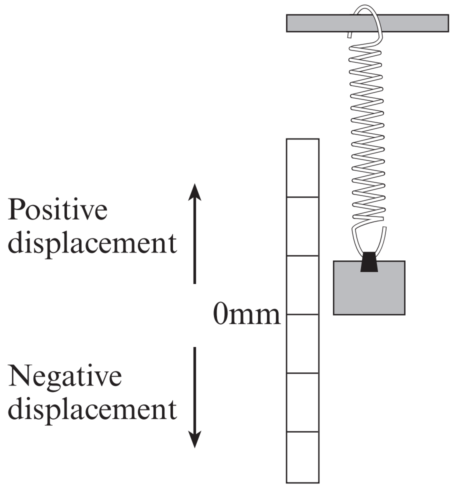
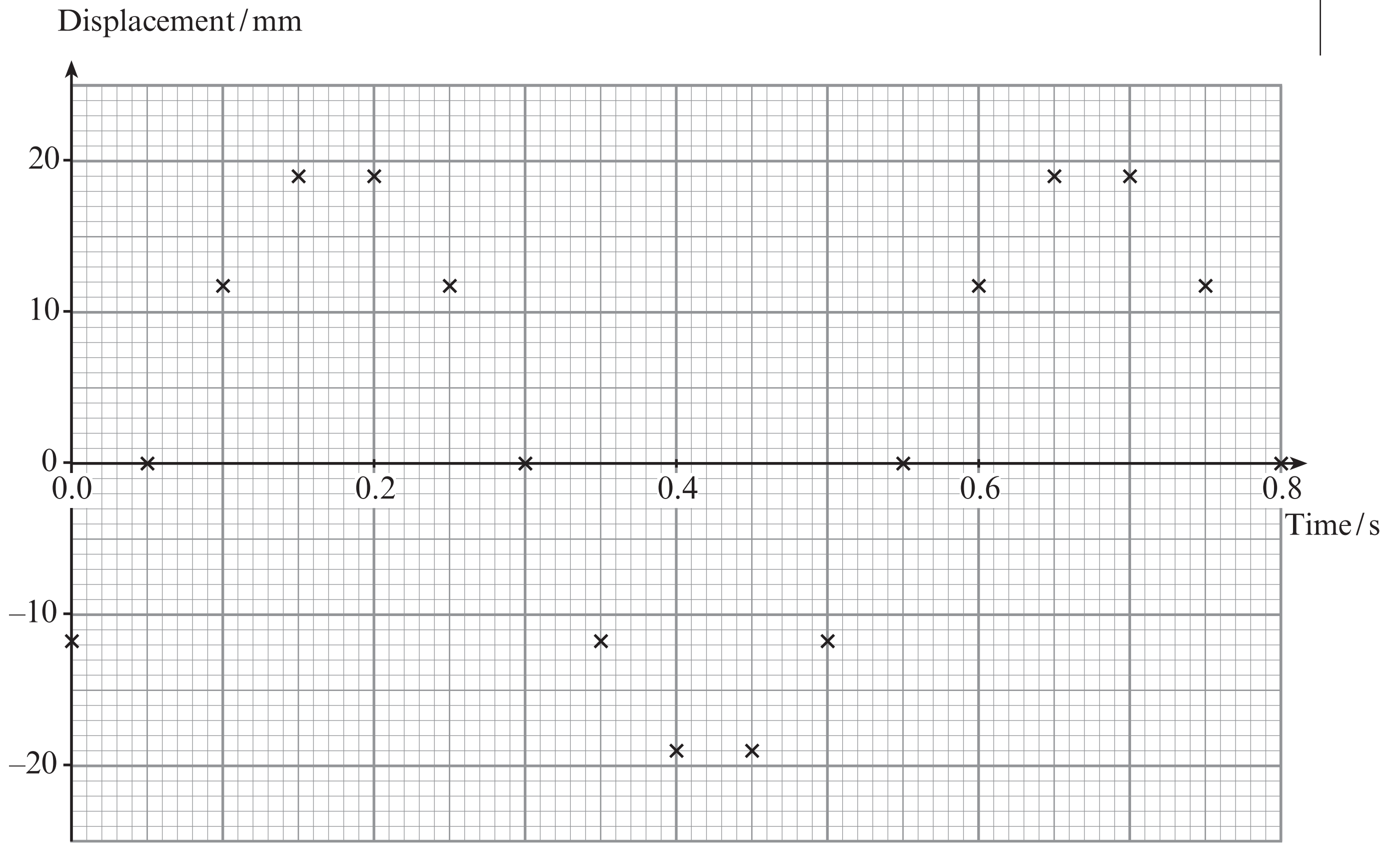
Examiner only

1. In a laboratory experiment a block with a mass of 0.04 kg is suspended from a vertical spring. The diagram shows the block in its equilibrium position. When it is pulled down and released it oscillates with simple harmonic motion (SHM).

The motion is recorded by a high speed video camera, and the displacement of the bottom of the block at regular times is shown on the graph.





Examiner only

(a) Define simple harmonic motion (SHM).

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....
[2]

(b) On the graph, plot carefully a curve through the points that shows how the displacement varies with time. [1]

(c) Show that the angular frequency, ω, of the oscillation is 12.57 rad s^{-1}.

....

....
[1]

(d) Calculate the maximum speed of the block.

....

....

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[2]

(e) Find the stiffness, *k*, of the spring (force per unit extension).

....

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....
[3]

1324 01 03

Examiner only

2. The air in a room of dimensions 6.0 m × 5.0 m and height 3.0 m is at atmospheric pressure, 1.01×10^5 Pa, and a temperature of 293 K.

(a) Write two assumptions of the kinetic theory of gases.

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....
[2]

(b) Calculate the number of air molecules in the room.

....

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....
[2]

(c) At some instant three of the molecules in the room have respectively speeds of 350 m s^{-1}, 420 m s^{-1} and 550 m s^{-1}. Calculate the root-mean-square (r.m.s.) speed of these three molecules at this instant.

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[2]

(d) Show that the r.m.s. speed of all the molecules in the room is approximately 500 m s^{-1}. (Mean relative molecular mass of air = 29)

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[4]

Examiner only

(e) Scent is sprayed in one corner of the room.

(i) Use the r.m.s. speed in part *(d)* to estimate a time of travel of a molecule from the spray to the far corner of the room.

....

....
[1]

(ii) Is this a reasonable estimate of the delay between the spraying of the scent and its detection at the far corner of the room? Explain your answer.

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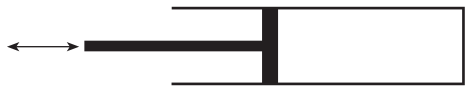
....
[2]

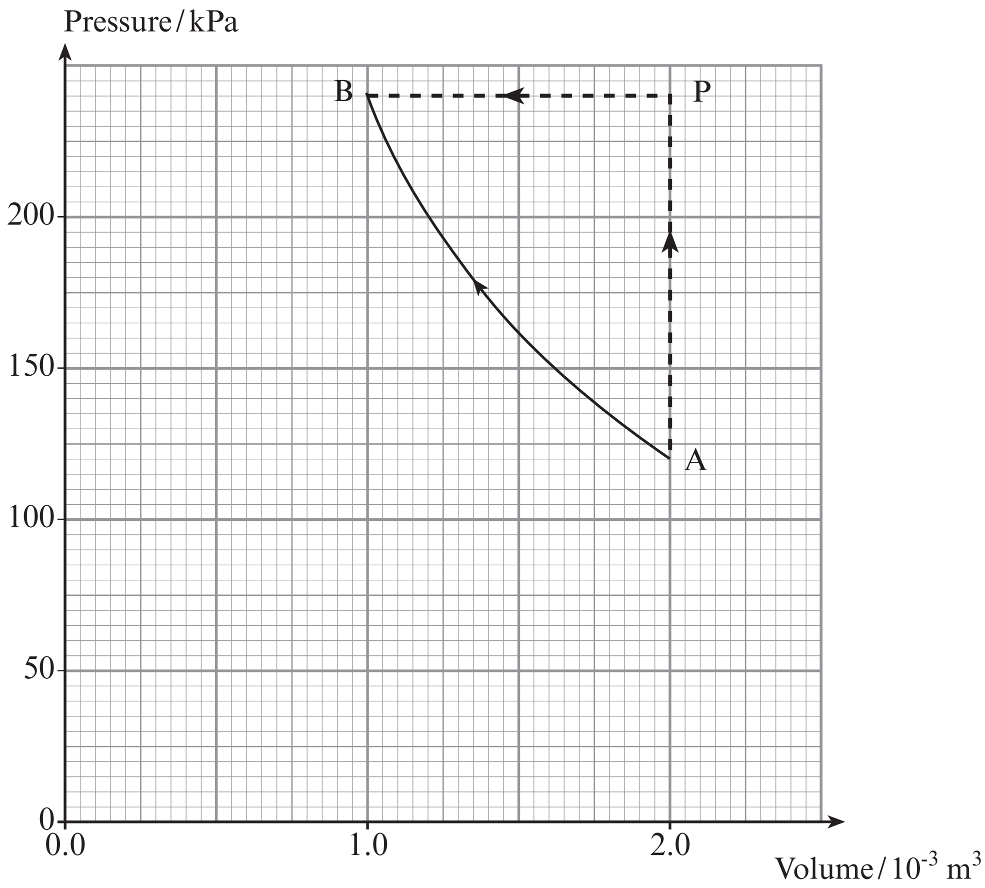
1324 01 05

Examiner only

3. A gas is contained in a metal cylinder with a leak-proof piston at one end



The pressure and volume of the gas during an experiment are shown on the graph below.



(a) The first law of thermodynamics may be written.

$$\Delta U = Q - W$$

By referring to the gas in the cylinder, explain the meaning of

(i) ΔU .... [1]

(ii) Q .... [1]

(iii) W .... [1]

Examiner only

(b) If the cylinder contains 0.1 mol of gas and the initial conditions are given by point A on the graph, show that the initial temperature of the gas is approximately 290 K.

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[3]

(c) The gas is compressed along the curved path AB at a constant temperature of 290 K. Show that the total work done along this path is approximately 170 J.

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[2]

(d) In an alternative process for changing the state, the gas follows path APB.

(i) Explain why no work is done on or by the gas along the path AP.

....

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....

[2]

(ii) Estimate the total work done along path PB, **indicating clearly** whether the work is done on or by the gas.

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[2]

(e) Use the first law of thermodynamics to explain why the heat flowing out of the gas system along path APB is different from the heat flowing out along path AB. A calculation is not required.

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[2]

1324 01 07

Examiner only

SECTION A

A1. *(a)* Calculate the binding energy **per nucleon** of ${}^{14}_{6}C$. [4]

($1u = 931MeV$, $m_{neutron} = 1.008665u$, $m_{proton} = 1.007276u$, mass of ${}^{14}_{6}C$ nucleus = 13.999950u).

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The following reaction can be regarded as evidence for the existence of neutrinos (or an anti-neutrino in this case).

$$ {}^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta^{-} + \bar{\nu}_e $$

The mass of the ${}^{14}_{6}C$ nucleus is 13.999950u and the mass of the ${}^{14}_{7}N$ nucleus is 13.999234u. The mass of the β^{-} particle is 0.000549u and the anti-neutrino ($\bar{\nu}_e$) has negligible mass.

(b) Calculate the energy released in this reaction ($1u = 931MeV$). [3]

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The evidence for the existence of the anti-neutrino came from the (unexpected) wide variation of the energies of the β^{-} particles emitted. However, you should now ignore the existence of the anti-neutrino.

(c) Explain briefly, using conservation of momentum, which particle (${}^{14}_{7}N$ or β^{-}) receives most of the energy of the reaction. [3]

Before the reaction (stationary ${}^{14}_{6}C$)

After the reaction

....

....

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A2. Caesium-137 ($^{137}_{55}Cs$) is a radioactive byproduct from fission nuclear power stations. It has a half life of 30 years and emits β^- radiation.

(a) Complete the following reaction equation by entering the appropriate numbers in the boxes. [2]

$$^{137}_{55}\text{Cs} \longrightarrow {}^{\square}_{\square}\text{Ba} + {}^{\square}_{\square}\beta^-$$

(b) Show that the decay constant of caesium-137 is approximately $7 \times 10^{-10}\ s^{-1}$. [2]

(c) Show that the initial activity of 1.0 kg of caesium-137 is approximately 3×10^{15} Bq. [2]

(d) Explain why 1.0 kg of caesium-137, although it has an activity of 3×10^{15} Bq, would be quite safe in a sealed metal box of thickness 1 cm. [1]

(e) When the activity of 1.0 kg of caesium has dropped to 1000 Bq (comparable to soil) it can be disposed of by mixing with soil and scattering on the ground. Calculate how long it takes for the caesium sample to reduce its activity from 3×10^{15} Bq to 1000 Bq. [3]

Examiner only

SECTION B

The questions refer to the Case Study. Direct quotes from the original passage will not be awarded marks.

B6. *(a)* Write brief notes about **one** of the following (paragraphs 3-5).

- The Higgs boson
- Grand Unification Theories
- Dark matter and dark energy. [3]

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(b) (i) Calculate the speed of a proton with 50 MeV of energy (paragraph 12). [2]

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(ii) Use the same method to calculate the speed of a 7 TeV proton (paragraph 12). [1]

....

....

(iii) Explain briefly which of your two answers *(b)*(i) or *(b)*(ii) cannot be valid. [2]

....

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....

(c) Explain briefly the role of the liquid helium in producing strong magnetic fields (paragraph 10, 15, 24). [2]

....

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....

Examiner only

(d) (i) Assuming a typical grain of sand to be a cube, make an estimate for the length of its side and hence its volume in m^3. [2]

(ii) Use your answer to *(d)*(i) to check whether *1.0 × 10^{-9} gram of hydrogen* occupies the volume of a grain of sand at room temperature and pressure (10^5Pa). (paragraph 20). [3]

(e) Some theoretical physicists believe that the large hadron collider might destroy the planet (paragraph 18) due to the formation of tiny black holes. The event horizon of a black hole is the distance from a black hole within which nothing can escape. This distance for a black hole formed from two protons is around 10^{-54}m. Explain why such a black hole would be unlikely to pull in the whole mass of the Earth rapidly. [2]

(f) Explain briefly why 'contaminating the proton tubes with soot' would be a problem (paragraph 24). [1]

(g) In the novel Angels and Demons an anti-matter bomb is produced. Calculate the energy released by an anti-matter reaction where 3.1 × 10^{-6} kg of anti-matter is annihilated (paragraph 27). [2]

U3HENS10

GCE A level

1325/01-A

PHYSICS

ASSESSMENT UNIT PH5

P.M. TUESDAY, 29 June 2010

CASE STUDY FOR USE WITH SECTION B

Examination copy

To be given out at the start of the examination.

The pre-release copy must not be used.

1325 01A 01

Large Hadron Collider (freely adapted from Wikipedia)

The **Large Hadron Collider (LHC)** is the world's largest and highest-energy particle accelerator,
intended to collide opposing particle beams, of either protons at an energy of 7 TeV per particle,
or lead nuclei at an energy of 574 TeV per nucleus. The Large Hadron Collider was built by the
European Organization for Nuclear Research (CERN) with the intention of testing various 1
predictions of high-energy physics, including the existence of the hypothesized Higgs boson. It lies
in a tunnel 27 kilometres (17 mi) in circumference, as much as 175 metres (570 ft) beneath the
Franco-Swiss border near Geneva, Switzerland. It is funded by and built in collaboration with
over 10,000 scientists and engineers from over 100 countries as well as hundreds of universities
and laboratories.

On 10 September 2008, the proton beams were successfully circulated in the main ring of the LHC
for the first time. On 19 September 2008, the operations were halted due to a serious fault between
two superconducting bending magnets. Due to the time required to repair the resulting damage 2
and to add additional safety features, the LHC was scheduled to be operational in mid-November
2009.

Purpose

- It is anticipated that the collider will demonstrate the existence of the elusive Higgs boson, 3
  the last unobserved particle among those predicted by the **Standard Model**.

  More generally, physicists hope that the LHC will help answer key questions such as:

- Are electromagnetism, the strong nuclear force and the weak nuclear force just different 4
  manifestations of a single unified force, as predicted by various **Grand Unification Theories**?

- What is the nature of **dark matter** and **dark energy**? 5

Of the discoveries the LHC might make, the possibility of the discovery of the Higgs particle is
the most keenly awaited by physicists and has been anticipated for over 30 years. Of the Higgs
Stephen Hawking said in a BBC interview, "I think it will be much more exciting if we don't find 6
the Higgs. That will show something is wrong, and we need to think again. I have a bet of one
hundred dollars that we won't find the Higgs. Whatever the LHC finds, or fails to find, the results
will tell us a lot about the structure of the universe."

Ion collider

The LHC physics program is mainly based on proton–proton collisions. However, shorter running
periods, typically one month per year, with heavy-ion collisions are included in the program.
While lighter ions are considered as well, the baseline scheme deals with lead ions. This will allow 7
an advancement in the experimental program currently in progress. The aim of the heavy-ion
program is to provide a window on a state of matter which characterized the early stage of the life
of the Universe.

Design

The LHC is the world's largest and highest-energy particle accelerator. The collider is contained in
a circular tunnel, with a circumference of 27 kilometres (17 mi), at a depth ranging from 50 to 175 8
metres underground.

The 3.8 m wide concrete-lined tunnel, constructed between 1983 and 1988, was formerly used to
house the Large Electron-Positron Collider. It crosses the border between Switzerland and France 9
at four points, with most of it in France. Surface buildings hold ancillary equipment such as
compressors, ventilation equipment, control electronics and refrigeration plants.

The collider tunnel contains two adjacent parallel beam pipes that intersect at four points. Each
pipe contains a proton beam. The two beams travel in opposite directions around the ring. Some
1,232 dipole magnets keep the beams on their circular path, while an additional 392 quadrupole
magnets are used to keep the beams focused, in order to maximize the chances of interaction 10
between the particles in the four intersection points, where the two beams will cross. In total, over
1,600 superconducting magnets are installed, with most weighing over 27 tonnes. Approximately
96 tonnes of liquid helium is needed to keep the magnets at their operating temperature of 1.9 K,
making the LHC the largest cryogenic facility in the world at liquid helium temperature.

Once or twice a day, as the protons are accelerated from 450 GeV to 7 TeV, the field of the
superconducting dipole magnets will be increased from 0.54 to 8.3 teslas (T). The protons will
each have an energy of 7 TeV, giving a total collision energy of 14 TeV (2.2 µJ). It will take less
than 90 microseconds (µs) for a proton to travel once around the main ring – a speed of about 11
11,000 revolutions per second. Rather than continuous beams, the protons will be bunched
together, into 2,808 bunches, so that interactions between the two beams will take place at discrete
intervals never shorter than 25 nanoseconds (ns) apart. However it will be operated with fewer
bunches when it is first commissioned, giving it a bunch crossing interval of 75 ns.

Prior to being injected into the main accelerator, the particles are prepared by a series of systems
that successively increase their energy. The first system is the linear particle accelerator LINAC 2
generating 50 MeV protons, which feeds the Proton Synchrotron Booster (PSB). There the
protons are accelerated to 1.4 GeV and injected into the Proton Synchrotron (PS), where they are
accelerated to 26 GeV. Finally the Super Proton Synchrotron (SPS) is used to further increase their 12
energy to 450 GeV before they are at last injected (over a period of 20 minutes) into the main ring.
Here the proton bunches are accumulated, accelerated (over a period of 20 minutes) to their peak
7 TeV energy, and finally circulated for 10 to 24 hours while collisions occur at the four
intersection points.

The LHC will also be used to collide lead (Pb) heavy ions with a collision energy of 1,150 TeV.
The Pb ions will be first accelerated by the linear accelerator LINAC 3, and the Low-Energy Ion 13
Ring (LEIR) will be used as an ion storage and cooler unit. The ions then will be further
accelerated by the PS and SPS before being injected into the LHC ring, where they will reach an
energy of 2.76 TeV per nucleon.

Test timeline

The first beam was circulated through the collider on the morning of 10 September 2008. CERN
successfully fired the protons around the tunnel in stages, three kilometres at a time. The particles
were fired in a clockwise direction into the accelerator and successfully steered around it at 10:28
local time. The LHC successfully completed its first major test: after a series of trial runs, two 14
white dots flashed on a computer screen showing the protons travelled the full length of the
collider. It took less than one hour to guide the stream of particles around its inaugural circuit.
CERN next successfully sent a beam of protons in a counterclockwise direction, taking slightly
longer at one and a half hours due to a problem with the cryogenics, with the full circuit being
completed at 14:59.

Turn over.

On 19 September 2008, a quench (sudden loss of superconductivity) occurred in about 100 bending magnets in sectors 3 and 4. This caused a loss of approximately six tonnes of liquid helium, which was vented into the tunnel, and a temperature rise of about 100 kelvins in some of the affected magnets. Vacuum conditions in the beam pipe were also lost. Shortly after the incident CERN reported that the most likely cause of the problem was a faulty electrical connection between two magnets, and that—due to the time needed to warm up the affected 15 sectors and then cool them back down to operating temperature—it would take at least two months to fix it. Subsequently, CERN released a preliminary analysis of the incident on 16 October 2008, and a more detailed one on 5 December 2008. Both analyses confirmed that the incident was indeed initiated by a faulty electrical connection. At most 29 magnets were damaged in the incident and needed to be repaired or replaced during the winter shutdown.

In the original timeline of the LHC commissioning, the first "modest" high-energy collisions at a center-of-mass energy of 900 GeV were expected to take place before the end of September 2008, and the LHC was expected to be operating at 10 TeV by the time of the official inauguration on 21 October 2008. However, due to the delay caused by the above-mentioned incident, the collider 16 was not scheduled to be operational again before the end of September 2009. Despite the delay, LHC was officially inaugurated on 21 October 2008, in the presence of political leaders, science ministers from CERN's 20 Member States, CERN officials, and members of the worldwide scientific community.

Expected results

Once the supercollider is up and running, CERN scientists estimate that if the Standard Model is correct, a single Higgs boson may be produced every few hours. At this rate, it may take up to 17 three years to collect enough data to discover the Higgs boson unambiguously.

Safety of particle collisions

The upcoming experiments at the Large Hadron Collider have sparked fears among the public that the LHC particle collisions might produce doomsday phenomena, involving the production of stable microscopic black holes with **event horizons** of around 10^{-54}m. Two CERN- 18 commissioned safety reviews have examined these concerns and concluded that the experiments at the LHC present no danger and that there is no reason for concern, a conclusion expressly endorsed by the American Physical Society, the world's second largest organization of physicists.

Operational challenges

The size of the LHC constitutes an exceptional engineering challenge with unique operational issues on account of the huge energy stored in the magnets and the beams. While operating, the 19 total energy stored in the magnets is 10 GJ (equivalent to 2.4 tons of TNT) and the total energy carried by the two beams reaches 724 MJ (173 kilograms of TNT).

Loss of only one ten-millionth part (10^{-7}) of the beam is sufficient to quench a superconducting magnet, while the beam dump must absorb 362 MJ (87 kilograms of TNT) for each of the two beams. These immense energies are even more impressive considering how little matter is carrying 20 it: under nominal operating conditions (2,808 bunches per beam, 1.15×10^{11} protons per bunch), the beam pipes contain 1.0×10^{-9} gram of hydrogen, which, in **standard conditions** for temperature and pressure, would fill the volume of one grain of fine sand.

On 10 August 2008, computer hackers defaced a website at CERN, criticizing their computer 21 security. There was no access to the control network of the collider.

Construction accidents and delays

- On 25 October 2005, a technician was killed in the LHC tunnel when a crane load was 22
  accidentally dropped.
- On 27 March 2007 a cryogenic magnet support broke during a pressure test involving one of
  the LHC's inner triplet (focusing quadrupole) magnet assemblies, provided by Fermilab and
  KEK. No one was injured. Fermilab director Pier Oddone stated "In this case we are
  dumbfounded that we missed some very simple balance of forces". This fault had been 23
  present in the original design, and remained during four engineering reviews over the
  following years. Analysis revealed that its design, made as thin as possible for better
  insulation, was not strong enough to withstand the forces generated during pressure testing.
  Details are available in a statement from Fermilab, with which CERN is in agreement.
  Repairing the broken magnet and reinforcing the eight identical assemblies used by LHC
  delayed the startup date, then planned for November 2007.
- Problems occurred on 19 September 2008 during powering tests of the main dipole circuit,
  when an electrical fault in the bus between magnets caused a rupture and a leak of six tonnes
  of liquid helium. The operation was delayed for several months. It is believed that a faulty 24
  electrical connection between two magnets caused an arc, which compromised the liquid-
  helium containment. Once the cooling layer was broken, the helium flooded the surrounding
  vacuum layer with sufficient force to break 10-ton magnets from their mountings. The
  explosion also contaminated the proton tubes with soot.
- Two vacuum leaks were identified in July, and the start of operations was further postponed 25
  to mid-November, 2009.

Popular culture

The Large Hadron Collider has gained considerable attention from outside the scientific
community and its progress is followed by most popular science media. The LHC has also sparked
the imaginations of authors of works of fiction, such as novels, TV series, and video games, 26
although descriptions of what it is, how it works, and projected outcomes of the experiments are
often only vaguely accurate, occasionally causing concern among the general public.

The novel *Angels & Demons* by Dan Brown, involves antimatter created at the LHC to be used as
a weapon (a bomb). In response CERN published a "Fact or Fiction?" page discussing the
accuracy of the book's portrayal of the LHC, CERN, and particle physics in general. The movie 27
version of the book has footage filmed on-site at one of the experiments at the LHC; the director,
Ron Howard, met with CERN experts in an effort to make the science in the story more accurate.

CERN employee Katherine McAlpine's "Large Hadron Rap" surpassed 5 million views. 28

END OF ARTICLE