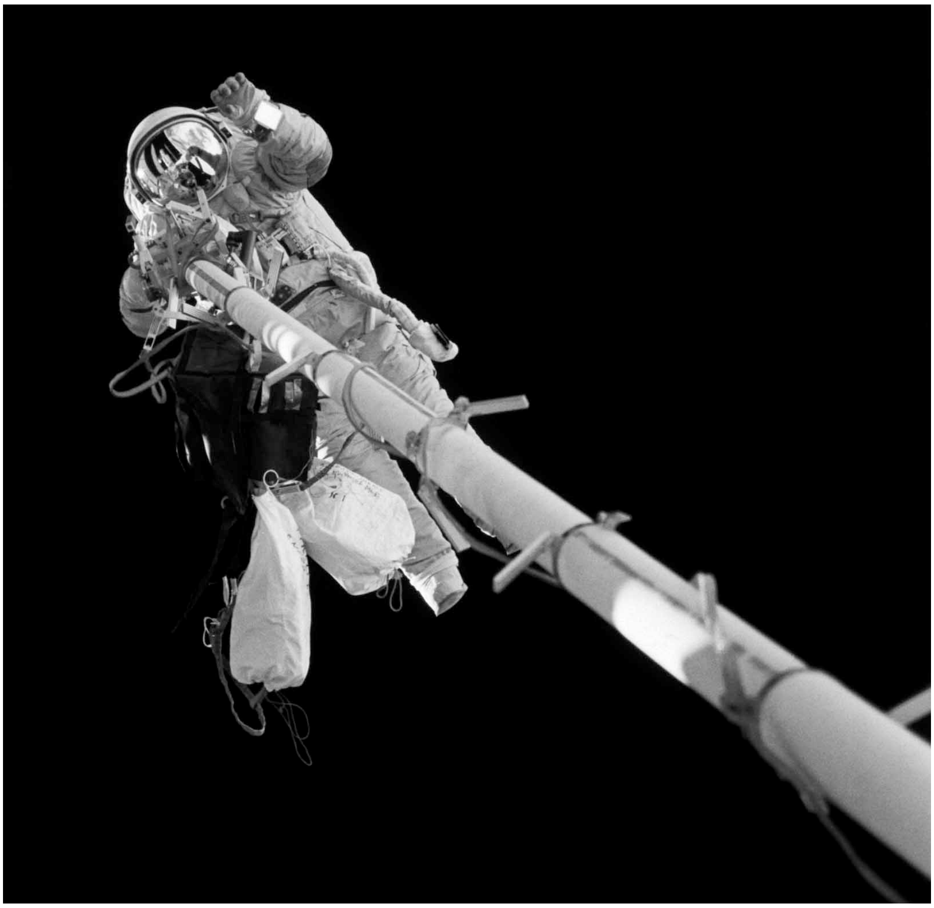
a) Write and adjust the chemical reaction.

CO_2 generation varies from 0.5 kg to 1.3 kg per person per day, depending on the physical effort and metabolism.

b) If you had to plan a 6-hour *extravehicular activity (EVA)* of an astronaut in space, what minimum mass of LiOH would you put in the space suit?

In the ISS, only regenerable systems are used to remove the CO_2, while LiOH canisters are always on standby as a backup.

c) Why are they not used as the main technology to eliminate the CO_2?



ESA astronaut Thomas Reiter during a spacewalk

If you want to know more: http://www.esa.int/esaHS

Solution "Removing gas contaminants in space"

a) $2LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O$

b) To be sure we will consider high workloads, where more CO_2 is produced, i.e. 1.3 kg per person and day (24 h).

Mass of CO_2 in 6 h = 0.325 g

$$\frac{48 \text{ g/mol LiOH}}{44 \text{ g/mol } CO_2} = \frac{x}{0.325 \text{g } CO_2} \qquad x = 0.354 \text{ g LiOH}$$

This is the theoretical quantity. In reality, you have to consider more parameters such as chemical reaction velocity, efficiency, chemical surface, etc. As a consequence more LiOH will be needed.

c) The spent LiOH is not regenerated and the canisters have to be disposed of or returned to Earth for replenishment with fresh absorbent.
For long missions the needed mass of LiOH would be very big and, as mass is one of the main parameters considered in launches, it is preferred to use other technologies and keep the LiOH canisters for emergencies.

3 - Space Chemistry

Complete this table:

	Formula	Chemical Name
Used to chemically adsorb the CO_2 exhaled by astronauts	LiOH	
Solar cells in the Cryosat satellite, which will study variations in the ice caps		Gallium Arsenide
Main constituent of Ariane-5 booster propellant	NH_4ClO_4	
There is a layer of this compound in one of the detectors of the Integral satellite		Cadmium Telluride
The heaviest element generated by stars during normal life	Fe	
Small particles of man-made space debris		Aluminum oxide
95.32% of Mars' atmosphere	CO_2	
Constituent of Titan's atmosphere; believed to form lakes on Titan's surface.		Methane
Nuclear electricity generated on the NASA/ESA spacecraft Cassini/Huygens is based on this element	Pu	
Envisat's batteries are made of this		Nickel-Cadmium

If you want to know more: http://www.esa.int

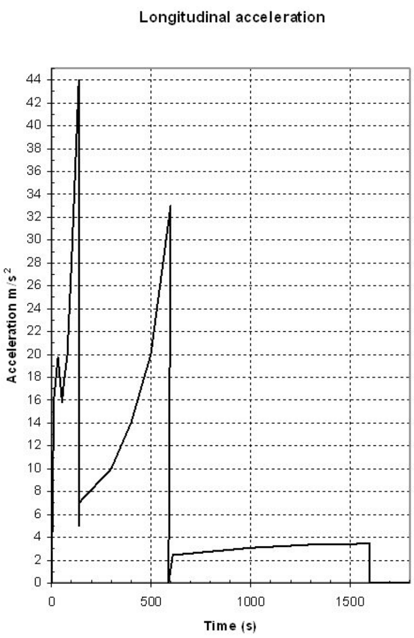
Solution “Space Chemistry”

	Formula	Chemical Name
Used to chemically adsorb the CO_2 exhaled by astronauts	$LiOH$	Lithium hydroxide
Solar cells in the Cryosat satellite, which will study variations in the ice caps	$GaAs$	Gallium Arsenide
Main constituent of Ariane-5 booster propellant	NH_4ClO_4	Ammonium perchlorate
There is a layer of this compound in one of the detectors of the Integral satellite	$CdTe$	Cadmium Telluride
The heaviest element generated by stars during normal life	Fe	Iron
Small particles of man-made space debris	Al_2O_3	Aluminum oxide
95.32% of Mars’ atmosphere	CO_2	Carbon dioxide
Constituent of Titan’s atmosphere; believed to form lakes on Titan’s surface.	CH_4	Methane
Nuclear electricity generated on the NASA/ESA spacecraft Cassini/Huygens is based on this element	Pu	Plutonium
Envisat’s batteries are made of this	Ni-Cd	Nickel-Cadmium

14 - Interpreting graphics: launching into geostationary transfer orbits

A launcher has to carry satellites into space. For good efficiency, most launchers have three stages, each stage dropping away once it has fulfilled its purpose.
Below is an example of how an Ariane-5 rocket launches satellites into geostationary transfer orbit.

Compare pictures 1 and 2 to answer the questions.



a) Match and locate points 2, 4 and 7 from the picture on the graph.

b) Why does the acceleration become 0 after finishing the second stage? Why does it not do this after the first stage?

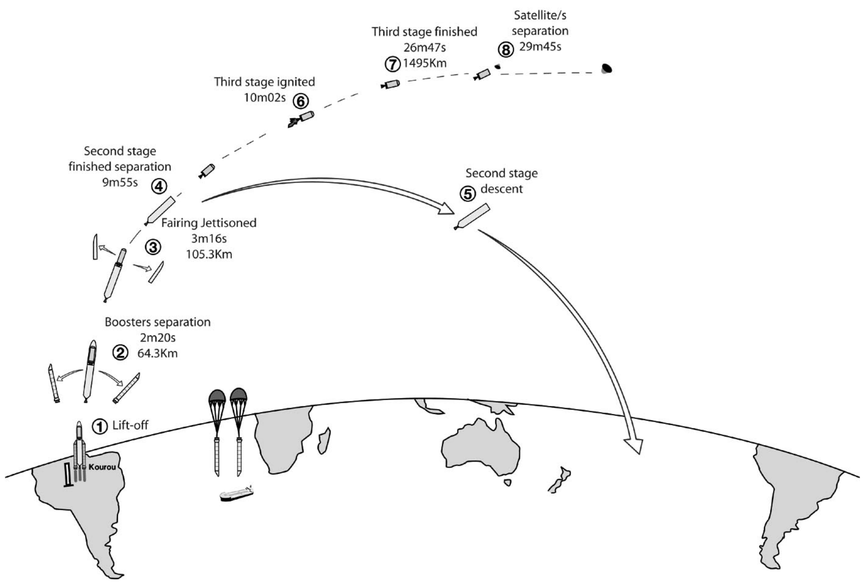
c) During the second stage the engine works at constant force. How is it possible that acceleration increases as shown in the graphic?

d) The outer limit of the atmosphere is at around 100 km height. Why is the fairing that protects the satellite jettisoned?

e) What will happen with the central tank (No. 5)?

f) At which stage is the aerodynamic drag the highest? Why?

g) After 1600 seconds the acceleration is constant at 0 m/s^2, why?



If you want to know more: http://www.esa.int/launchers

Solution “Interpreting graphics: launching into geostationary transfer orbits”

a) They fit in the graphic with:
2, First fall (140 s) in acceleration when first stage is finished and second stage continues
4, Second fall (595 s) in acceleration when second stage is finished
7, Third fall (1607 s) in acceleration when third stage is finished

b) Because during a very short time no force is produced. Then $F = 0 \Rightarrow a = 0$
Because the tank of the second stage was already ignited $F \neq 0 \Rightarrow a \neq 0$

c) $a = \dfrac{F}{m}$, force is constant but mass is consumed so it becomes smaller, producing an increase in acceleration.

d) Now the launcher is outside the atmosphere this satellite protection is no longer needed, it would be extra mass.

e) It will be partially burnt in its re-entry into the atmosphere.

f) In the first part, 2, when the launcher is still in the atmosphere. This is one of the reasons why so much force is needed at this stage.

g) Because there are no more propulsive forces from the launcher.
From this moment the satellite will be released and injected into the elliptical geostationary transfer orbit. The launcher’s task has finished, the satellite is in orbit.
The apogee of this elliptical orbit is the common point to the circular geostationary orbit. Here the thrusters of the satellite will inject it into the right geostationary orbit.

15 - NUNA: powered by the Sun

An ESA-sponsored solar car called Nuna won the World Solar Challenge 2001, a race across Australia with cars purely powered by the Sun. Nuna broke all existing speed records. The type of *solar cells* used on Nuna will soon be flown on ESA satellites. The car even used solar cells from the Hubble Space Telescope, which had been taken back to Earth by ESA astronaut Claude Nicollier. Let's now consider a couple of cases in which you have to determine the best strategy for a solar car and see if you could win the race.

Nuna was designed by a group of Dutch students

<u>Nuna parameters</u>

Roll resistance coefficient, C_r	= 0.0045
Mass car	= 270 kg
Battery efficiency	= 95%
Gravity constant, g_0	= 9.81 m/s^2

During a 50-km drive you (mass = 80 kg) have a headwind of 20 km/h. Your strategy program shows you that you can drive at 92 km/h. During this period your *solar array* input is 1200 W. Table 1 shows the aerodynamic forces on the solar car.

Speed of the car [km/h]	Headwind [km/h]	F_{aero} [N]
82	20	50.15
82	0	32.41
92	20	60.47
92	0	40.80
102	20	71.75
102	0	50.15

Table 1: Aerodynamic forces at different speeds

There are 2 possible driving strategies for a solar car, namely (1) constant velocity and (2) constant power.

a) If you wanted to drive with constant power and consume the same energy as driving with a constant velocity of 92 km/h, what would your constant power be?

b) How much energy do you consume during this ride? The state of charge (SOC) of the battery was 4100 W·h when you started. What will the SOC be at the end?

Imagine during the first 25 km you have an input of the solar arrays of 1400 W, during the next 25 km of 1000 W. If you keep driving at 92 km/h your battery state-of-charge will be the same at the end of the journey. However, there is a way to drive faster and still consume the same amount of energy from your batteries.

c) Can you explain how? What would you do when entering a rainy or cloudy part of the race trajectory – brake or accelerate?

Imagine that you know that you will have a headwind of 20 km/h in the first 25 km, and that there will be no headwind in the last 25 km. You could drive with constant velocity, however, you could also go for a more aggressive strategy of slowing down (Headwind, 82 km/h) or accelerating (102 km/h) in the different parts of the trajectory.

d) If you were the strategist, which strategy would you follow?

If you want to know more: http://www.esa.int/education/solarcar

Solution "NUNA: powered by the Sun"

a) $P = Fv$

- F_{drag}= 60.47 N (See table 1)
- $F_{roll} = C_r m(\text{mass car} + \text{mass driver})g_0 = 0.0045 \times (270 + 80)\ \text{kg} \times 9{,}81\ \text{m/s}^2 = 15.45\ \text{N}$
- *Power* = $(F_{drag} + F_{roll})\cdot$ *car velocity* = 1940 W

b) $E = P\Delta t$

- $t = \dfrac{d}{v} = \dfrac{50\ \text{km}}{92\ \text{km/h}} = 0.543\ \text{h} = 1955\ \text{s}$

- Energy consumed = $Power \cdot t = 1940\ \text{W} \times 1955\ \text{s} = 3.792\ \text{MJ}$

- Energy attained = $P_{array} \cdot t = 1200\ \text{W} \times 1955\ \text{s} = 2.346\ \text{MJ}$

- Energy balance = Energy attained - Energy consumed
  $= 3.792\ \text{MJ} - 2.346\ \text{MJ} = 1.446\ \text{MJ} = 402\ \text{W}\cdot\text{h}$

- Battery SOC = SOC (t=0) - E (cons)·(1/efficiency)
  $= 4100\ \text{W}\cdot\text{h} - 402 \cdot \dfrac{1}{0.95}\ \text{W}\cdot\text{h} = 3677\ \text{W}\cdot\text{h}$

c) By slowing down in the sunny part, you will spend a longer time in the sunny part. Therefore you will receive more energy for your solar arrays for a longer time. In the cloudy part you can then speed up. This way you can drive the trajectory faster than the time you would spend driving at constant speed. Some teams in the World Solar Challenge did not realise this and slowed down in cloudy parts to save battery power. This meant that they spent more time in cloudy parts and lost valuable time.

d) <u>Case 1: Constant velocity (92 km/h)</u>

$$t(1) = t(2) = \frac{25\ \text{km}}{92\ \text{km/h}} = 0.271\ \text{h} = 975.6\ \text{s}$$

92 km/h = 25.5 m/s

Headwind
$P(1) = (F_{aero} + F_{roll})v = (60.47\ \text{N} + 15.45\ \text{N}) \times 25.5\ \text{m/s} = 1936\ \text{W}$

No headwind
$P(2) = (F_{aero} + F_{roll})v = (40.8\ \text{N} + 15.45\ \text{N}) \times 25.5\ \text{m/s} = 1434.3\ \text{W}$

$E_{total} = P(1)\, t(1) + P(2)\, t(2) = 1936\ \text{W} \times 975.6\ \text{s} + 1434.3\ \text{W} \times 975.6\ \text{s} = 3.288\ \text{MJ}$

Case 2: Aggressive wind strategy

$$\text{v}(1) = 82\ \text{km/h},\ t(1) = \frac{25\ \text{km}}{82\ \text{km/h}} = 0.305\ \text{h} = 1098\ \text{s}$$

$$\text{v}(2) = 102\ \text{km/h},\ t(2) = \frac{25\ \text{km}}{102\ \text{km/h}} = 0.245\ \text{h} = 882\ \text{s}$$

82 km/h = 22.7 m/s

102 km/h = 28.35 m/s

Headwind

$$P(1) = (F_{aero} + F_{roll})v = (50.15\ \text{N} + 15.45\ \text{N}) \times 22.7\ \text{m/s} = 1489\ \text{W}$$

No headwind

$$P(2) = (F_{aero} + F_{roll})v = (50.15\ \text{N} + 15.45\ \text{N}) \times 28.35\ \text{m/s} = 1859.7\ \text{W}$$

$$E_{total} = P(1)\,t(1) + P(2)\,t(2) = 1489.1\ \text{W} \times 1098\ \text{s} + 1859.7\ \text{W} \times 882\ \text{s} = 3.275\ \text{MJ}$$

You see that you can gain a little (~1%) by having a more aggressive wind strategy in gusty wind conditions. However, in the tough competition between the solar cars, this can be the difference between losing or winning.

16 - Galileo, giving worldwide accuracy positioning

In the year 2011, the European global navigation system Galileo will be operational. Galileo consists of 30 satellites in three circular orbit planes at 23616 km altitude, providing positioning accuracy down to the metre range and very good coverage at polar latitudes.

Imagine that a scientist in Iceland is exploring the Vatnajokull glacier. The scientist gets lost because of sudden bad weather. Fortunately he has a satellite receiver and a map.

For positioning the receiver detects the time it takes the signal, travelling at the speed of light, from the satellites and calculates the intersection point. See images 1, 2 and 3.

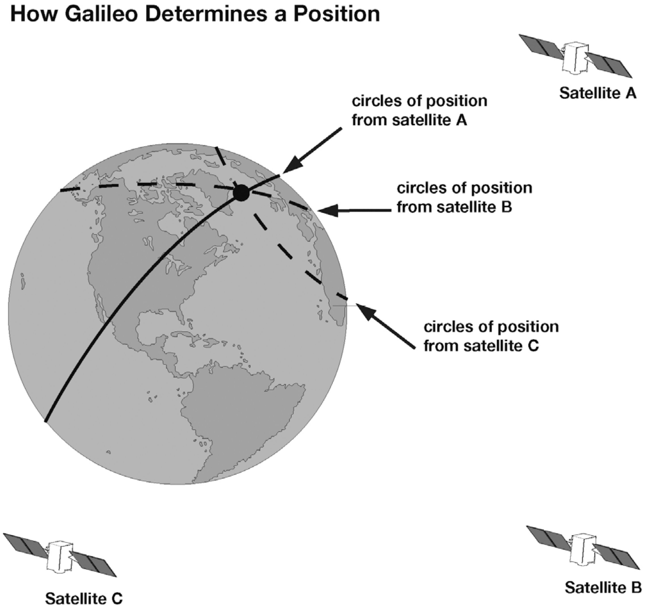


Image 1

a) What is the distance to each satellite?

$t_A = 0.0796963586$ s
$t_B = 0.0832568645$ s

The clocks onboard the satellites are atomic and their timing is perfect. However, the receivers' clocks are imperfect (if not they would be very expensive and nobody could afford them).

The scientist's receiver gives a tiny mistake of a few thousandths of seconds for each satellite

$t_A = 0.0797963586$ s
$t_B = 0.0835568645$ s

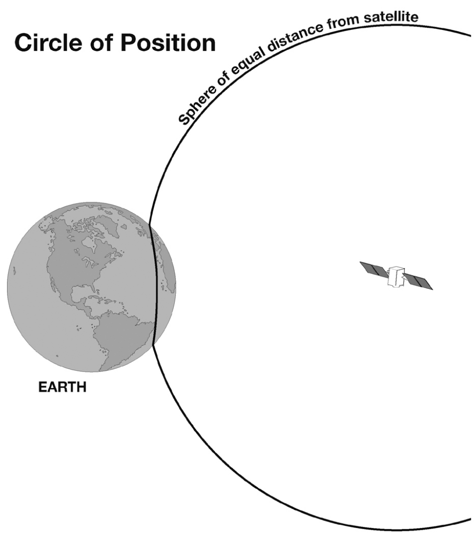


Image 2

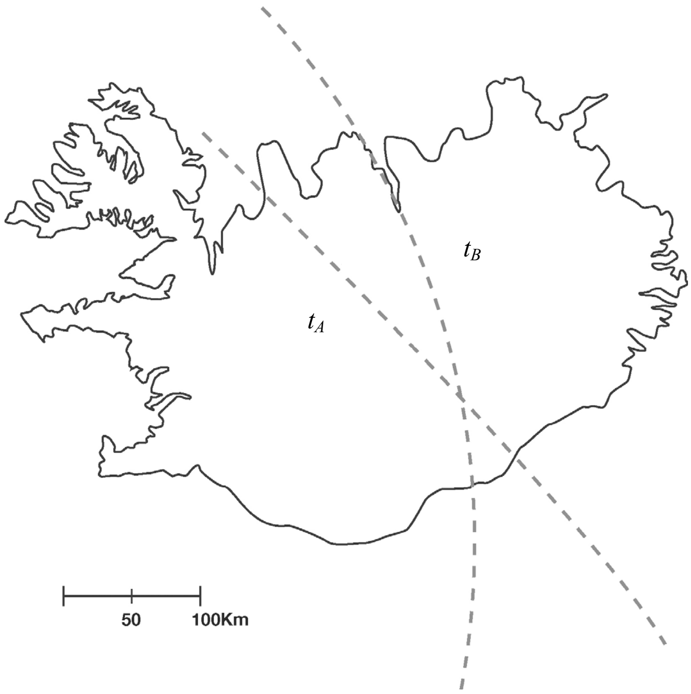


Image 3

b) Find the error positioning in km and draw in the map where approximately the wrong position would be.

Fortunately, a third satellite signal is received and the receiver detects a time offset for each measurement because more than a single point is possible.

c) How could this additional information be used?

1) To subtract the extra time and give the right position through an internal correction in the receiver.
2) To highlight a warning message in the screen of the receiver.
3) To send a help signal to a Galileo control centre.

The real world is three-dimensional, and another coordinate (altitude) is always needed.

d) How many satellite signals would be needed continuously to guide and give the right position of a plane?

Data: c = Speed of light = 300 000 km/s

Note: For simplicity we consider a two-dimensional exercise. The 3D model is obvious once the 2D is understood.

If you want to know more: http://www.esa.int/galileo

Solution “Galileo, giving a worldwide accuracy positioning”

a) Satellite A

$d_A = t_A\, c$ = 0.0796963586 s × 300000 km/s = 23908.90758 km

Satellite B

$d_B = t_B\, c$ = 0.0832568645 s × 300000 km/s = 24977.05935 km

Note: In reality two points are mathematically possible, but one of them is physically impossible and thus rejected.

b) Satellite A

$d_A = t_A\, c$ = 0.0797963586 s × 300000 km/s = 23938.90758 km

Circle error: 30 km

Satellite B

$d_B = t_B\, c$ = 0.0835568645 s × 300000 km/s = 25067.05935 km

Circle error: 90 km

Drawing the new intersection point in the map would give a position on the Atlantic Ocean. Bad thing!

c) The correct answer is 1).

The idea is to make an extra satellite measurement as a cross-check to get a perfect timing. This is applied to all receivers and in this way they behave as accuracy atomic clocks.

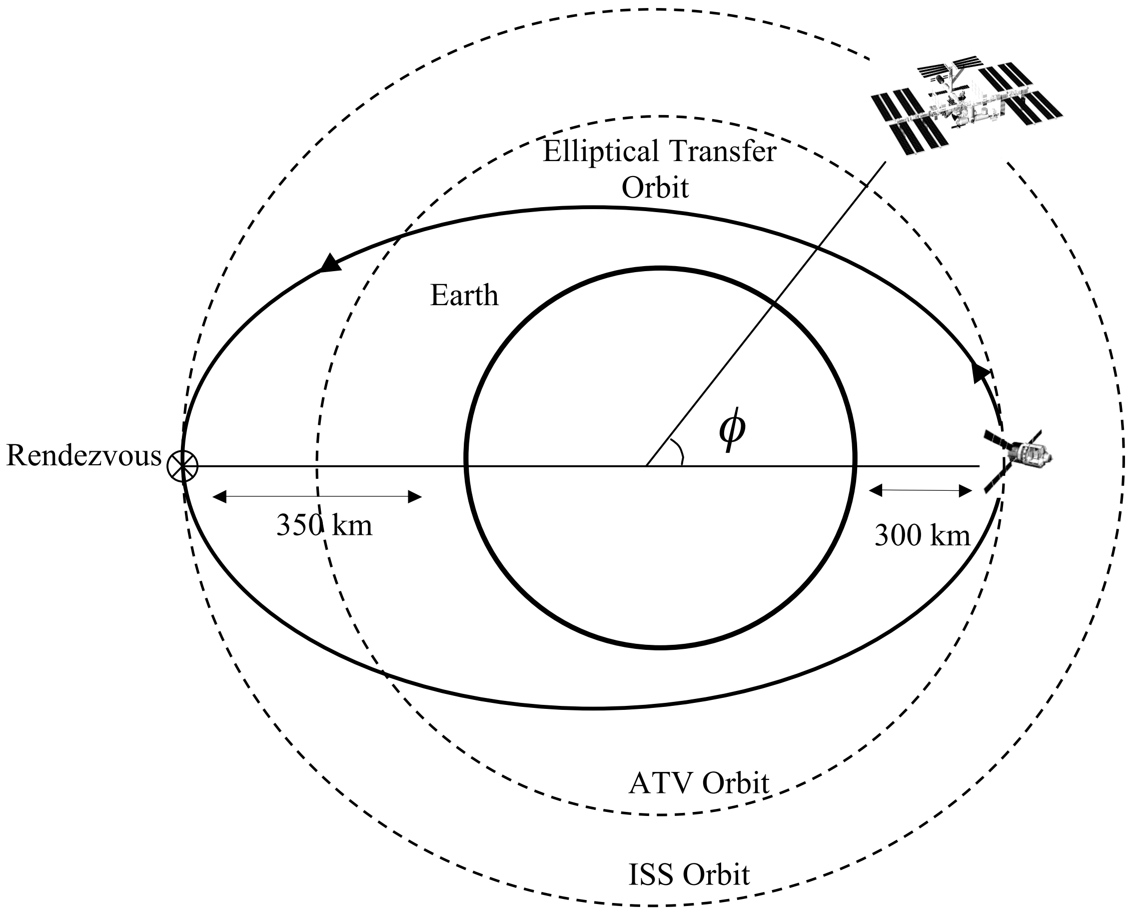
d) At least 4 satellite signals are required. From most locations, six to eight satellites will always visible for taking position, as the Galileo system will be interoperable with the US system of 24 GPS satellites.

17 - ATV and ISS – rendezvous in space

The International Space Station (ISS) depends on regular deliveries of propellant, food, air and water for its permanent crew and equipment for experiments. Every 12 months, Europe's *Automated Transfer Vehicle* (ATV) will be launched by an Ariane-5 from the European Spaceport at Kourou in French Guiana (South America) to re-supply and *re-boost* the Station.

The ATV is launched into a 300-km orbit, from which an elliptical *transfer orbit* is used to carry the ATV into a rendezvous trajectory towards the ISS at 350 km altitude.

Data:	Mass of Earth:	$M = 6 \times 10^{24}$ kg
	Radius of Earth:	$R = 6378$ km
	Gravitational constant:	$G = 6.67 \times 10^{-11}$ m^3/kg$\cdot$s^2
	Kepler's third law	$\frac{T^2}{a^3} = k$



Consider the ISS orbit as fixed in space inclined 51.6º over the equator and the Earth rotating underneath.

a) When is the best moment to launch ("*launch window*") the ATV and why?

b) Find the value of the constant in Kepler's 3rd law and the period of an elliptical orbit.
Hint: Consider circular orbits as a particular case of elliptical orbits.

c) What is the period of an elliptical orbit around the Earth with a semimajor axis of 6703 km?

d) What is the correct angle ϕ between the ATV and the ISS to insert the ATV into the appropriate transfer orbit for a successful rendezvous?

If you want to know more: http://www.esa.int/export/SPECIALS/ATV

Solution "ATV and ISS – rendezvous in space"

a) When Kourou is almost underneath the position of the ISS orbit. This way, the ATV will be put into an orbit which is in the same plane as the ISS, allowing fewer corrections in the transfer orbit.

b) Kepler's 3rd law

$$\frac{T^2}{a^3} = k$$ Where a is the semimajor axis

In a circular orbit $a = r$

So $\frac{GMm}{r^2} = m\omega^2 r$ where $\omega = \frac{2\pi}{T}$

So $\frac{GMm}{r^2} = \frac{mr4\pi^2}{T^2}$ and $\frac{T^2}{r^3} = k$

And working out the value of $k = \frac{4\pi^2}{GM}$ then $T = 2\pi\sqrt{\frac{a^3}{GM}}$

c) $$T = 2\pi\sqrt{\frac{a^3}{GM}} = 2\times 3.14\times\sqrt{\frac{(6703000\,\text{m})^3}{(6.67\times10^{-11}\,\frac{\text{m}^3}{\text{kg}\cdot\text{s}^2})\times(6\times10^{24}\,\text{kg})}} = 5447.8\,\text{s}$$

d) As we can see in the picture, the axis of the elliptical transfer orbit is
$2a$ = diameter of Earth + 300 km ATV orbit + 350 km ISS orbit=13406 km
So the semimajor axis is $a = 6703\,\text{km}$ and the period of the orbit is $T = 5447.8\,\text{s}$
Only half of the orbit is needed so the time is $t_{ATV\to ISS} = 2723.9\,\text{s}$
From c) we can calculate the orbital time of the ISS $t_{ISS} = 5478.35\,\text{s}$
The angular velocity of the ISS is

$$\omega = \frac{2\pi}{t_{ISS}} = \frac{2\times3.14}{5478.35\text{s}} = 1.146\times10^{-3}\,\text{rad/s}$$

We have to calculate the angle covered by the ISS in $t_{ATV\to ISS}$

$$\omega\, t_{ATV\to ISS} = 1.146\times10^{-3}\,\text{rad/s}\times 2723.9\,\text{s} = 3.12\,\text{rad} = 178.8^\circ$$

So $\phi = 180^\circ - 178.8^\circ = 1.2^\circ$

18 - Preparing a mission to Mars

Europe is preparing a long-term plan for the robotic and human exploration of the Solar System, with Mars, the Moon and asteroids as most likely targets. Scientists need a good knowledge of the physical features of each target to design successful missions.

Calculate the atmospheric density on the surface of Mars, assuming ideal gases. Compare with the atmospheric density on Earth.

Data:

<u>Earth</u>

Average temperature	15 ºC
Surface Pressure	1013 mbar = 1atm
Atmospheric Composition (dry air)	78.07% N_2 21% O_2 0.9% Ar 0.03% CO_2

<u>Mars</u>

Average temperature	-55 ºC
Surface Pressure	6.35 mbar
Atmospheric Composition (dry air)	95.49% CO_2 2.7% N_2 1.6% Ar 0.13% O_2 0.08% CO

Gas Constant: R=0.082 l·atm/mol·K

If you want to know more: http://www.esa.int

Solution "Preparing a mission to Mars"

To calculate the density:

Molecular weight $M = \dfrac{m}{n}$ so $m = nM$ then

Density $d = \dfrac{m}{V} = \dfrac{nM}{\left(\dfrac{nRT}{P}\right)} = \dfrac{MP}{RT}$

Earth surface density

First we have to calculate the average molecular weight for the mixture of gases

$$M_{Earth} = 0.7807 \times (28\ \text{g/mol}) + 0.21 \times (32\ \text{g/mol}) + 0.009 \times (40\ \text{g/mol}) +$$
$$+ 0.0003 \times (44\ \text{g/mol}) = 28.95\ \text{g/mol}$$

$$d = \frac{(28.97\ \text{g/mol}) \times (1\ \text{atm})}{(0.082\ \text{l} \cdot \text{atm/mol} \cdot \text{K}) \times 288\ \text{K}} = 1.22\ \text{g/l} = 1.22\ \text{kg/m}^3$$

Mars surface density

First we have to calculate the average molecular weight for the mixture of gases

$$M_{Mars} = 0.9549 \times (44\ \text{g/mol}) + 0.027 \times (28\ \text{g/mol}) + 0.016 \times (40\ \text{g/mol}) +$$
$$+ 0.0013 \times (32\ \text{g/mol}) + 0.0008 \times (28\ \text{g/mol}) = 43.47\ \text{g/mol}$$

$$P = 6.35\ \text{mbar} \times 1\ \text{atm}/1013\ \text{mbar} = 0.0062\ \text{atm}$$

$$d = \frac{(43.47\ \text{g/mol}) \times (0.0062\ \text{atm})}{(0.082\ \text{l} \cdot \text{atm/mol} \cdot \text{K}) \times 218\ \text{K}} = 0.015\ \text{g/l} = 0.015\ \text{kg/m}^3$$

The Earth's surface atmospheric density is approximately 80 times higher than that of Mars.

These values can vary on the surface of Mars due to the range of temperatures, i.e. 27 ºC in summer during the day to –133 ºC in winter at the pole.

19 - New technologies for satellites: the Li-ion battery

The Li-ion technology is an excellent source for high-energy power and lightweight *batteries* for commercial portable devices, such as portable computers or cellular phones.

More and more spacecraft use batteries based on this technology. Proba is a micro-satellite used for Earth Observation and for testing new technologies. Its 9 A·h (Ampere·hour) Li-ion battery is mainly used in the *eclipse* phase. The maximum charge voltage corresponds to 25 V, the minimum discharge voltage is 15 V. The average discharge voltage to be used for questions is 21.6 V. The battery weighs 1.87 kg, the satellite 100 kg.

a) Calculate the energy capacity of the battery in Watt·hour (W·h) and in Joules.

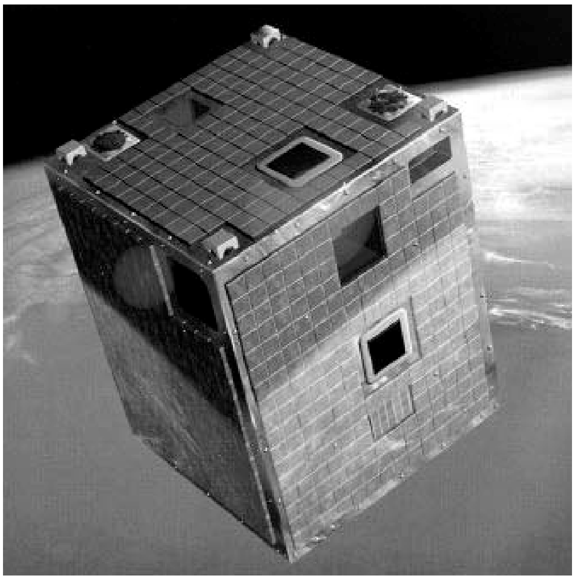
b) Calculate the battery-specific energy Watt·hour/kg.

To increase the lifetime and avoid low voltage levels in the instruments the maximum discharge is limited to 20% depth of discharge.

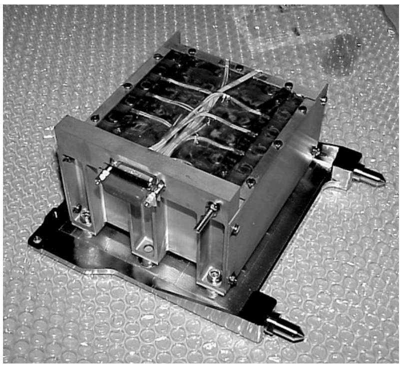
c) Calculate the energy stored in the battery at maximum discharge.

Mass is one of the main parameters to consider in the design of a satellite because good design can save fuel and thus money at launch. The Ni-Cd technology is also used for satellite batteries. Its battery-specific energy is 35 W·h/kg

d) How much heavier would this satellite be carrying Ni-Cd batteries?



The Proba satellite



Proba's Li-ion battery

If you want to know more: http://www.esa.int/proba

Solution "New technologies for satellites: the Li-ion battery"

a) $E = Pt = VIt = 9\ \mathrm{A \cdot h} \times 21.6\ \mathrm{V} = 195\ \mathrm{W \cdot h} = 195\ \mathrm{W} \times 3600\ \mathrm{s} = 700000\ \mathrm{J}$
This energy could be delivered in one hour at 100% discharge.

b) Specific energy $= \dfrac{195\ \mathrm{W \cdot h}}{1.87\ \mathrm{kg}} = 104\ \mathrm{W \cdot h/kg}$

c) Energy at 20% discharge $= \dfrac{80 \times 195\ \mathrm{W \cdot h}}{100} = 156\ \mathrm{W \cdot h}$

d) $m_{Ni-Cd} = \dfrac{195\ \mathrm{W \cdot h}}{35\ \mathrm{W \cdot h/kg}} = 5.57\ \mathrm{kg}$
5.57 kg – 1.87 kg means 3.70 kg mass saving on the total satellite weight.

Note: For an Ariane 5 launcher the price of launch mass into low Earth orbits is around 11000 Euro per kg, the launch cost saving for an Ariane 5 launch would have been 41000 Euro.

20 - 3D images from Mars

The European spacecraft Mars Express orbits Mars. The mission's main objective is to search for water under the surface of the planet. Mars Express also studies the Martian atmosphere, the planet's geology, composition and structure. A high-resolution stereo camera will take pictures of the planet in 3D with a *resolution* of about 10 m.

a) Compare the quantity of data you would obtain with this camera for the land surface area of Mars and of Earth.

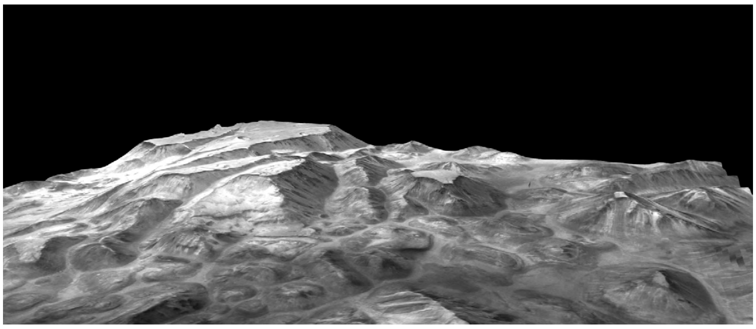
The data collected will be transmitted to an ESA ground station in Australia at an average rate of 100 kbps (kilo*bits* per second).

Imagine water has been discovered in a particular area.

b) How long would it take to receive on Earth a 200-MB image from Mars Express, located at a distance of 300 000 000 km?

Note: All this 200 MB of data is processed and compressed to JPEG or TIFF-type images of a few MB.

c) Every day up to 5 Gbits of scientific data will be downlinked from the spacecraft to Earth. How long does it take to send the data?



A view of Mars by a camera on Mars Express

Data: Mars Radius= 3397 km, Earth Radius= 6378 km
71% of the Earth is covered by water
Speed of signal=speed of light (c)=300 000 km/s

Data storage

	Bit	Byte	Kilobyte	Megabyte	Gigabyte
1 Byte	8	1	-	-	-
1 Kilobyte (KB)	8 192	1 024	1	-	-
1 Megabyte (MB)	8 388 608	1 048 576	1 024	1	-
1 Gigabyte (GB)	8 589 934 592	1 073 741 824	1 048 576	1 024	1

Data transfer: 1 Gbits=1000 Mbits=10^6 Kbits=10^9 bits

If you want to know more: http://www.esa.int/science/marsexpress

Solution "3D images from Mars"

a) Earth surface area = $4\pi (R_{Earth})^2 = 4 \times 3.14 \times (6378\ \text{km})^2 = 510926783\ \text{km}^2$

Earth land area (29%)= $148168767\ \text{km}^2$

Mars surface area = $4\pi (R_{Mars})^2 = 4 \times 3.14 \times (3397\ \text{km})^2 = 144937489\ \text{km}^2$

The data obtained would be approximately the same, in fact the surface area of Mars plus an area the size of India would have exactly the Earth's land surface area.

b) Time for signal to arrive from Mars Express to Earth

$$t_{signal} = \frac{d}{c} = \frac{3 \times 10^8\ \text{km}}{3 \times 10^5\ \text{km/s}} = 1000\ \text{s} = 16\text{m}\ 40\text{s}$$

Time to send the whole data

$$t_{data} = \frac{200\ \text{MB} \times 8388608\ \text{bits/MB}}{100000\ \text{bits/s}} = \frac{1677721600\ \text{bits}}{100000\ \text{bits/s}} = 16777\ \text{s} = 4\text{h}\ 39\text{m}\ 37\text{s}$$

$$t = t_{signal} + t_{data} = 16\text{m}\ 40\text{s} + 4\text{h}\ 39\text{m}\ 37\text{s} = 4\text{h}\ 56\text{m}\ 17\text{s}$$

c) $$t_{data} = \frac{5\ \text{Gbits}}{100000\ \text{bits/s}} = \frac{5 \times 10^9\ \text{bits}}{100000\ \text{bits/s}} = 50000\ \text{s} = 13\text{h}\ 53\text{m}\ 20\text{s}$$

Note:

The HRSC (High Resolution Stereo Camera) will image:

- 50% of Mars' surface with a resolution of 10 – 15 meters /pixel
- 70% of Mars' surface with a resolution of 30 meters /pixel
- 100% of Mars' surface with a resolution of 100 meters/pixel.
- Selected areas with a resolution about 2 meters/pixel.

21 - SMART-1 – an innovative way of propulsion

The European satellite to the Moon, SMART-1, is propelled by electrical propulsion. The simplified version of the electrical propulsion system is shown in Figure 1. The propellant used is Xenon gas.

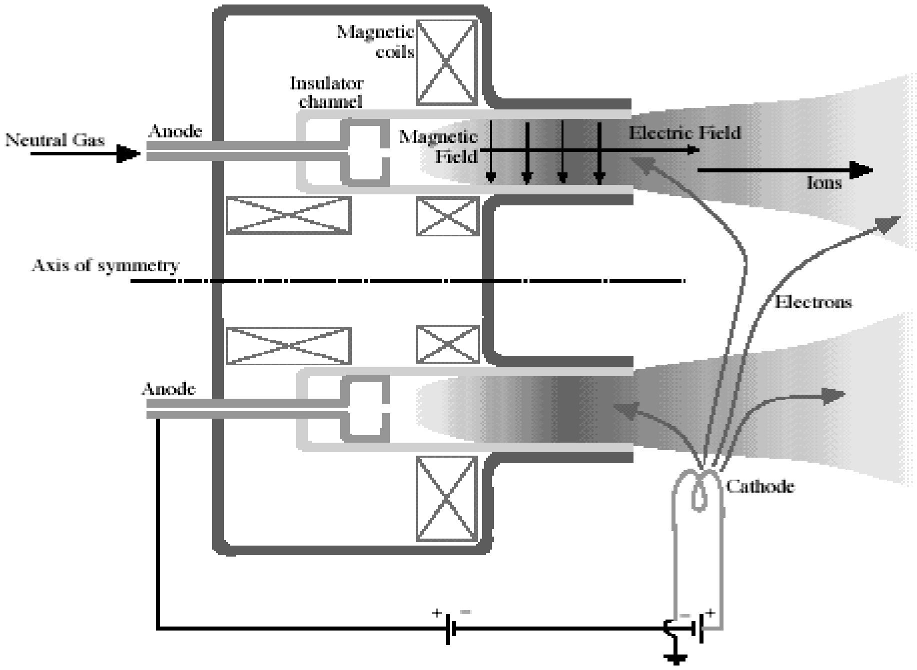


Figure 1: Schematic representation of electrical propulsion

a) Calculate the electric and magnetic forces on the Xe-ions and electrons.

b) Calculate the radius and the angular velocity w of the helicoidal motion executed by charged particles in a magnetic field.

If the Hall parameter $\Omega = \frac{w}{v_c}$ is large, the particles are trapped in the chamber. If the parameter is small, the particles are able to escape. The collision frequency v_c is a theoretical constant determined by various theories of statistical particles interactions, e.g. 2.6×10^{11} s^{-1}

c) Which particle has a bigger Hall parameter?

d) To start the process of electric propulsion, electrons emitted by the cathode move towards the anode under the influence of the electric field. Which is the direction of the acting force?

As seen in c) these electrons are trapped, forming a virtual cathode held at nearly the same potential of the external cathode.

e) **What will happen when the neutral gas (Xenon) collides with the electrons?**

f) **Assuming a constant speed, which particle would you choose to be expelled and produce thrust, Xe–ions or electrons? Why?**

Data from the SMART-1 Hall-effect Thruster:

$E = 7500 \text{ V/m}$
$B = 0.035 \text{ T}$
$v_i = 14000 \text{ m/s}$
$v_i \in [230, 20000] \text{m/s}$

$m_{Xe^+} = 2.187 \times 10^{-16} \text{ kg}$
$m_{e^-} = 9.1 \times 10^{-31} \text{ kg}$
$q = 1.6 \times 10^{-19} \text{ C}$

If you want to know more: http://www.esa.int/science/smart1

Solution "SMART-1 – an innovative way of propulsion"

a) $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) = (\vec{F}_E + \vec{F}_B)$

Xe-ions and electrons

$F_E = qE = 1.6\times10^{-19}\ \text{C}\times 7500\ \text{V/m} = 1.2\times10^{-15}\ \text{N}$

$F_B = qvB\sin 90 = 1.6\times10^{-19}\ \text{C}\times 14000\ \text{m/s}\times 0.035\ \text{T} = 7.8\times10^{-17}\ \text{N}$

b) The magnetic force acts as a centripetal force, so

$$\frac{mv^2}{r} = qvB\sin 90°$$

$$r = \frac{mv}{qB}$$

$v = wr$ so $w = \dfrac{qB}{m}$

Xe-ions

$r = 5.4675\times10^{8}\ \text{m}$ $w = 2.5\times10^{-5}\ \text{s}^{-1}$

Electrons

$r = 2.2\times10^{-6}\,\text{m}$ $w = 6.2\times10^{9}\ \text{s}^{-1}$

c) The electrons

d) Perpendicular to the plane containing the two fields

e) The gas is ionised allowing the ions to be accelerated by the electric field and to be expelled
The exhaust velocity of the Xe-ions is 20 km/s

f) As the ions are more massive than electrons; at the same speed the thrust produced is bigger as shown in *the law of momentum conservation*

22 - Chemical reactions in a rocket

The main *cryogenic stage* of an Ariane-5 is based on the combustion of liquid hydrogen and liquid oxygen. The oxygen compartment contains 132 tonnes of oxygen and the hydrogen compartment contains 25 tonnes of hydrogen. The chemical reaction is:

$$H_2 + O_2 \rightarrow H_2O + \text{Energy}$$

a) What kind of chemical reaction is this?

b) Which of these elements limits the reaction? Give a reason for the mass excess.

c) Knowing that liquid oxygen is driven into the combustion chamber at a rate of 221 litres per second, how much hydrogen (in kg) is required every second for the oxygen to react completely?

An Ariane-5 on the launch pad

d) The energy released by the combustion is 12.792 kJ/g. How much energy is released in 10 seconds? Calculate the height from which a 20-tonne-lorry needs to fall to lose the same amount of energy.

(Note: Assume no drag forces and acceleration due to gravity at 10 m/s$^{2.}$)

Data: Density of liquid oxygen 1.14 g/cm^3

If you want to know more: http://www.esa.int/launchers

Solution "Chemical reactions in a rocket"

a) Exothermic

b) First we need to adjust the equation:

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Energy}$$

We test first with hydrogen.
The oxygen needed to react completely with 25 tonnes of hydrogen is given by:

$$\frac{4\ \text{g/mol}\ H_2}{32\ \text{g/mol}\ O_2} = \frac{25000\ \text{kg}}{\text{x}} \qquad \text{x} = 200000\ \text{kg}$$

As the Ariane-5 launcher contains only 132 tonnes of liquid oxygen it is the oxygen that is limiting the reaction.

Part of the excess of liquid hydrogen at –252.8 °C is used to refrigerate the combustion chamber, where temperature rises to 1500 °C.

c) The mass of oxygen is given by:

$$m = Vd = 0.221\ \text{m}^3 \times 1140\ \text{kg/m}^3 = 252\ \text{kg}$$

To find the mass of oxygen:

$$\frac{4\ \text{g/mol}\ H_2}{32\ \text{g/mol}\ O_2} = \frac{\text{x}}{252\ \text{kg}} \qquad \text{x} = 31.5\ \text{kg}$$

d) The energy released in 10 seconds is given by:

$$E = (252000 + 31500)\ \text{g/s} \times 10\ \text{s} \times 12.792\ \text{kJ/g} = 36265320\ \text{kJ}$$

To compare with the fall of 20-tonne-lorry we must find the height for the same potential energy

$$h = \frac{E}{mg} = \frac{36265320\ \text{kJ}}{20000\ \text{kg} \times 10\ \text{m/s}^2} = 181.3\ \text{km}$$

23 - Parabolic Flights – microgravity research on Earth

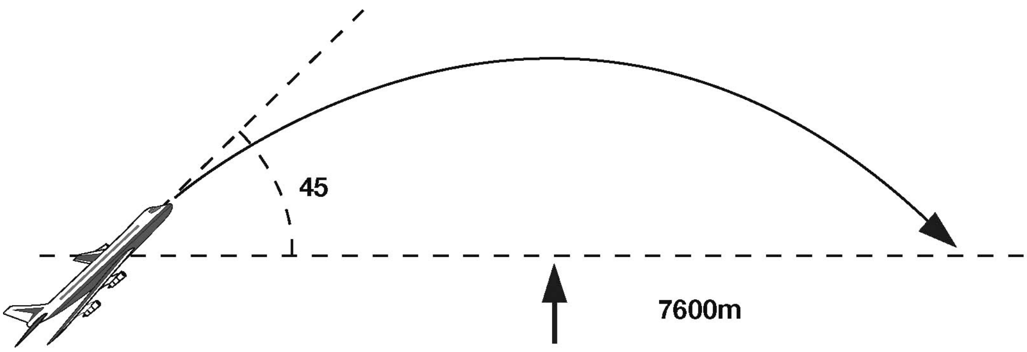
On ESA's annual Student Parabolic Flight Campaign 120 university students experience *microgravity* and test their experiments on board an Airbus A300 aeroplane as it falls on a parabolic trajectory (just like the trajectory of a ball when you throw it).

Students working in zero-G

At the start of each parabola the aeroplane is at an altitude of 7600 m, travelling upwards at an angle of 45 degrees and a velocity of 580 km/h. The engines are then turned off to allow the plane to move only under the influence of gravity. The parabola ends when the aeroplane has fallen back down to an altitude of 7600 m.

a) How long do the students spend in microgravity during each parabola?

b) What is the greatest altitude the Airbus A300 reaches?



If you want to know more: http://www.esa.int/education/parabolic

Solution “Parabolic Flights – microgravity research on Earth”

a) Initial vertical velocity:

$580\ \text{km/h} = 161\ \text{m/s}$
$v_{oy} = 161\ \text{m/s} \times \sin 45° = 112.7\ \text{m/s}$

Vertical distance at each end of the parabola: $y = 0\ \text{m}$ (vector quantity)

Acceleration due to gravity: $a = -9.8\ \text{m/s}^2$

Equation of motion (1): $y = v_{oy}t + \frac{1}{2}at^2$

So, for part (a), from (1): $0 = 112.7\,t - 0.5 \times 9.8\,t^2$

$t = 0\ \text{s}$ (start point) or $t = 23\ \text{s}$

b) Find time when at the top (half of total time):

Equation of motion (2): $v_y = v_{oy} + at$

Vertical velocity when at top: $v = 0\ \text{m/s}$

So from (2) $0 = 112.7 - 9.8\,t$
$t = 11.5\ \text{s}$
So, from (1) $y = 112.7\ \text{m/s} \times 11.5\ \text{s} - \frac{1}{2} \times 9.8\ \text{m/s}^2 \times (11.5\ \text{s})^2$
$y = 648\ \text{m}$

Add to initial height Altitude = 7600 m + 648 m = 8248 m

24 - Foton-M, research in microgravity

Foton-M is a Russian satellite. It often carries *payload* from the European Space Agency, and sometimes even experiments designed and built by university students! The Foton-M satellites orbit the Earth at an altitude of 300 km and a speed of 7.74 km/s. They each have a mass of 6.5 tonnes.

Foton-M spacecraft are launched by Soyuz-U rockets.

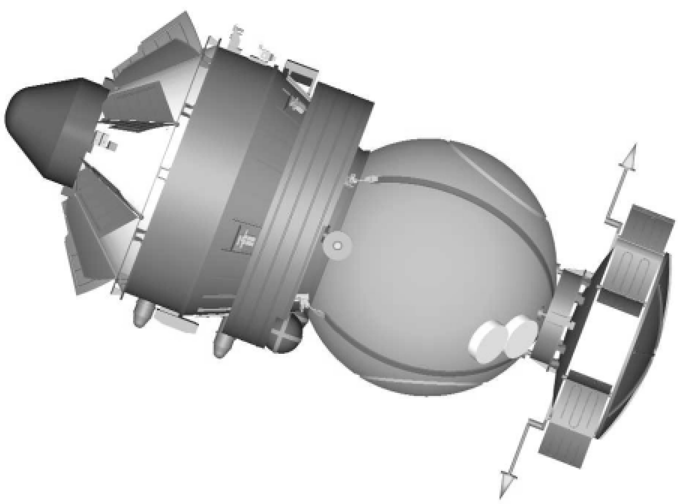
a) How much kinetic energy do these rockets give to each Foton-M satellite?

b) How much gravitational potential energy does a Foton-M in orbit have, and what percentage of its total energy is this?

The Foton-M spacecraft includes a re-entry capsule that has a mass of 2.4 tonnes. During re-entry this capsule loses almost all of its energy through friction with the atmosphere.

c) How much energy must the capsule lose to make a safe landing?

Take the average acceleration due to gravity experienced by one of the Foton-M spacecraft to be 9.5 m/s^2.



Foton-M Spacecraft

If you want to know more: http://www.esa.int/education/foton

Solution "Foton-M, research in microgravity"

a) Gravitational potential energy: $E_g = mgh$

Kinetic energy: $E_k = \frac{1}{2}mv^2$

Substituting… $E_k = 0.5 \times 6500\,\text{kg} \times (7740\,\text{m/s})^2 = 1.946 \times 10^{11}\,\text{J}$

b) Substituting… $E_g = 6500\,\text{kg} \times 9.5\text{m/s}^2 \times 300000\,\text{m} = 1.852 \times 10^{10}\,\text{J}$

Proportion of E_g in $E_{total} = \frac{E_g}{(E_g + E_k)} = 0.0869 = 8.69\%$

(Note: advanced students can set up and evaluate $\int_{ground}^{orbit} \frac{G \cdot M \cdot m}{r^2} dr$

to get a more accurate value, $E_g = 1.831 \times 10^{10}\,\text{J}$)

c) In order to make a safe landing (zero potential and zero kinetic energy) the capsule must of course lose ALL of the energy it gained during the launch. Since the energy is directly proportional to the mass and the capsule is 0.369 of the mass of the spacecraft, the energy dissipated during re-entry must be:

$E_{re-entry} = 0.369 \times E_{total} = 7.86 \times 10^{10}\,\text{J}$

25 - Maintaining the right orbit

In March 2002, the European Space Agency launched Envisat, an Earth Observation satellite that takes measurements of the atmosphere, ocean, land and ice with the purpose of monitoring and studying our environment on a global scale.

a) **For this mission a *polar orbit* (90º inclination over the equator) was chosen. Does this orbit offer complete Earth coverage?**

The propulsion module comprises 4 *propellant* tanks with a fuel capacity of 300 kg of *hydrazine* (N_2H_4)

b) **Calculate the mass of nitrogen and hydrogen.**

The catalytic decomposition of hydrazine is:
$N_2H_4 \rightarrow NH_3 + N_2$ About 2/5 of ammonia is decomposed via the chemical reaction $NH_3 \rightarrow N_2 + H_2$. The three elements (ammonia, nitrogen and hydrogen) are expelled to produce thrust.

c) **If 2 kg of hydrazine are injected into the catalyst, calculate the mass of hydrogen, nitrogen and ammonia ejected into space.**

Ten instruments on board Envisat take measurements of Earth, sometimes re-targeting areas where a detection of changes is important, for example in flooded areas. For this task it is very important to maintain the correct orbit.

d) **How could the propulsion system provide orbital manoeuvring? On which physical law of conservation is this based?**

e) **The exhaust velocity of ejected gases is around 3000 m/s on average. We want to increase the velocity of Envisat (8 tonnes) by 0.35 m/s. How many kilograms of hydrazine do we need?**

If you want to know more: http://www.esa.int/envisat

Solution "Maintaining the right orbit"

a) Yes. The orbit is fixed in space and the Earth rotates underneath. It allows stable and highly repeatable measurements

b) 1 mol of N_2H_4 = 32 g where 28 g are nitrogen (87.5%) and 4 g are hydrogen (12.5%), so keeping the mass rate in the 300 kg of hydrazine 262.5 kg are nitrogen and 37.5 kg are hydrogen.

c) The adjusted reactions are:

$3N_2H_4 \rightarrow 4NH_3 + N_2$ and $2NH_3 \rightarrow N_2 + 3H_2$

Now we have to calculate the masses of NH_3 and N_2

$$\frac{96\ \text{g/mol}\ N_2H_4}{68\ \text{g/mol}\ NH_3} = \frac{2000\ \text{g}\ N_2H_4}{x} \qquad x = 1416.6\ \text{g}\ NH_3$$

so the mass of nitrogen is 583.4 g

2/5 of ammonia is decomposed, that is 566.4 g

Using the second reaction:

$$\frac{34\ \text{g/mol}\ NH_3}{28\ \text{g/mol}\ N_2} = \frac{566.64\ \text{g}\ NH_3}{x} \qquad x = 466.64\ \text{g}\ N_2$$

so the mass of hydrogen is 100 g

N_2= 1050.04 g H_2= 100 g NH_3= 849.96 g

d) The propulsion systems provide forces and torques enabling the needed changes in its translatory and angular velocity to maintain the orbit.
A satellite moves and increases its velocity by conserving momentum between the mass and velocity of the expelled propellant and the mass and velocity of the satellite.
The Law of momentum conservation

e) $m \cdot v = (M - m) \cdot \Delta V$ where m is the mass of gases expelled, v is the velocity of the gases, M is Envisat's mass and ΔV is the change in velocity.
The solution after this simple equation is 0.93 kg of Hydrazine.

Glossary

Astronomical Unit (AU)
1 Astronomical Unit corresponds to the distance separating the Earth from the Sun. 1AU=150 million km.

Automated Transfer Vehicle (ATV)
Unmanned vehicle which is put into orbit by the European Ariane 5 launcher. It provides the International Space Station with pressurised cargo, water, air, nitrogen, oxygen and attitude control propellant. It also takes waste from the station and re-boosts it to a higher altitude to compensate for atmospheric drag.

Battery
A series or group of electrochemical cells that store energy. Batteries are carried onboard most spacecraft as a secondary power supply.

Bit
"Binary Digit" is the basic measure unit for digital information. It can be 0 or 1.

Black hole
An object with so much mass concentrated in it, and therefore such a strong gravitational pull, that nothing (not even light) can escape from it. One way in which black holes are believed to form is when massive stars collapse at the end of their lives.

Booster
Component of a launch vehicle for producing thrust.

Cryogenic stage
High-performance propulsion using liquid hydrogen propellant and liquid oxygen as oxidiser. Low temperatures must be reached to condensate both elements and store them in the launcher’s tank.

Eclipse
A partial obscuration of a spacecraft by another body. During eclipse phases of the Sun most spacecraft powered by solar cells use batteries as a power supply. The batteries are recharged once sunlight is available again.

Extravehicular activity (EVA)
A spacewalk, where astronauts leave their spacecraft in special protective suits to perform repairs, experiments or construction work.

Galaxy
A structure formed by the assembly of thousands of millions of stars together with gas and dust. Our Galaxy, the Milky Way, is a spiral galaxy. Galaxies can be elliptical, irregular or spiral. Our Galaxy is just one among many millions.

Hydrazine (N_2H_4)
A storable liquid propellant frequently used in rocket engines. It is decomposed to ammonia, nitrogen and hydrogen. These gases are ejected to produce thrust.

Launch window
The launch window is a term used to describe a time period in which a particular mission must be launched to reach its designated target.

Microgravity
An environment in which there is very little net gravitational force, as of a free falling object, an orbit, or interstellar space.

Payload
The equipment carried into space by a space vehicle. The payload of a satellite includes all of the instruments and science experiments.

Polar Orbit
Orbits with the inclination of 90 degrees or closer to 90 degrees are called "Polar Orbits". While a satellite is in its orbit, the Earth rotates underneath it, thus the satellite can cover the whole Earth including the north and south poles.

Propellant
Any substance or combination of substances that constitute a mass to be expelled at high velocity to produce a propulsive reaction force or thrust.

Radiation
Used as a synonym for electromagnetic radiation.

Re-boost
To boost a satellite back into its original orbit after the orbit has become lower because of atmospheric drag.

Resolution
A measurement of the ability to distinguish visual details between separate parts of an image. The higher the resolution, the more details are visible.

Solar array or panel
Panel on a spacecraft used to generate electrical power. It comprises a large number of solar cells that generate electricity when exposed to sunlight. For most of spacecraft it is considered the primary power supply.

Solar cell
A device for the conversion of solar energy into electrical energy. Typical materials used are silicon, gallium arsenide and indium phosphide.

Supernovae
Explosion of a massive star at the end of its life. Supernova explosions are so luminous that they can outshine a galaxy.

Space debris
Man-made material orbiting the Earth consisting of decommissioned satellites, spent upper stages, mission-related objects (launch adapters, lens covers, etc.) and on-orbit fragmentations.

Tracking Station
Ground facilities that follow the progress of a satellite and communicate with it. The main ESA tracking stations are in French Guiana, Belgium, Australia, Spain, Sweden and Kenya.

Transfer Orbit
Elliptical orbit linking two other orbits. Examples: low Earth orbit to geostationary orbit, or to change from Earth orbit to Moon orbit, for example.