science

THE SALTERS' APPROACH



GCSE UNIT GUIDE

SPORTS SCIENCE

Heinemann

NEW EDITION

science

THE SALTERS' APPROACH

GCSE UNIT GUIDE

SPORTS SCIENCE

Heinemann

Heinemann Educational Publishers,
a division of Reed Educational and Professional Publishing Limited,
Halley Court, Jordan Hill, Oxford OX2 8EJ

OXFORD FLORENCE PRAGUE MADRID ATHENS
MELBOURNE AUCKLAND KUALA LUMPUR SINGAPORE TOKYO
IBADAN NAIROBI KAMPALA JOHANNESBURG GABORONE
PORTSMOUTH NH (USA) CHICAGO MEXICO CITY SÃO PAULO

© University of York Science Education Group 1990

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise without either the prior written permission of the publishers or a licence permitting restricted copying in the United Kingdom issued by the Copyright Licensing Agency Ltd, 90 Tottenham Court Road, London W1P 9HE.

The Student Sheets in this book may be copied only for use within the institution for which they have been purchased. Under no circumstances may copies be offered for resale.

First published 1990
This edition 1997

01 00 99 98 97
10 9 8 7 6 5 4 3 2 1

ISBN 0 435 63042 3

Typeset by Books Unlimited (Nottm), NG19 7QZ
Cover design by Leigh Harrison
Printed by Athenaeum Press Ltd, Gateshead, Tyne & Wear

The authors and publishers would lilke to thank
Times Newspapers Limited for permission to use the article on page 54
by Robin Young from The Times, 30 July 1996.

The publishers have made every effort to trace the copyright holders, but if they have inadvertantly overlooked any, they will be pleased to make the necessary arrangement at the first opportunity.

The project is indebted to many companies and institutions for their encouragement and financial assistance; in particular to
BP
Heinemann Educational Publishers
ICI
The Salters' Institute of Industrial Chemistry
The Training, Enterprise and Education Directorate
The University of York

Salters' Science project teams

Management team
David Waddington, *University of York (Project Organiser)*
Bob Campbell, *University of York*
David Edwards, *Huntington School*
John Garratt, *University of York*
Peter Kelly, *University of Southampton*
John Lazonby, *University of York*
Robin Millar, *University of York*
Peter Nicolson, *University of York*
John Raffan, *University of Cambridge*
Judith Ramsden, *University of York*

Writing team for the Unit Guides
Susan Adamson, *Poynton County High School, Stockport*
Don Ainley, *University of Hull*
Mary Aitken, *Redland High School, Bristol*
Andrew Boothroyd, *Royds School, Leeds*
Martin Braund, *Boroughbridge High School*
Bob Campbell, *University of York*
Sue Clarke, *The Westgate School, Winchester*
Annabel Curry, *Amersham College of Further Education*
Kevin de Burg, *Avondale College, NSW, Australia*
David Edwards, *Huntington School, York*
Beverley Forsyth, *University of York*
Patrick Fullick, *Bournemouth School*
Francesca Garforth, *University of York*
John Garratt, *University of York*
Eluned Harries, *Heinemann Educational Books*
John Holman, *Watford Grammar School*
Andrew Janes, *Boroughbridge High School*
Peter Kelly, *University of Southampton*
Steve Lane, *Watford Grammar School*
John Lazonby, *University of York*
Jim Lewis, *Garforth Comprehensive School, Leeds*
Jean McLean, *Worthing High School*
Miranda Mapletoft, *University of York*
Alan Marsden, *University of York*
Robin Millar, *University of York*
Tom Murray, *Oaklands School, York*
Peter Nicolson, *University of York*
Richard Page-Jones, *North London Science Centre*
John Raffan, *University of Cambridge*
Judith Ramsden, *University of York*
Steve Smyth, *University of York*
Elizabeth Swinbank, *University of York*
Carol Tear, *Garforth Comprehensive School, Leeds*
David Waddington, *University of York*
Carole Walton, *King James's School, Knaresborough*

The following authors also contributed to the development of the Unit Guides
Philip Cheshire, *Rugby School*
Frank Harriss, *Malvern College*
Graham Hill, *Dr Challoner's Grammar School, Amersham*
Frank McKim, *Marlborough College*
Mick Price, *Boston Spa Comprehensive School*
Richard Price, *Midland Examining Group*
Alan Pritchard, *University of Southampton*
Katherine Whyman, *Heinemann Educational Books*

Editorial team for the Unit Guides
Mary Aitken
Beverley Forsyth
Jean McLean
Peter Nicolson
Judith Ramsden
Elizabeth Swinbank

Authors and editors for the Student Books
Bob Campbell
Eluned Harries
John Lazonby
Robin Millar
Steve Smyth
Ruth Holmes

INSET support team
Alan Jury
Peter Nicolson

Secretarial team
Nancy Newton
Valmai Firth

For the Midland Examining Group
Howard King, *Secretary to the Oxford and Cambridge Schools Examining Board*
Charles Newbould, *Director of Research, Oxford and Cambridge Schools Examining Board*
Richard Price, *Servicing Officer for Science (to 1990)*
David Barrett, *Servicing Officer for Science (from 1990)*

Writing team for revision of the Unit Guides
John Lazonby, *University of York (Project Co-organiser)*
Peter Nicolson, *University of York (Project Co-organiser)*
Gillian Alderton, *Sheredes School, Hoddesdon*
Caroline Barnes
Harry Chalton
Roger Essex, *Castledown Comprehensive School*
David Fortun, *Grange School, Bradford*
Jan Hatherall, *Hardenhuish School*
Terry Hayes, *Leigh Environmental Classroom*
Alan Hewitt, *Dinnington Comprehensive School*
Michael Knight, *Highcliffe School*
Malcolm Leigh, *West Hatch High School*
Keith Palfreyman, *Pope Pius X School, Rotherham*
Jonathan Saint, *Heinemann Educational Books*
Ian Saville, *The Robert Smyth School, Market Harborough*
Peter Smith, *Withernsea High School*
Stuart Twiss, *Dorset Professional Development Centre*

Contents

Introduction v

Overview vii

Syllabus cross-match viii

Pre-planner xi

Section 1: A question of sport

Planner 1
Teachers' Notes 3
Student Sheets 7

Section 2: The human engine

Planner 14
Teachers' Notes 16
Student Sheets 25

Section 3: A living machine!

Planner 37
Teachers' Notes 39
Student Sheets 44

Section 4: Faster and higher

Planner 59
Teachers' Notes 60
Student Sheets 63

© University of York Science Education Group, 1997

Introduction

The Salters' Science course for GCSE

The Salters' Science course provides curriculum support materials for a complete programme of balanced science for Key Stage 4.

The Salters' materials may be used as a basis for schemes of work leading to GCSE examinations in Science: Double Award (MEG syllabus 1774), Science: Single Award (1775), Science: Biology (1790), Science: Chemistry (1791) or Science: Physics (1792). This second edition of the course has been extensively revised to match the post-Dearing Programme of Study for Science at KS4, and offers a valuable resource in schools following **any** GCSE science courses.

This book is the guide for teachers for one unit of the GCSE course. It was originally developed by a team of over 30 science teachers working with The University of York Science Education Group. This second edition has been extensively revised by UYSEG, working with a new team who are teaching the course and who have based their work on their experience and on feedback from schools who have been using the course over the past six years.

The activities described in this Unit Guide have been designed to satisfy the following criteria –

- Each topic should have its origins, and hence its justification for study, in aspects of everyday life with which students aged 14–16 years will be familiar either personally or through the media.
- Scientific concepts and explanations should be introduced as they are needed for understanding of the topics being studied.
- Students should be involved in a wide variety of activities.

Industrial, technological, economic, social and environmental aspects of science are, therefore, fundamental to the whole course.

The double award course consists of 23 teaching units. The titles are given on the back cover of this book. Additional units to support the extension material needed for the separate sciences are available from The University of York.

Additional support

Student books, containing one chapter to support each of the course units, are also available. In this Unit Guide, cross-references to the student book material are given at frequent intervals.

GCSE syllabuses, end-of-unit tests for each course unit, sample examination papers and other materials are available from the Midland Examining Group.

INSET support for teachers, including residential courses at York and other centres, is provided at regular intervals.

For further information please contact:

The Project Officer, Science Education Group,
Department of Chemistry, University of York,
Heslington, York YO1 5DD

tel: 01904 432524
fax: 01904 434078
e-mail: pen1@york.ac.uk

© University of York Science Education Group, 1997

The Subject Officer for Salters' Science,
Midland Examining Group,
Purbeck House, Purbeck Road, Cambridge CB2 2PU
tel: 01223 411211

About this guide

In designing the Unit Guide, the following criteria have been kept in mind –

- New users must be able to acquire quickly an overview of the whole unit and an understanding of the content of each section.
- The guidance must be sufficient to support the inexperienced as well as the experienced teacher. It should be helpful to those who are starting their career and those who are teaching outside their main specialisation.
- The materials must be flexible enough to allow teachers to introduce modifications to, or replacements of, sections or activities where they feel it is appropriate, or to match the needs of students at different levels of attainment.

The next few pages provide general information about this teaching unit.

1 An **overview** which gives a brief summary of the topics covered in the unit.

2 A **syllabus cross-match** chart. For each suggested activity in the unit, cross-references are given to the Key Stage 4 Programme of Study and to assessable outcomes in the GCSE syllabus.

3 A **pre-planner** for the unit. This indicates any requirements which are less usually available or may need advance preparation.

The remainder of the Unit Guide is divided into sections. Each section contains activities which relate to a topic or sub-topic within the unit. A section contains material which may occupy one, two or more lessons.

Each section includes:

4 A **planner** which lists a sequence of suggested teaching and learning activities and identifies the key teaching points covered. It also includes a table of requirements which identifies apparatus and materials required for the activities.

5 **Teachers' Notes** which provide background information, suggestions for managing the activities and for differentiation in the approach and answers to the questions on the Student Sheets.

6 Copy-masters for producing **Student Sheets** which contain information and activities for students.

This Unit Guide is seen as the starting point from which an individual teacher or a department may develop their own scheme of work.

© University of York Science Education Group, 1997

Overview of the unit

The unifying context for this unit is the use of scientific ideas to explain human performance. The unit begins by considering how tissue respiration makes energy available to the body. This leads to study of the lungs and circulatory system which distribute food and oxygen around the body and transport waste.

Students then consider how bones and muscles allow the production of movement. Turning effects in different sports are considered, and the question of balance introduces the concept of centre of mass which is then applied to compare high jumping techniques. The final section deals with interconversion of gravitational potential energy and kinetic energy, and the concept of conservation of energy.

Section 1: *A question of sport*

Pages 1–13, Student Sheets 1.1–1.5

Students discuss their ideas of what is meant by being fit. They compare different uses of the word 'work' and are given a formal definition. Calculations of work done and rate of working lead to measurements of their own power and fitness.

Section 2: *The human engine*

Pages 14–36, Student Sheets 2.1–2.8

Respiration is introduced as a mechanism for transferring energy in tissues. This unit takes an overall view of aerobic and anaerobic respiration. They are treated again at a sub-cellular level in the unit *Staying Alive.*

The function of the lungs and the circulatory system in transporting materials around the body is studied.

Section 3: *A living machine!*

Pages 37–58, Student Sheets 3.1–3.10

Students revise ideas about levers then carry out tests with a model arm to show the function of bones and muscles in producing movement. Work on turning moments leads to ideas about balance and centre of mass. These ideas are applied in a comparison of three different techniques for high jumping.

Section 4: *Faster and higher*

Pages 59–69, Student Sheets 4.1–4.4

This section introduces ideas about potential energy and kinetic energy. Students measure the energy transfers in a variety of simple tasks. Pole vaulting and free fall parachuting are used as contexts for analysis of energy conversions and this leads to the concept of conservation of energy.

Finally, students revise the use of energy flow arrow diagrams as a way of representing energy transfers.

© University of York Science Education Group, 1997

Syllabus cross-match

The table below lists the activities in this unit, section by section. Beside each activity are shown those assessable outcomes from the syllabus content which are addressed through the activity.

The first column identifies the activities. The second column shows the Programme of Study (PoS) section reference which can be used to speed location of the relevant outcomes in the GCSE syllabus booklet. The assessable outcomes are shown in the third column.

Outcomes which are assessed in **both** the Science: Double Award and the Science: Single Award syllabuses are shown in normal type. Outcomes which are assessed **only** in the double award syllabus are shown in *italic type*. Thus, any activity which addresses **only** outcomes shown in *italic type* **is not needed for syllabus coverage for single award** candidates. (However, you may decide to retain some of these activities to provide continuity in the flow of ideas for these students.)

Some syllabus outcomes will only be assessed in the Higher Tier of the examinations. These outcomes are identified by a bullet mark (■) beside the PoS reference code. This indication is given to help when planning schemes of work which include differentiated pathways through the unit. In general, activities which address Higher Tier outcomes may be more suitable for higher-attaining students. However, both the accessibility of an activity and the learning outcomes can be altered by amending the student sheets, or adopting a different approach. Thus, each activity should be considered to see whether it is suitable as written for lower-attaining students, will need to be modified, or might be omitted altogether for such groups.

Particular syllabus outcomes may often be addressed by more than one activity, and sometimes from more than one unit of the course, allowing for revisiting, reinforcement and extension of ideas from one unit to another. The final column shows the letter codes of other units in the course where work on the same or a closely related topic may be found (earlier units where a topic may already have been introduced, or later units where it can be extended or reinforced). These other units should be consulted when developing schemes of work, to decide on the most appropriate level of treatment of the topic in this unit, and how that relates to work done elsewhere in the course.

Section/Activity		PoS	Assessable syllabus outcomes	Unit links
1	**Text activity 1:** What do you need to be good at sport?			
	Discussion: Is sport hard work?	4.5h	be able to use appropriate units for force, energy, work and power	ES
	Practical work 1: How hard do you work?	4.5f	understand that when a force moves an object, energy is transferred and work is done	
		4.5f	know that the work done is a measure of the energy transferred	
	Practical work 2: Power to the people	4.5f	understand the equation work done (J) = force (N) × distance moved in the direction of the force (m)	
		4.5g	understand that power is the rate of doing work	
	Text activity 2: The Havard step test	*2.2g*	*understand how breathing volume or pulse rate measurements of recovery after exercise indicate a person's level of fitness*	SA

© University of York Science Education Group, 1997

	Section/Activity	PoS	Assessable syllabus outcomes	Unit links
2	**Demonstration 1:** The human engine	4.5b	be able to calculate the energy transferred in simple calorimetry experiments as energy transferred = mass × specific heat × temperature change	A
	Practical work 1: Respiration in living things	*2.2f*	*understand that cellular respiration involves oxidation of food to release energy*	SA
		2.2f	*know the overall chemical equation for respiration of glucose*	
	Practical work 2: What happens when the oxygen runs out?	*2.2f*	*know the difference between aerobic and anaerobic respiration*	
	Text activity 1: The oxygen race	*2.2g* ■	*understand the concept of oxygen debt*	
	Text activity 2: Blood – the superhighway	2.2c	know that the blood provides a transport system for the body	KH
	Demonstration 2: The structure of the heart	*2.2c*	*understand how the heart pumps blood around the circulatory system*	
	Practical work 3: The network	*2.2c*	*know the differences between arteries, veins and capillaries*	
	Use of models: The structure of the lungs	*2.2e*	*understand how gaseous exchange takes place in the alveoli*	
3	**Discussion:** Levers	4.5f	recognise examples of levers used as force multipliers and as distance multipliers	
	Practical work 1: A living machine!			
	Text activity 1: Just a moment!	4.5f	understand how to calculate the moment of a force about a fixed point	
	Text activity 2: Some sporting moments	4.5f	understand the law of moments	
	Practical work 2: Finding your own centre of mass	4.2h	understand the concept of centre of mass	
		4.2h	be able to explain the stability or instability of objects in terms of the movement of the centre of mass when they are tilted	
	Text activity 3: One giant leap ...			
	Practical work 3: How best to jump higher	4.2h	know how to locate the centre of mass for a laminar shape	
	Text activity 4: How much energy do you expend when walking?	4.5f	understand the equation work done (J) = force (N) × distance moved in the direction of the force (m)	A
		4.5g	understand that power is the rate of doing work	
4	**Practical work:** How fast, how high?	4.2a	understand the quantitative relationship between speed, time and distance	MO
	Text activity 1: Faster and higher?	4.5h ■	know that the kinetic energy associated with movement can be calculated using KE = $0.5mv^2$	ES
		4.5h ■	understand the gravitational potential energy relation PE = mgh	
		4.5h	understand the law of conservation of energy and be able to use it in problems involving kinetic and gravitational energy	

© University of York Science Education Group, 1997

Section/Activity		PoS	Assessable syllabus outcomes	Unit links
4 (cont)	**Text activity 2:** Free for all	*4.2a* ■	*be able to interpret velocity–time graphs*	ES
		4.2h	know that weight is the gravitational pull on an object	
		4.2h	know that falling objects are accelerated downwards by gravitational attraction	
		4.2i	know that air resistance eventually limits the rate of fall	
	Text activity 3: Energy transfers in sport	4.5g	be able to represent energy changes using energy arrow diagrams	

© University of York Science Education Group, 1997

Unit pre-planner

Detailed lists of requirements for each activity will be found in the plans for each section of the unit. This sheet merely indicates those requirements which may be less readily available, may take some time to collect or may need preparation in advance.

SECTION	REQUIREMENTS
1	access to bathroom scales
2	crisps or other food sample to burn live woodlice active yeast suspension methylene blue solution sheep's heart model of the heart model showing the structure and location of the lungs bell-jar model of the lungs (see page 23) slides of transverse sections of arteries, veins and capillaries blood smear slides made using the same stains as the transverse section slides computer programs (see Notes 1, 2, and 3)
3	model arms (one per student working group – see Note 4) plank of wood bathroom scales
4	bathroom scales

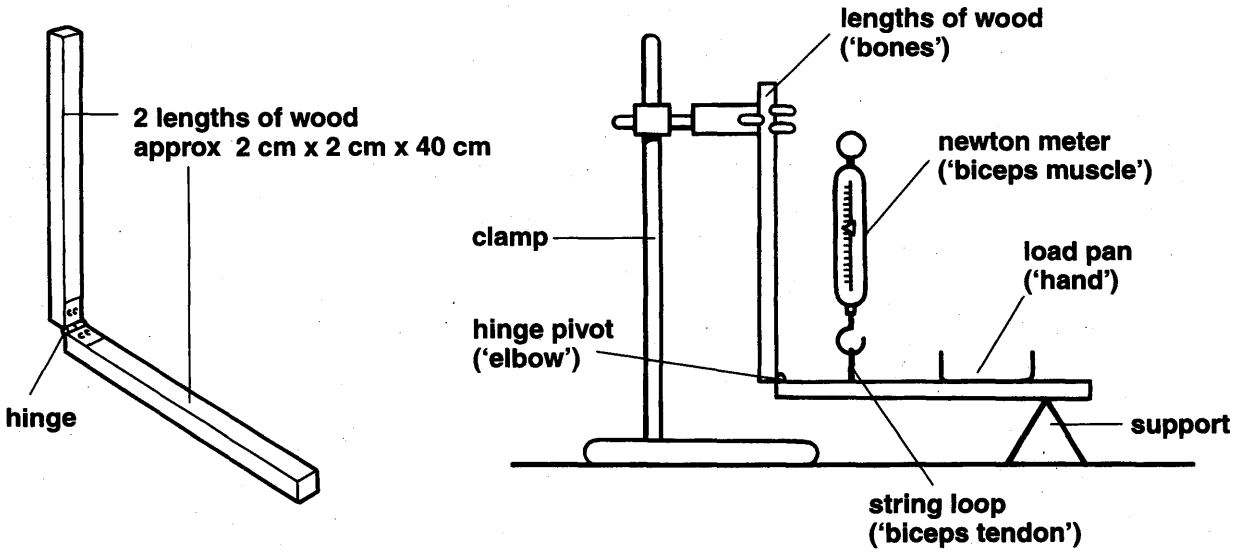
Notes

1 The computer program *Blood circulation* is part of a pack of 12 computer programs produced by AVP, School Hill Centre, Chepstow, Gwent NP5 5PH. *Blood circulation* is number 6 in the set. Reference: COM202B06

2 The computer program *Maze* provides a game simulation tracking pathways through the circulatory system. It is also marketed by AVP.

3 The computer program *Respiration* is number 5 in the pack of programs from AVP. Reference: COM202B05

4 A suitable model arm can be constructed as follows (a heavy duty spring will be needed as the load on it may be up to 100 N):



© University of York Science Education Group, 1997

A question of sport

3 – 4 lessons

This first section allows students to review their knowledge about the concepts of work, power and fitness in a sporting context.

Students begin by discussing the qualities needed for success in sport. They then carry out a series of activities which introduces the concept of work in the context of personal energy expenditure.

Students then have an opportunity to measure their own fitness and power output.

ACTIVITY	OUTLINE	KEY POINTS
Text activity 1 (Student Sheet 1.1)	Students discuss what is needed for success in various sports.	
Discussion (Student Sheet 1.2)	Students compare 'everyday' and scientific definitions of 'work'.	In science, **work** is done when a force is moved through a distance. Energy is transferred as work is done.
Practical work 1 (Student Sheet 1.3)	Students carry out a series of experiments on work.	Work = force x distance moved
Practical work 2 (Student Sheet 1.4)	Students carry out a step test and calculate their own power output.	Power is the rate of transferring energy. Power can also be described as the rate of doing work. It is possible to measure a person's power output.
Text activity 2 (Student Sheet 1.5)	Students calculate fitness levels using the 'Harvard step test'. If desired, they may go on to measure their own fitness ratings.	Vigorous exercise raises breathing and pulse rates. Tests exist which enable athletes, and other people, to measure their fitness.

© University of York Science Education Group, 1997

ACTIVITY	REQUIREMENTS FOR THE ACTIVITY
Text activity 1	Student Sheet 1.1 *What do you need to be good at sport?*
Discussion	Student Sheet 1.2 *Is sport hard work?*
Practical work 1	Student Sheet 1.3 *How hard do you work?* *each group will need:* 10 similar masses (e.g. heavy books, small sacks of sand) a metre rule
Practical work 2	Student Sheet 1.4 *Power to the people* *each group will need:* a sturdy chair a tape measure or ruler a stopclock bathroom scales to enable students to measure their own mass
Text activity 2	Student Sheet 1.5 *The Harvard step test* (note: if students are to carry out this test, they will need apparatus as for Practical work 2 above)

Student book



Thinking About 1: *What is work?*, ***Thinking About 2:*** *How powerful are you?* and ***Thinking About 3:*** *What is fitness?* all provide additional information about the content of this section.

© University of York Science Education Group, 1997

A question of sport

In this first section of the unit, students consider what is meant by 'work'. They see that physical activities involve transfer of energy and consider power as rate of transfer of energy.

Text activity 1: *What do you need to be good at sport?*

Student Sheet 1.1 accompanies this activity.

Working in small groups, students consider what qualities are needed for success in different sports.

It is important to stress that people of very different types and builds can participate with enjoyment in a wide range of sports. However, at a very high level of participation, there are some sports where a particular build can be an advantage.

In deciding what qualities are needed for a particular sport, students need to consider the demands of that sport. Which is most important, speed, agility or strength?

Answers to questions on *Student Sheet 1.1*

Q1 There are a number of different answers which may be correct. At high levels of participation, it is often found that people who are short and fairly heavily built concentrate on sports where strength is an important factor, e.g. weightlifting and judo. People who are very tall and slightly built tend to be good at basketball, jumping and some running events. However, there are many exceptions to this.

Q2 NB: 'fortius' means 'braver'.

(a) Answers will vary.

(b) Answers will vary.

(c) Answers will vary. Students may well suggest sports where one or more of the following are important: stamina, strength, agility, accuracy.

Discussion: *Is sport hard work?*

Student Sheet 1.2 accompanies this activity.

The pictures on *Student Sheet 1.2* should be used as a basis for a discussion on the scientific use of the word **work**. Students are given a formal definition of 'work' and consider what measurements are needed to calculate the work done in different situations.

To reinforce the meaning of the word work and to familiarise students with the equation, there is a further selection of calculations which may be set as a class exercise or as homework.

Answers to questions on *Student Sheet 1.2*

Q1 The high jumper is probably doing most work at the instant shown (take-off), then the runner. Neither the weightlifter nor the gymnast are doing any external work at the instant shown.

Q2 Work is being done by the runner and the jumper.

For the runner, it would be necessary to measure the average 'driving force' and the length of the race. For the jumper, the weight of the athlete and the height of the jump would need to be measured.

© University of York Science Education Group, 1997

Q3 450 J

Q4 (a) 0.2 m

(b) 500 N

(c) 100 J

(d) 100 000 J or 100 kJ

Q5 Al does the most work (1840 J, compared with Steve's 1827.5 J)

Q6 (a) 275 J

(b) 80 step-ups

Q7 (a) 776 400 J or 776.4 kJ

(b) Same as (a).

(c) There may be several suggestions here. Try to steer in the direction of who could complete the task in the shorter time.

Practical work 1: *How hard do you work?*

Student Sheet 1.3 accompanies this activity.

Students should work in twos or threes for this activity. *Student Sheet 1.3* gives instructions to pupils to carry out a series of 'weightlifting' tasks. Students are asked to comment on aspects of these tasks, and to then calculate the amount of work done in each task.

Students must be cautioned not to volunteer for this activity if there is any medical or other reason why they should not undertake strenuous exercise.
Warn students to stop at once if they feel tired or distressed.
Do not allow a competitive atmosphere to develop.



This is an appropriate time to remind students of the difference between **mass** and **weight**. In science, these terms have precise and different meanings. The mass of an object is the amount of the material present. Mass is measured in kilograms. The mass of an object stays the same unless something is done to alter the object. The weight of an object is the force of gravity on that object. Weight is a force, and is therefore measured in newtons. The weight of an object changes if the force of gravity changes. On Earth, gravity gives an acceleration of approximately 10 m/s^2. The weight of an object in newtons is therefore found by multiplying its mass in kilograms by 10.

On the moon, where gravity is about one-sixth of that on the Earth, an object would have the same mass but one-sixth of the weight.

Answers to questions on *Student Sheet 1.3*

Q1 Answers will vary.

Q2 Again answers will vary. The response to these two questions provides an opportunity to discuss how a less subjective judgement could be made.

Q3 Answers will depend on the weights lifted, and the heights of the lab stools and benches.

Q4 Tasks 3 and 4. Each of these involves the same amount of work done on the masses.

Q5 (a) Task 5. Holding the masses out at arms length involves no work done on the masses.

(b) There is no movement involved.

© University of York Science Education Group, 1997

(c) Students will probably comment that their arms ache. This is due to the rapid contracting and relaxing of the muscle fibres as they support the masses.

Where a mechanical task is carried out by a person, rather than a machine, the 'science' definition of work done on the object being moved often gives answers which feel intuitively different from the sense of tiredness of the muscles. This is because human movement involves internal movements of muscle fibres, as well as the movement of the external load. In some tasks, e.g. holding up a mass, this internal effort will be large compared with the external work.

Practical work 2: *Power to the people*

Student Sheet 1.4 accompanies this activity.

Although all students performed the same tasks in Practical work 1, and therefore did the same amount of work, measurement of work done gives only limited information.

It is often useful to know how long it has taken to do the work. This is the concept of **power** as the rate of transferring energy, or the rate of doing work.

Thus two fell runners of the same weight would do the same amount of work if they ran up a mountain, but the one who got up in the shorter time would have developed the greater power.

Students measure their own weight, then carry out a simple step test. The time taken to complete the test is measured and the results can be used to calculate the average power developed by each student.

Most chairs are too high and/or unstable for this activity. Borrow a P.E. bench from the gym or suitable low rostrum from the Drama department. Benches should be steadied by other students during each test.

Once again, caution students not to volunteer if there is any reason why they should not undertake vigorous exercise.

Do not allow a competitive atmosphere to develop.



Following the activity, ask students to recall how they felt whilst doing the test, and whether they noticed any changes in themselves. Answers should include faster breathing and pulse rate, and increased surface temperature.

During exercise, energy is transferred more rapidly in the muscles. This requires a more rapid supply of oxygen (this will be dealt with in more detail in Section 2, and again in the unit *Staying Alive*). Breathing rates and pulse rates rise to achieve this increased supply.

Because more energy is being transferred, body temperature will tend to rise. Students may be asked to recall the temperature control mechanisms studied in the unit *Controlling Change*. Capillaries near the skin will be dilated, making the skin feel hotter and look flushed.

Text activity 2: *The Harvard step test*

Student Sheet 1.5 accompanies this activity.

Fitness is a complex topic which involves elements of strength, suppleness, stamina and the ability to recover quickly from exertion. Thus it is difficult to provide any absolute scale for measuring it. However, recovery rate is a useful indicator.

This activity describes the 'Harvard step test', which is a more controlled version of the

© University of York Science Education Group, 1997

step test students have already done. It is often used as a measure of fitness.

Students are provided with data, and this gives them an opportunity to do some more calculations and to compare this fitness test to the one they carried out. This is an activity which could easily be used as a homework.

If you wish, students could carry out the test to make comparative measures of their own fitness. This would provide practice in measuring their pulse rates, and they may need instruction on the technique.

Some schools have used this test as the basis for assessed investigations. However, the lack of an explanatory theoretical model at this level makes it difficult for students to score highly.

If you do decide to use this test as a practical activity, make it clear that students should not attempt to continue stepping beyond the point where it begins to feel uncomfortable. Also stress that this is only one aspect of fitness. Be sensitive to the possibility of distress to students who achieve low scores.

Answers to questions on *Student Sheet 1.5*

Q1 Fitness index = 40 (unfit)

Q2 (a) Fitness index = 75 (fit)

(b) He did 45 000 J of work, assuming he did 150 step-ups.

(c) He developed 150 W of power.

Students may find it surprising that a fit person in this test only develops power equivalent to a large light bulb!

The peak power which an individual can exert for very short periods is much higher than this, but it is difficult to sustain power outputs at much above this level.

© University of York Science Education Group, 1997

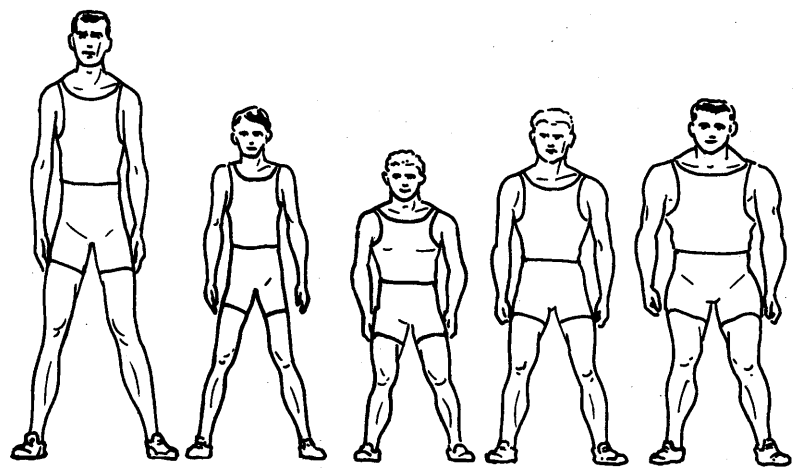
What do you need to be good at sport?

What sort of qualities do you need to be good at sport?

Is the answer the same for all sports?

◆ *Who does what sport?*

Q1 The picture shows five people who play different sports.



(a) Use your judgement to match each person with the sport you think they play. The sports are:

basketball

javelin

weightlifting

marathon running

judo

(b) Explain your reasons for each choice.

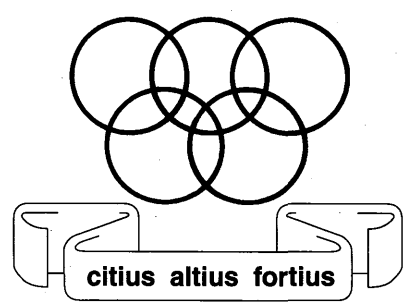
◆ *Different qualities for different sports*

Q2 The motto of the Olympic games is made from three Latin words:

'citius' (which means '**faster**')

'altius' (which means '**higher**')

'fortius' – try to find out what 'fortius' means.



(a) Make a list of three sports where the ability to go **faster** is important.

(b) Make a list of three sports where the ability to go **higher** is important.

(c) Make a list of three sports which you would find difficult to put into either of these groups. What heading would you want for these sports?

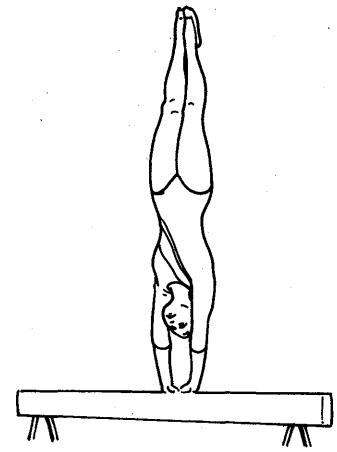
© University of York Science Education Group, 1997

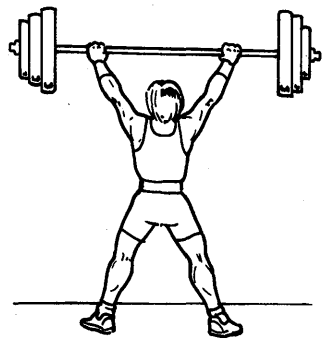
Is sport hard work?

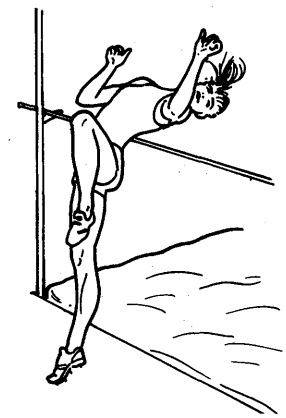
You will probably have heard people talk about having a 'work out' when they are taking part in a sport.

These pictures show people taking part in different sporting events.









Q1 Use your judgement to put these people in order of who is working the hardest at the instant shown in the picture.

- Put the person you think is working the hardest at the top of the list.
- Explain your reasons for each choice.

◆ *Is this really work?*

Work is one of those words which is used in lots of ways in everyday conversation.









In science, the word work has a very precise meaning.

FACT FILE
Work is done when a force moves an object.
THE AMOUNT OF WORK DONE = FORCE x DISTANCE MOVED

© University of York Science Education Group, 1997

Is sport hard work?

◆ *Work, force and movement*

The key thing from a science point of view is that something must be *moving* for work to be done.

- The size of the force is usually measured in newtons (N).
- The distance is measured in metres (m).

Work is measured in joules (J), or kilojoules (kJ). These are the same units as used to measure energy. In fact, another way that scientists describe work is as the transfer of energy.

◆ *Who does the most work?*

Look again at the pictures of athletes doing different sports top of page 8).

Q2 For each of the pictures:

- say whether work is being done or not;
- if work is being done, say which forces and distances you would need to measure to calculate the amount of work being done.

◆ *Calculating the work done*

Answer the following questions on work.

Q3 Saira is a gymnast. She weight 450 N. How much work does she have to do when she jumps onto a beam which is 1 m high?

Q4 Brenda skips as part of her fitness programme. Brenda weighs 500 N, and each time she skips, she jumps 20 cm off the ground.

(a) What distance in metres does Brenda jump with each skip?

(b) What force is moved?

(c) How much work does Brenda do in each skip?

(d) If Brenda does 1000 skips, how much work does she do in total?

Q5 Al and Steve are weightlifters. Al, who is taller than Steve, can lift 800 N to a height of 2.3 m. Steve can lift 850 N to a height of 2.15 m. Who does more work?

Q6 Part of Mike's fitness programme involves stepping up and down onto a bench 50 cm high. Mike weighs 550 N.

(a) How much work does Mike do each time he steps on to the bench?

(b) How many step-ups would Mike have to make to do 22 kJ of work?

Q7 Chris and Alison are fell runners. They are taking part in a race up to the top of Ben Nevis (the highest mountain in the United Kingdom). The race starts in a car park 50 m above sea level, and their map shows the highest point of Ben Nevis is 1344 m.

(a) Use this information to calculate how much work Chris did when she ran up Ben Nevis. Chris weighs 600 N.

(b) Alison also weighs 600 N. How much work did she do running up Ben Nevis?

(c) What else might you want to measure if you wanted to decide who was the better athlete?

© University of York Science Education Group, 1997

How hard do you work?

These tasks will help you to understand more about work. Work with a partner. There are five different activities to do.

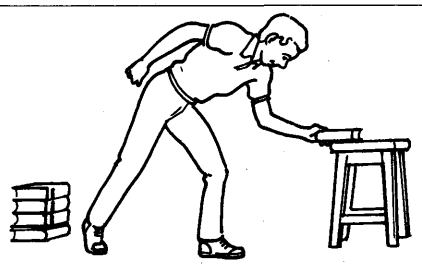
Each one of you in turn should do the first activity, then each do the second and so on until each of you has had a turn to do each of the activities.

Try to remember what each one feels like. At the end, you will be asked which one was hardest!

◆ *Lifting loads*

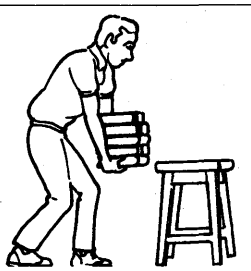
Task 1:

Lift the five masses **one at a time** from the floor onto the seat of a chair or stool.



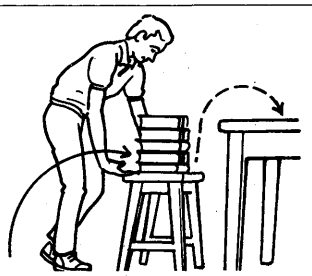
Task 2:

Lift the five masses **all at the same time** from the floor onto the seat of a chair or stool.



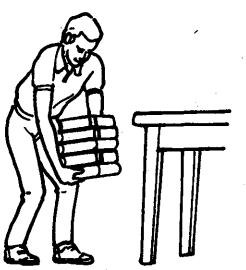
Task 3:

Lift the five masses together first from the floor to the seat, then from the seat to the table top.



Task 4:

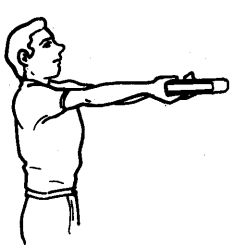
Lift the five masses together straight from the floor to the table top in one move.



Task 5:

Hold one of the masses out at arm's length in front of you for 1 minute.

If this becomes uncomfortable before the minute is finished, stop at once.



Q1 Which task was the most tiring? Why?

Q2 Which task do you think involved the most work?

Now measure three things:

- the height of the seat (metres)
- the height of the bench (metres)
- the weight of one of the masses you lifted (newtons)

(Remember that weight is a force. Weight in newtons = mass in kg × 10.)

Q3 Use the formula **work = force × distance moved** to calculate how much work was done in each of the five tasks.

Q4 Which task involved the most work?

Q5 One task involved no work at all!

(a) Which task was this?
(b) Explain why no work was done.
(c) How did you actually feel when you were doing this task?

© University of York Science Education Group, 1997

Power to the people

In your previous activity, you calculated how much work was done in each task.

It is also useful to know how long it took to do the work.

FACT FILE
Power is the rate of doing work.
power (in watts) = **work done** (joules)/ **time taken** (seconds)

You often hear about the power of a machine. Your body is a machine too! By measuring how quickly you can do work, you can calculate how much power you developed.

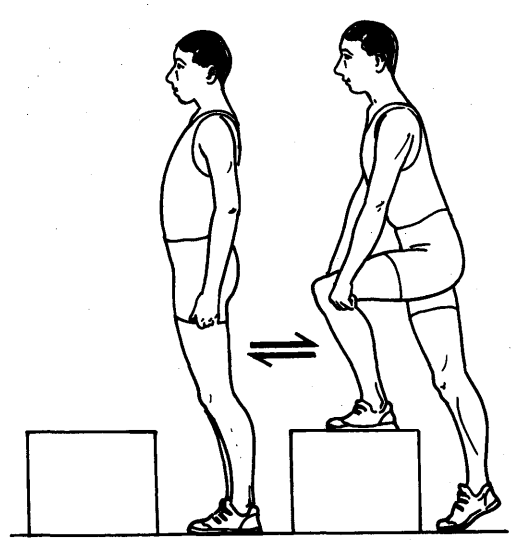
◆ *Step up your power*

When you step up to a higher level, you do work. To calculate how much work, you need to know the force which is opposing the movement (your weight, the effect of gravity pulling you down) and the height of the step.

In this activity, you will step up and down as quickly as you can to measure how fast you can work.

You need a firm, safe platform to step up onto. You might step from the ground onto the first step of a flight of stairs, or onto a rostrum (platform) or onto a PE bench. If you use a bench, it must be a strong one, and at least one other person must hold it steady so that you do not slip.

- Ask a partner to time you with a stopwatch.
- On their signal, step up, so that you are standing upright with knees straight.
- As quickly as possible, step down, then up again.
- Go on stepping up and down as quickly as possible.
- Your partner must stop the watch as soon as you have stepped up for the tenth time.
- Each person in turn can carry out this 'ten step test'.
- Calculate the power (rate of working) for each person.



© University of York Science Education Group, 1997

Power to the people

◆ *Results of the 'ten step test'*

Use this table to record your results from the test and work out how much power was developed by each person.

Height of the step (**in metres**) = ...

name	weight (newtons)	work done (joules)	time (seconds)	power (watts)

The work done = weight × height of step × number of steps

This table will help you to find your weight force in newtons. If your weight is in between two of the values in the table, add on 4.5 N for each pound.

your weight in stones and pounds	your weight in newtons
6 stone	380
6 stone 7 pounds	415
7 stone	445
7 stone 7 pounds	480
8 stone	510
8 stone 7 pounds	540
9 stone	570
9 stone 7 pounds	605
10 stone	635
10 stone 7 pounds	665
11 stone	700
11 stone 7 pounds	730
12 stone	760
12 stone 7 pounds	790

Who was able to keep up the greatest rate of working?

© University of York Science Education Group, 1997

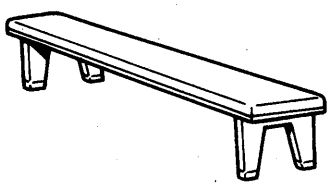
The Harvard step test

Ashraf is hoping to take part in a local half marathon. His trainer has suggested that he can see if his fitness is improving if he uses the Harvard step test. This is the instruction card he was given:

SAFETY NOTE

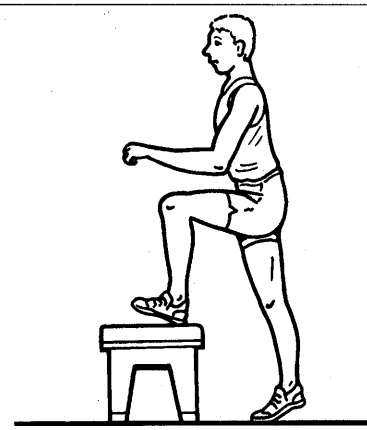
Do not do this test if there is any medical reason for you not doing strenuous exercise.

Find a bench 0.5 m high.

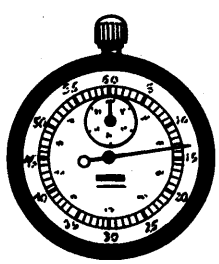
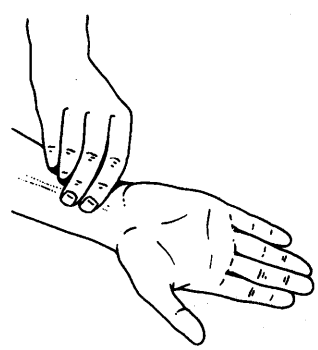
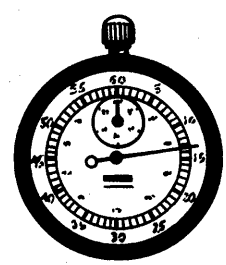


Step up and down onto the bench or chair every 2 seconds for 300 seconds (5 minutes). Straighten your legs each time you step up.

Stop if you feel very tired, and make a note of how long you were actually doing the test.



Time spent on exercise =

Rest for 1 minute, then take your pulse for 30 seconds.	Wait for 30 seconds, then take your pulse again for 30 seconds.	Wait for another 30 seconds, then take your pulse again for 30 seconds.
		
First pulse count =	*Second* pulse count =	*Third* pulse count =

Fitness = $\frac{\text{time spent on exercise} \times 100}{2 \times (\text{first} + \text{second} + \text{third pulse counts})}$

Fitness scale:

90+ = extremely fit; 80+ = very fit; 70+ = fit; 60+ = fair; below 59 = unfit

Q1 When Ashraf first took the test, he could only do the step-ups for 240 seconds. His pulse rates were 115, 100 and 85. Calculate Ashraf's fitness index.

Q2 After he had been training for three months, Ashraf could do the test for the full five minutes, and his pulse rates were 75, 65 and 60.

(a) Where does Ashraf now come on the fitness scale?
(b) Ashraf weighs 600 N. How much work did he do in the full test?
(c) How much power did he develop?

© University of York Science Education Group, 1997

The human engine

This second section considers the human body as an engine requiring fuel to work. **3 – 4 lessons**

It considers the concept of respiration as a means of transferring energy by oxidation of food, and links this to ideas about anaerobic respiration and oxygen debt resulting from vigorous exercise.

Students then consider the transport arrangements which ensure that food and oxygen are delivered to the respiring cells, and that carbon dioxide is removed from them.

ACTIVITY	OUTLINE	KEY POINTS
Demonstration 1 (Student Sheet 2.1)	Discussion of ideas from Section 1 reminds students that a supply of energy is needed for life processes. Food is burnt to illustrate the source of this energy.	Work requires energy. Energy is transferred in the body by breakdown of food, which usually requires oxygen.
Practical work 1 (Student Sheet 2.2)	Methylene blue is used as an indicator to show that oxygen is used up during respiration by yeast. Students also show that carbon dioxide is produced.	Aerobic respiration uses oxygen and produces carbon dioxide. The word equation for aerobic respiration.
Practical work 2 (Student Sheet 2.3)	Students carry out an exercise which promotes anaerobic respiration in their arms.	Anaerobic respiration can supplement the normal aerobic process during vigorous exercise.
Text activity 1 (Student Sheet 2.4)	Students analyse data for respiration processes in athletics track events.	Oxygen debt may occur in muscles during vigorous exercise.
Text activity 2 (Student Sheet 2.5)	Prior knowledge of the composition and functions of blood is discussed, with particular emphasis upon its role as a transport system.	Red blood cells carry oxygen to respiring cells. Plasma carries dissolved food materials, waste and hormones. The blood system is a transport system for the body.
Demonstration 2 (Student Sheet 2.6)	Dissection of a heart; see Teachers' Notes for options. Students label a diagram to identify the main features, and are shown artery and vein tissue.	The heart is the pump for the blood system. It has four chambers, separated by valves which control blood flow.
Practical work 3 (Student Sheet 2.7)	Students examine slides of artery, vein and capillary tissue and relate structure to function for each.	Structure and function of arteries, veins and capillaries.
Use of models (Student Sheet 2.8)	Students consider the structure of the lungs and how it helps efficient gas transfer. Students consider the mechanism of breathing.	The alveoli in the lungs provide a very large surface area for gas exchange. Capillaries on the surface of the alveoli provide good contact between the blood and the air in the lungs. The mechanism of inspiration and expiration.

© University of York Science Education Group, 1997

ACTIVITY	REQUIREMENTS FOR THE ACTIVITY
Demonstration 1	Student Sheet 2.1 *The human engine* selected pieces of food, e.g. crisps mounted needle, thermometer, boiling tube, clamp stand
Practical work 1	Student Sheet 2.2 *Respiration in living things* *for optional demonstration:* 3 large test tubes with 2-hole bungs delivery tubes (see page 17) wire gauze platform to fit into one tube filter pump bicarbonate indicator several live woodlice *methylene blue test for demonstration for each group:* conical flask 10 cm^3 active yeast suspension 50 cm^3 5% glucose solution methylene blue solution (**solid is irritant**) *apparatus required to show the production of carbon dioxide by respiration of yeast will depend on the investigation plans developed by students*
Practical work 2	Student Sheet 2.3 *What happens when the oxygen runs out?* stopclocks
Text activity 1	Student Sheet 2.4 *The oxygen race*
Text activity 2	Student Sheet 2.5 *Blood – the superhighway*
Demonstration 2	Student Sheet 2.6 *The structure of the heart* sheep heart (available from butchers or may be obtainable from a local abattoir) dissecting board, forceps, scalpel, scissors, blunt seekers, disinfectant solution model of the heart
Practical work 3	Student Sheet 2.7 *The network* slides of transverse sections of vein, artery and capillaries slides of blood smears stained with the same stain as the sections *optional:* computer program *Blood circulation* (see the unit pre-planner) computer program *Maze* (see the unit pre-planner)
Use of models	Student Sheet 2.8 *The structure of the lungs* model of the thorax and lungs bell jar and balloon model of the thorax – see Teachers' Notes computer program *Respiration* (see the unit pre-planner)

© University of York Science Education Group, 1997

The human engine

In this section, respiration is introduced and considered as an overall process which provides the energy supply necessary for life. The role of the lungs, heart and blood system in transporting food, oxygen and waste products is also considered.

The unit *Staying Alive* extends the treatment of respiration by considering it at the cellular level.

Demonstration 1: *The human engine*

Student Sheet 2.1 accompanies this activity.

In Section 1, students have observed that exercise has the following effects on their bodies:

- pulse rate increases
- breathing rate increases (they puff and pant)
- they become flushed or feel hot

To carry out exercise (work) requires energy. In this respect the human body may be considered as a living engine. Without an energy supply, an engine stops working.

A car engine for example will only work if provided with a fuel and air (oxygen). Combustion of the fuel in oxygen produces a lot of energy. Some can be harnessed to make the engine do work and some is given out as heat.

The human engine also requires fuel, in the form of food, and oxygen, so that the food can be chemically broken down to release energy. Some of the energy produced will be used for work, but some is liberated in the form of heat (hence we feel hotter when we exercise).

Increased exercise causes an increased energy demand, therefore more oxygen and food are required at the muscle cells. The blood needs to move around the body more quickly to deliver the extra oxygen and food, so the heart beats faster and this results in an increased pulse rate. The increased breathing rate may also be explained at this stage in terms of trying to provide enough oxygen to keep pace with the increased demand. These ideas will be revisited in more detail within this section.

To establish that energy is released when food is burnt, demonstrate the energy evolved when a crisp is burnt.

Note: Foods with a high fat content are most effective for this demonstration. Nuts work well, but if you propose to use a nut, it is essential to check that no students suffer from allergic reactions. In some cases even entering a room where peanuts have been burnt causes a severe reaction.



Put 10 cm^3 tap water in a boiling tube and secure in a clamp stand about 20 cm above a fireproof mat. Record the temperature of the water. Pierce the food with a mounted needle and allow it to catch light. Immediately, hold it close to the bottom of the boiling tube until the food stops burning. Measure the temperature of the water again, and use the increase in temperature as a very rough measure of the amount of energy present in that particular food substance.

The demonstration shows that burning food can release energy. It now remains to consider how this might be carried out inside our bodies given that it would not be practical to have individual bonfires within our cells.

By this stage students should have come across enzymes (in the units *Keeping Healthy*, *Food for Thought* and *Controlling Change*) and be aware that high temperatures and enzymes are not a happy combination.

© University of York Science Education Group, 1997

The discussion therefore needs to be steered in the direction that although the final result is that food (glucose) is burnt with oxygen to produce energy and waste products (water and carbon dioxide), in reality this is very much an oversimplification and merely summarises events. Glucose is converted to water and carbon dioxide via a series of minute, complicated reactions, each one controlled by enzymes and designed to ensure that only small, collectable amounts of energy are released at any one time.

Answer to questions on *Student Sheet 2.1*

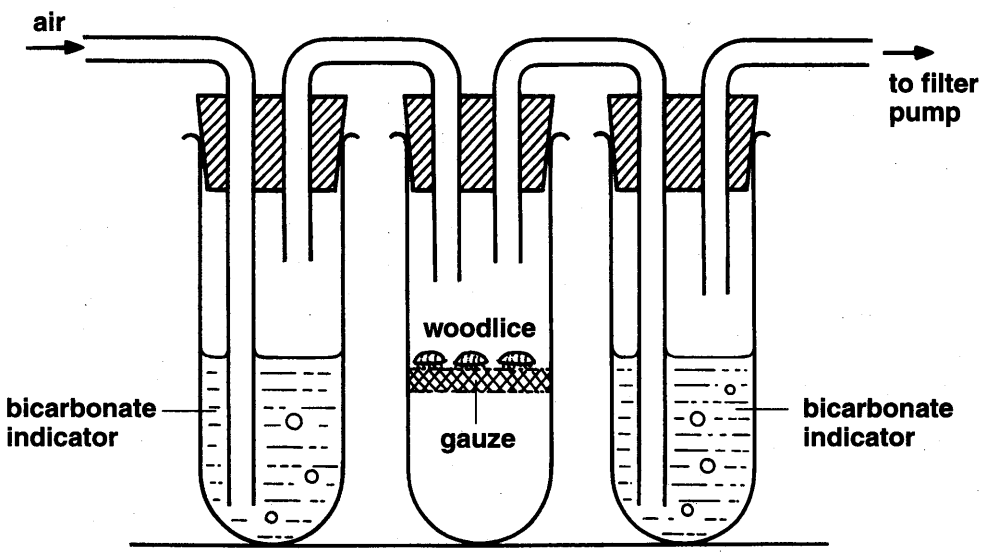
Q1 During exercise a more rapid supply of oxygen is needed.

Practical work 1: *Respiration in living things*

Student Sheet 2.2 accompanies this activity.

One of the important points which may have emerged from the discussion above is that, because respiration is such a vital process to all organisms, it is very difficult to actually study. If respiration is interfered with, then the organism tends to die. For this reason, the practical work on respiration is carried out on yeast.

Because students sometimes have difficulty in believing that yeast is a living organism, it may be useful to have a demonstration set up as below with woodlice or some other obviously living beastie. Failing that, they could always exhale into the bicarbonate indicator themselves!



In sugar solution in the presence of air, yeast cells respire and convert the carbon in the sugar into carbon dioxide gas.

Adding methylene blue to a suspension of yeast in sugar solution may either be used as extension material or it could be used as a simple and entertaining demonstration. It is very simple to carry out but it has two levels of explanation.

At its most basic level it can be used to demonstrate oxygen being used up during respiration. The dye methylene blue is blue when there is plenty of oxygen around, but when the oxygen has been used up the dye becomes colourless. Therefore if it is added to an actively respiring yeast suspension, it will soon go from blue to colourless. If the suspension is given a good shake, it will be reoxygenated and (magic!) the yeast suspension turns blue again.

© University of York Science Education Group, 1997

For use as extension material, methylene blue is a hydrogen acceptor. One step in the oxidation of glucose involves the removal of hydrogen atoms by the enzyme dehydrogenase. This enzyme attaches the hydrogen to a hydrogen acceptor which passes the hydrogen onto another and another until eventually it is joined to oxygen to make water. The methylene blue acts as one of the hydrogen acceptors and becomes colourless when it accepts hydrogen. When it is shaken, the methylene blue is quickly re-oxidised by the air which dissolves in the liquid.

This is an experiment which needs to be pre-tested to ensure that the methylene blue changes within the required time frame. It will vary tremendously from one centre to the next, even though everyone will be using theoretically the same dilution.

The second part of *Student Sheet* 2.2 may be used as the basis of a complete investigation. Alternatively it could form the basis of a class planning discussion, with each student group carrying out different experiments, and the pooled results could be used as an exercise in analysis and evaluation.

In order to measure rates of carbon dioxide production, the yeast must be respiring anaerobically. You may wish to defer discussion of this until the following activity.

Answers to questions on *Student Sheet 2.2*

Q1 Yeast concentration, sugar concentration, temperature and pH are all likely to be mentioned.

Q2 All conditions should be kept standard except the sugar concentration. Compare the time needed for the solution to go colourless. The shorter the time, the more concentrated the sugar solution (this should be true up to the stage at which the solution becomes so concentrated that the yeast begins to become inhibited).

Q3 Carbon dioxide.

Q4 Bubble the gas through limewater. The limewater goes cloudy.

Practical work 2: *What happens when the oxygen runs out?*

Student Sheet 2.3 accompanies this activity.

This activity serves to introduce the idea of anaerobic respiration by enabling students to experience the effect of lactic acid in their muscles.

Raising the arm reduces the blood flow to the hand and continuous vigorous exercise forces the hand muscles to respire anaerobically. Students should experience a feeling of tiredness and fatigue within these muscles as lactic acid accumulates in them. Once the hand is returned to bench level and the circulation is restored, the lactic acid is removed in the blood and the muscles rapidly return to normal.

Comparison of the results should lead students to conclude that, despite a large amount of individual variation, it was possible to clench and unclench their fists at bench level (good blood supply) for a longer period of time without discomfort, than it was with the hand held aloft (restricted blood supply).

The key to this is the availability of oxygen. If there is not enough oxygen available, then an alternative mechanism for respiration comes into play.

When insufficient oxygen is available the muscles do not simply stop. Instead they use the backup method of **anaerobic respiration**. This occurs in the cytoplasm of the cell and involves the conversion of glucose to lactic acid. In terms of the amount of energy available from a given amount of glucose, this process is much less efficient than aerobic respiration. A small amount of energy is released, but much remains still locked up in the lactic acid.

© University of York Science Education Group, 1997

In a similar way, yeast can survive in the absence of oxygen. Anaerobic respiration of yeast produces carbon dioxide and ethanol (alcohol), a reaction which humans have taken advantage of for centuries!

Lactic acid is mildly toxic and as it accumulates in the cells it causes fatigue and then pain (cramp). This is the body's way of warning that enough is enough. At the end of a period of vigorous activity, dissolved oxygen levels in muscle tissues, blood and other cells are lower than normal. Extra oxygen must be circulated to restore normal levels. It is the need to recover this 'oxygen debt' which causes people to go on panting after exercise.

For your information:

Lactic acid passes out fairly rapidly from muscle cells into the bloodstream. It is absorbed into the liver, where much of it is converted back to glucose. This process absorbs energy and must be 'driven' by normal aerobic respiration. The glucose formed may be stored as glycogen in the liver, or recirculated in the bloodstream.

Answers to questions on *Student Sheet 2.3*

Q1 Most students should find that they can continue for longer when their arm is not raised.

Q2 There should be very few exceptions.

Q3 When the hand is held up, less blood reaches it.

Q4 This will reduce the blood supply and hence the oxygen supply to the hand.

Text activity 1: *The oxygen race*

Student Sheet 2.4 accompanies this activity.

The link to the main context of this unit can be re-established by looking at the balance between aerobic and anaerobic respiration for runners in races of different lengths.

Anaerobic respiration is an emergency backup system, which cannot be sustained for any length of time. It is important to sprinters, because circulation cannot supply oxygen fast enough to keep up with their very intensive effort. For longer distances, pace is limited by the efficiency of the breathing and circulatory systems.

Answers to questions on *Student Sheet 2.4*

Q1 Anaerobic respiration is the production of energy from glucose in the absence of oxygen. In animals this results in the formation of lactic acid.

Q2 Oxygen debt is the amount of extra oxygen which has to be taken into our bodies to restore oxygen levels after a period of anaerobic respiration.

Q3 Shorter distance races are largely anaerobic, but as the distance increases, so does the aerobic component. Over short periods of time it is possible for anaerobic respiration to top up aerobic respiration, but this cannot continue for too long otherwise the accumulated lactic acid will start to interfere with performance. In the longer races any lactic acid produced over the initial stages of the race is broken down during the race itself.

Text activity 2: *Blood – the superhighway*

Student Sheet 2.5 accompanies this activity.

Students should be reminded that they have already come across the idea of blood as a transport system in the body (for antibodies in the unit *Keeping Healthy* and for

© University of York Science Education Group, 1997

hormones in the unit *Controlling Change*). Initial small group or class discussion can be used to revise ideas:

- what substances must be delivered to cells (glucose and oxygen for respiration; amino acids for tissue repair; hormones for cell control)
- what substances must be taken away from cells (carbon dioxide)

Student Sheet 2.5 starts by considering some of the materials which are transported by the blood, and then moves on to consider what blood actually needs in order to be an efficient transport system. This should lead to identifying:

- a pump to keep the blood moving
- a network of vessels to hold the blood and conduct it around the body

Together, blood, pump and vessels constitute the circulatory system. The diagram is consumable. Students can fill it in and retain it. It provides an opportunity for students to:

- locate and name the main blood vessels of the body
- see that the pump (the heart) has two distinct halves
- see that some vessels carry deoxygenated blood and some carry oxygenated blood
- begin to appreciate the concept of a double circulatory system

A double circulatory system is one in which a blood cell will pass through the heart twice in one complete circuit of the body. It is advantageous because it means that blood leaving the heart to go to the lungs can go at a relatively low pressure and therefore not risk formation of excess fluid in the lungs. Once oxygenated it can return to the other side of the heart to be propelled at great pressure around the rest of the body.

Answers to questions on *Student Sheet 2.5*

material carried in blood	from	to
oxygen	***lungs***	whole body
carbon dioxide	whole body	lungs
digested food (glucose)	intestine	***whole body***
nitrogenous waste	liver	***kidney***
hormones	***glands***	target organs
heat	abdomen and muscles	whole body

Labels for the empty boxes in the diagram of the circulatory system are, from the top down: head, lungs, liver, legs.

Demonstration 2: *The structure of the heart*

Student Sheet 2.6 accompanies this activity.

The object of this activity is to take a closer look at the pump (the heart). This may be approached as a teacher demonstration, in which case it is often possible to obtain a large heart with blood vessels and atria intact.

Dissection can be a very sensitive topic. There may be school or other local rules about it. An alternative approach is to use *Student Sheet 2.6* as a basis for discussion.

© University of York Science Education Group, 1997

Hearts may be obtained from butchers, although some notice may be needed.

Both computer programs and videos dealing with the structure and function of the heart are available. See the unit pre-planner for details.

After this activity, the bench should be washed with disinfectant solution. Do not simply wash equipment in the sinks; it must be returned for cleaning with disinfectant. Laboratory coats or overalls should be worn to protect clothing. Take care with sharp instruments.



Answers to questions on *Student Sheet 2.6*

Q1 Valves prevent back-flow of the blood from the ventricles to the atria.

Q2 The tendons from the valves act like parachute strings to hold the valves against the pressure of the blood.

Q3 The ventricle walls are thicker than the atria because they do the pumping; the atria only receive incoming blood. The left ventricle is larger and has thicker more muscular walls because it has to provide enough pressure to pump the blood all round the body, not just to the lungs.

Q4 Blockage of these vessels leads to the area becoming starved of oxygen and then dying. This may lead to a coronary heart attack.

During the dissection and/or labelling exercise it is important to stress that the heart itself is a muscle. It must have a plentiful supply of glucose and oxygen so that it can keep working efficiently. With reference to athletes, the heart is a muscle and can have its performance improved with exercise. Regular training increases the heart volume which in turn leads to a lower rate of heart beat to move the same volume of blood. A slower heart beat gives greater capacity for increase during heavy exertion, and the heart does not become so fatigued. Faster recovery of resting pulse rate is a sign of quick recovery, so a fit person leads to a fit heart.

Save some of the artery and vein tissue for the next session, or if carrying out a demonstration dissection point out the thick walls and relatively small lumen of the arteries leaving the heart, compared to the thin walled, wide lumened veins. Point out the semi-lunar valves at the mouth of the arteries and explain their function. This is a good time to mention that arteries do not contain valves but veins do.

Labels for diagram on *Student Sheet 2.6*

A1, B6, C2, D8, E3, F5, G4, H7

Practical work 3: *The network*

Student Sheet 2.7 accompanies this activity.

Student Sheet 2.7 includes a table which has cross-sections of the three types of blood vessel. If suitable slides are available, these drawings can be blanked out when duplicating the student sheet. Students can then examine transverse sections of arteries, veins and capillaries and draw these into the top sections of the table.

Depending on the range and quality of slides available, it may be helpful to start with a slide of a blood smear so that students recognise the characteristically shaped blood cells and can then use these to help them find the lumen of the various blood vessels. Students should note the difference in the thickness of the walls and the size of the lumen.

Students should now have seen for themselves that the three different blood vessels

© University of York Science Education Group, 1997

have different sized lumens and walls. They should be encouraged to suggest reasons for these differences, either as a large group or in smaller groups. They can then go on to consider other differences between the vessels which will enable them to complete the table on the student sheet.

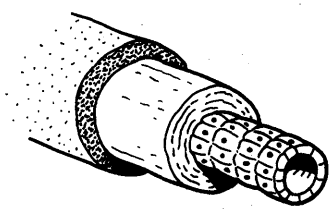
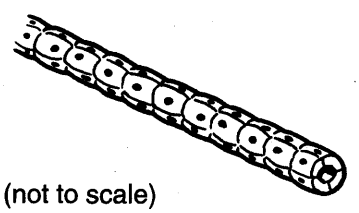
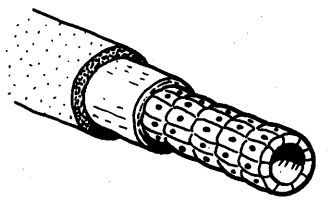
Arteries carry blood away from the heart and, with the exception of the pulmonary arteries, the blood they contain will be oxygenated. The pumping action of the heart causes surges of blood and generates excess pressure. Therefore the artery walls must be strong and elastic to even out the blood flow and maintain the blood pressure.

Capillaries are the main area for exchange of materials so they have to be very thin walled. Passage of blood through fine capillaries reduces the pressure and the blood entering the veins is at a relatively low pressure, deoxygenated and carrying a high carbon dioxide content (the exception to this is the pulmonary vein).

Vein walls therefore do not need to be thick to even out the flow and withstand blood at high pressure. They are a lot thinner, but still contain elastic fibres so that they are not damaged by body movements. Veins also contain 'one-way' valves (semi-lunar valves) which ensure that blood does not flow in the wrong direction. Blood is kept moving in the veins in part by the movement of the long muscles in the body, and also by pressure changes in the thorax.

Computer programs are available which will help to reinforce understanding of the circulatory system. See the unit pre-planner for details.

Answers for the table on *Student Sheet 2.7*

artery	capillary	vein
	 (not to scale)	
carry blood away from heart	allow tissue fluid to supply all the cells of the body	carry blood back to heart
narrow lumen	narrow lumen	wide lumen
thick walls	very thin walls	thin walls
large proportion of elastic fibres	no elastic fibres	some elastic fibres
blood at high pressure	blood at relatively low pressure	blood at low pressure
usually carry oxygenated blood	blood oxygenated but concentration gradually decreasing	usually carry deoxygenated blood
blood normally contains more food	blood with a good supply of food but gradually decreasing	blood usually contains less food
blood normally contains less carbon dioxide	carbon dioxide content gradually increasing	blood usually contains a high carbon dioxide content

Use of models: *The structure of the lungs*

Student Sheet 2.8 accompanies this activity.

Breathing is an essential activity. Students have already studied the part played by oxygen in tissue respiration, and will be aware how vital oxygen is to our well-being. It is very important to stress that breathing/gas exchange is not respiration, and to avoid

© University of York Science Education Group, 1997

reference to the confusing term 'respiratory system' when dealing with the lungs and associated structures.

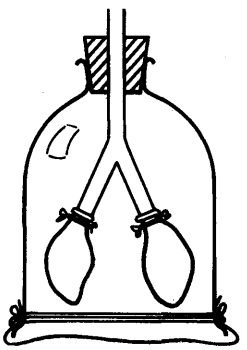
This activity will be enhanced if models of the lungs or even fresh lungs are available. Students can then relate the diagram on the student sheet to the structures they see on the models.

There is a computer program *Respiration* which may be helpful during this activity, but take care not to confuse students with the name!

Students should focus on the following:

- The supporting rings of cartilage which enable the neck to turn without restricting the passage of air.
- The numerous bronchioles which subdivide to produce a vast branching network terminating in thin-walled alveoli (when spread out they will cover the surface of a tennis court). This provides a huge surface area for gas exchange.
- Alveoli provide a moist surface for diffusion and exchange of gases, they are well supplied with blood capillaries and are very thin walled.
- The pleural fluid and pleural membranes reduce friction between the lungs and the ribs, ensuring that movements of the ribs are accompanied by smooth movements of the lungs.
- The mechanism of inspiration and expiration. This may well be helped by using a simple model of the lungs, as below.

The bell jar is the ribs, balloons are the lungs, a rubber sheet or old swimming cap is the diaphragm, and glass tubing is the trachea.



Answers to questions on *Student Sheet 2.8*

Q1 Labelling from pleural cavity clockwise, the labels should be:

pleural fluid; pleural membranes; capillaries; bronchioles; alveoli; bronchus; trachea; epiglottis.

Q2

	inspiration	expiration
intercostal muscles	contract	relax
ribs	move up and out	move down and in
diaphragm	moves down	moves up
volume of thoracic cavity	increases	decreases
pressure in thoracic cavity	decreases	increases
air movement	air moves into lungs	air moves out of lungs

Q3 (a) The larger the surface area, the more rapid the gas exchange can be.

(b) Fine blood vessels close against the membranes reduce the distance gas has to diffuse to reach the blood.

© University of York Science Education Group, 1997

(c) Thin membranes also reduce the distance for the gas to diffuse.

(d) Moisture dissolves the gases to carry them through the membrane.

Q4

	concentration in		
substance	**blood coming to the lungs**	**air in the lungs**	**blood leaving the lungs**
oxygen	*low*	*decreasing*	*high*
carbon dioxide	*high*	*increasing*	*low*

© University of York Science Education Group, 1997

The human engine

You have measured the amount of work which you can do.

Energy is needed to do work.

You can think of your body as an engine which transfers energy to do work. Just like a car engine, your body needs fuel.

Fuel for the body is food – especially the sugar called glucose. Chemical processes in the body break down glucose. These processes release energy.

◆ *Aerobic respiration*

The usual way of breaking down glucose is reaction with oxygen:

glucose	+	**oxygen**	=	**carbon dioxide**	+	**water**	+	**energy**
$C_6H_{12}O_6$	+	$6O_2$	=	$6CO_2$	+	$6H_2O$	+	**energy**

This process takes place in muscles and other body cells. The oxygen which is needed comes from the air and is carried to cells in the blood.

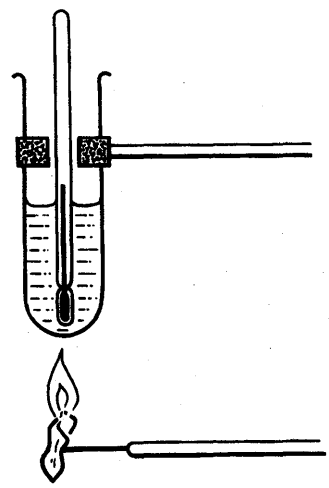
The whole process is called **aerobic respiration**.

◆ *Energy, but no flames!*

The final result of aerobic respiration is the same as if you had burned the food!

You can see the energy change which takes place if you burn a crisp or other bit of food.

The amount of energy transferred can be measured by using it to heat up water:



energy transferred (J) = mass of water (g) × temperature change × 4.2



Of course, food does not burn all at once in your body!

Instead, it is broken down gradually, step-by-step, in a long series of chemical reactions.

Q1 Why do you think your breathing and heart rates get faster when you exercise hard?

© University of York Science Education Group, 1997

Respiration in living things

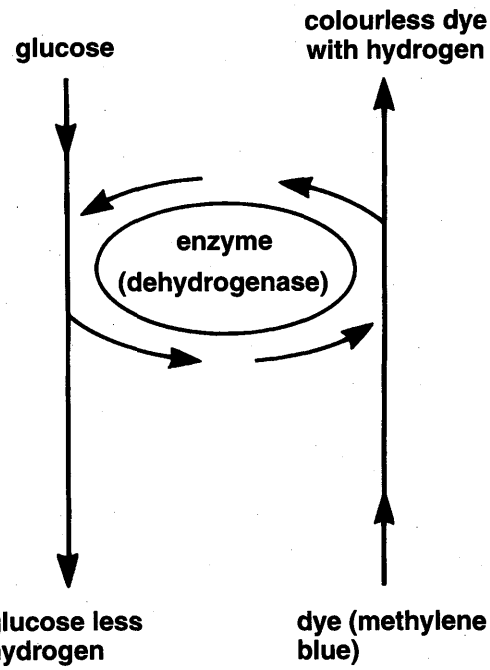
Yeast is a small organism. It can feed on glucose (sugar) as a source of energy. The process of **respiration** converts the sugar to carbon dioxide gas.

◆ *Aerobic respiration uses up oxygen*

During **aerobic respiration**, glucose is oxidised to release energy. This is a complicated process, which takes place in many small stages. The first stage is to remove a hydrogen atom from the molecule of glucose.

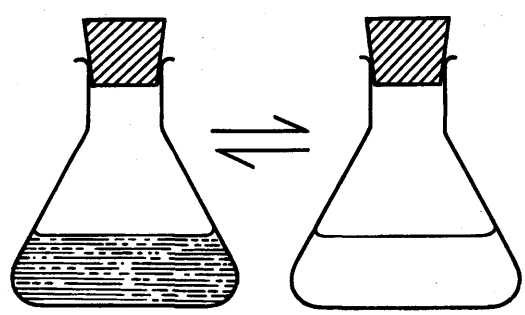
In this experiment, you use a dye called methylene blue to accept the hydrogen from the glucose. When methylene blue accepts hydrogen, its colour fades.

To get the colour back again, oxygen must be supplied. The oxygen combines with the hydrogen to form water and the blue colour reappears.



These reactions are a model for the process which happens in cells. As the yeast respires, the blue colour fades. To get the colour back, shake the flask so that oxygen dissolves in the water.

By timing how fast the colour fades, you can measure how fast oxygen is being used up as the yeast respires.



Q1 List the different factors which you think might affect the rate of this reaction.

Q2 How could you use this test to compare the concentration of two different solutions of glucose?

© University of York Science Education Group, 1997

Respiration in living things

◆ *Carbon dioxide from respiration*

When yeast is placed in a warm solution of glucose, bubbles of gas are given off.

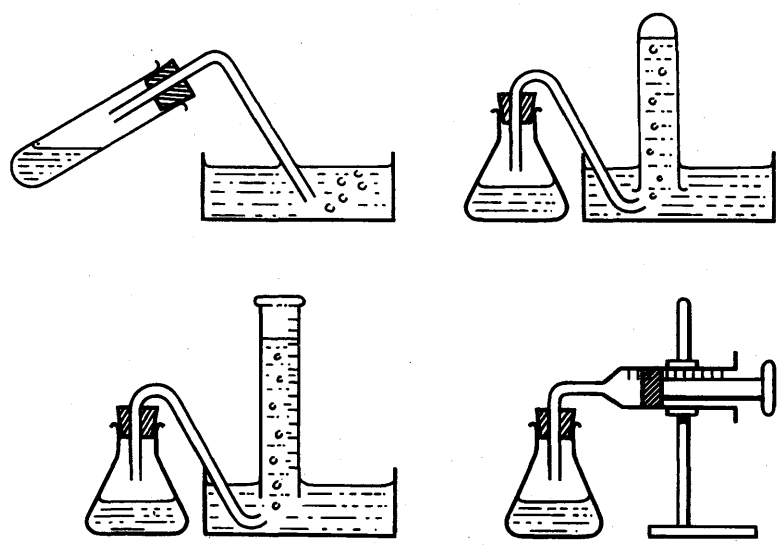
Q3 What gas would you expect to be given off as a result of respiration?

Q4 How could you test to identify this gas?

◆ *Measuring the rate of respiration in yeast*

If you can measure how quickly carbon dioxide gas is given off, this will be a measure of how quickly the yeast is respiring.

- Look at these pictures.
- Make a list of different ways of measuring how quickly gas is being formed.
- Think carefully about what you would need to measure in each case.
- Decide which method you think is best and list the apparatus you would need.



The chemical changes which make up respiration are controlled by enzymes.

- Think about what you know about enzymes.
- How would you expect the rate of respiration to be affected by:
  - (a) the concentration of the sugar solution?
  - (b) the amount of yeast?
  - (c) the temperature?
- Think about any other factors which you might have to control if you wanted to investigate respiration.
- Work out the range of values you would have to test to see whether your prediction was correct.

© University of York Science Education Group, 1997

What happens when the oxygen runs out?

Under normal circumstances, your body gets its energy from **aerobic respiration**. This needs a supply of oxygen, which is brought to cells in the blood.

What happens if you cannot supply enough oxygen?

◆ *Working beyond normal limits*

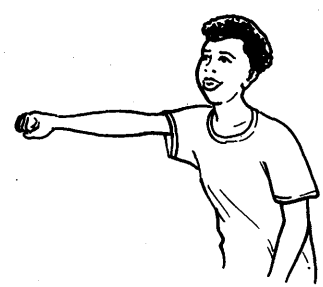
Here is a simple way to test what happens when demand for energy cannot be met by supplies of oxygen.

- Put one arm straight up in the air, above your head.
- Bunch and unbunch your fist as rapidly as you can.
- Go on as rapidly as possible until you cannot hold your arm up any longer.
- Remember what it feels like.
- Rest your arm back on the bench and note what it feels like over the next few minutes.
- Record how your arm felt when it was held in the air, and how it felt when it was returned to the bench.
- Repeat the exercise with your other arm, but this time use a stopclock to time how long you can continue with the arm upright and exercising.



Wait for a few minutes to let both arms recover completely.

- Now hold one arm straight out in front of you. Time how long you can go on clenching and unclenching your fist.
- Collect the times from other groups in your class, and calculate the average endurance time for each exercise.
- Compare the class results for each activity. Try to explain any pattern.



Q1 Which could you do for longest, work with your arm up, or down?

Q2 Was this the same for everyone in the class?

Q3 What difference do you think the position of your hand makes to the amount of blood which reaches it?

Q4 How might this affect the oxygen supply to the hand?

◆ *Anaerobic respiration*

If you run short of oxygen, your body does not just stop. Glucose can be partly broken down even when no oxygen is available. However, this **anaerobic respiration** forms lactic acid, which causes the discomfort you felt in your arms.

Anaerobic respiration can keep you going for a very short time only.

© University of York Science Education Group, 1997

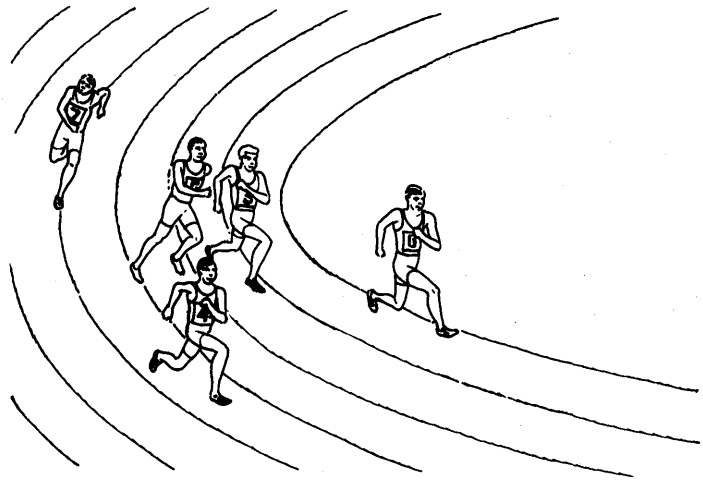
The oxygen race

When athletes perform, they need lots of energy.

Sometimes they cannot get all the energy they need from aerobic respiration.

This is due to two reasons.

1. They cannot breathe fast enough to supply the oxygen demand.
2. They cannot pump blood around the body quickly enough to supply the cells.



The body has a backup system called **anaerobic respiration**. The name means producing energy in the absence of oxygen.

Anaerobic respiration occurs in the cell cytoplasm (the fluid in cells).

Glucose is only partly broken down, forming lactic acid.

Only a small amount of energy is released.

This is far less energy efficient than aerobic respiration, and the lactic acid produced is poisonous. However, it does enable our muscles to carry on working for a little while when they cannot get sufficient oxygen. As lactic acid accumulates it causes pain in the muscle (cramp).

Exercise uses up reserves of dissolved oxygen in the blood and muscle cells. After the exercise stops, you go on puffing and panting until this 'oxygen debt' has been 'paid back' and oxygen levels are normal again.

◆ *Different breathing for different races*

If you watch athletes running 100 m races, you may notice that they do not breathe throughout the race. They are very fast over relatively short distances, but are unable to sustain it for long.

A marathon runner on the other hand will not reach such speeds, but is able to break down any lactic acid formed whilst still continuing to run, hence their ability to just keep going.

Event	% of energy obtained from	
	aerobic respiration	anaerobic respiration
100 m	0–5	95–100
800 m	35	65
1500 m	55	45
10 000 m	90	10
42 186 m (marathon)	98	2

Q1 What do you understand by the term **anaerobic respiration**?

Q2 What do you understand by the term **oxygen debt**?

Q3 Describe and explain the pattern you can see in the table of data above.

© University of York Science Education Group, 1997

Blood – the superhighway

Blood acts as an amazing transport system to carry materials all over our bodies.

Copy out this table and fill in the missing information.

materials carried by blood	from	to
oxygen		whole body
	whole body	lungs
digested food (glucose)	intestine	
nitrogenous waste	liver	
hormones		target organs
heat	abdomen and muscles	whole body

To carry out its job as a transport system, blood needs to have:

- a pump – the heart
- a network – all the blood vessels

Together these form the circulatory system.

◆ *The circulatory system*

You will be given a map of the circulatory system.

The system carries blood to and from all parts of the body. The heart, arms, intestines and kidneys have already been labelled for you.

- Label the remaining boxes with names selected from:

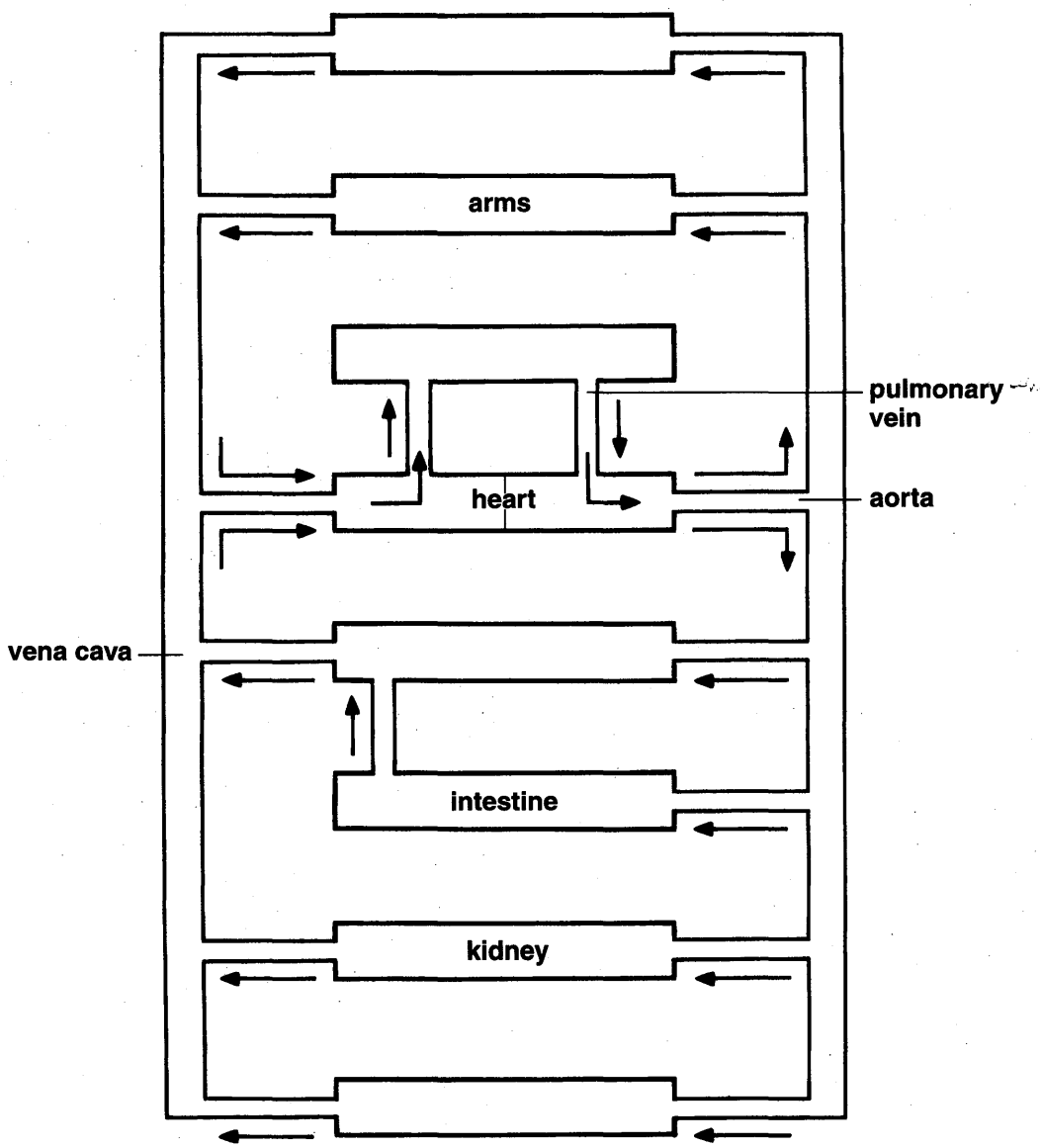
  head **legs** **liver** **lungs**

The blood is carried through tubes called blood vessels.

- Label the following blood vessels:
  - pulmonary artery – goes from the heart to the lungs
  - renal artery – goes from the aorta to the kidneys
  - hepatic portal vein – goes from the intestine to the liver
  - carotid artery – goes from the aorta to the head
  - iliac vein – goes from the legs to the vena cava
  - renal vein – goes from the kidneys to the vena cava
- The aorta is the main blood vessel carrying oxygen-rich blood from the heart to the rest of the body. On your map colour in the aorta and all the side-branches off it, red. This is to show oxygen-rich blood.
- The vena cava is the main blood vessel returning deoxygenated blood to the heart. Colour it and all its side-branches in blue to represent deoxygenated blood.
- Now consider the pulmonary artery and pulmonary vein. What colour do you think they should be coloured? What is unusual about this?

© University of York Science Education Group, 1997

The circulatory system



© University of York Science Education Group, 1997

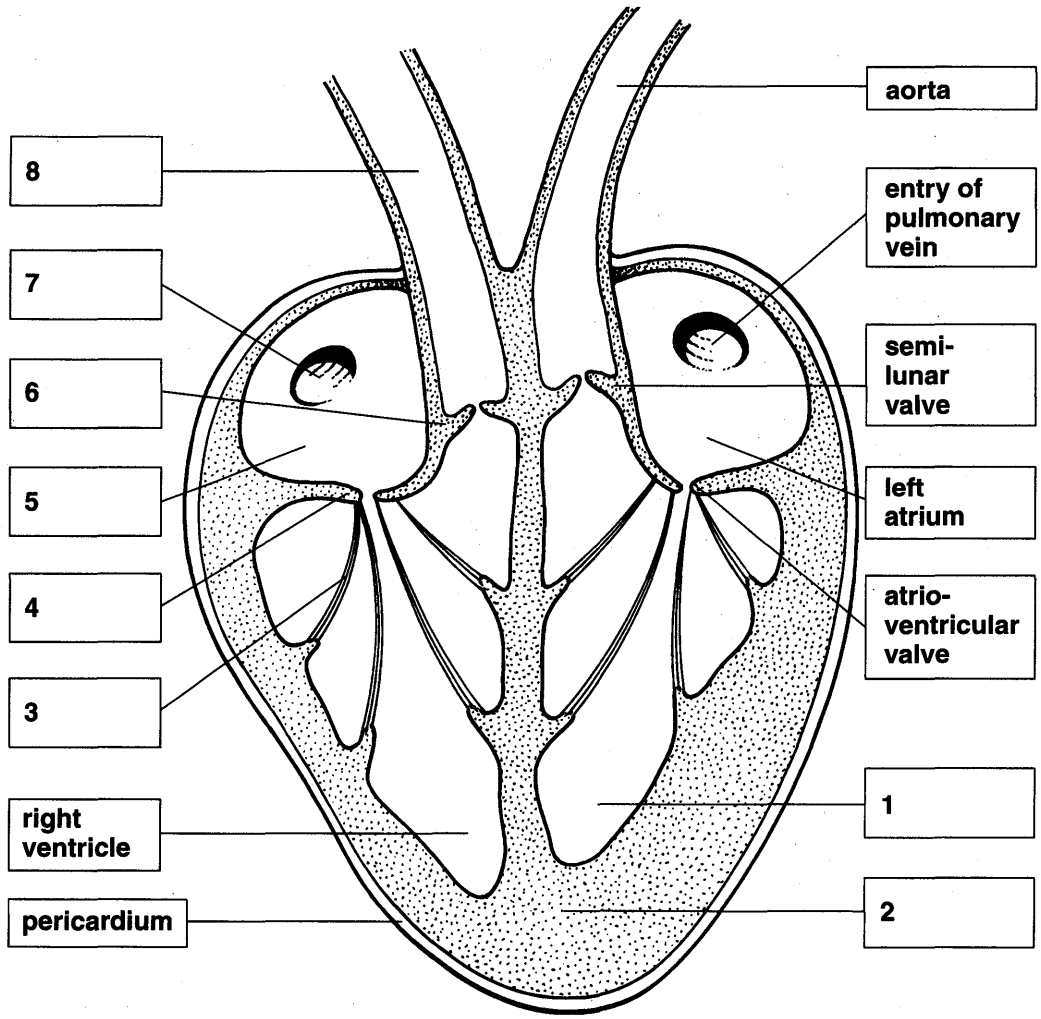
The structure of the heart

The diagram shows a cross-section of the heart (looking from the front).

Some of the parts have been labelled for you, others have been left blank. In your group, pool your knowledge to fill in the blanks.

The names you have to use appear in the following list:

- **A** left ventricle
- **B** semi-lunar valve
- **C** cardiac muscle
- **D** pulmonary artery
- **E** tendons securing atrio-ventricular valve (heart strings)
- **F** right atrium
- **G** atrio-ventricular valve
- **H** entry of the vena cava



Q1 What is the job of the valves at the top of the ventricles?

Q2 How are the valves prevented from bending backwards?

Q3 What do you notice about the thickness of the walls of the two ventricles. Can you explain this?

Small blood vessels called coronary vessels carry blood to the heart itself.

Q4 What do you think would happen if one of them became blocked?

© University of York Science Education Group, 1997

The network

The blood circulatory network is made up of three main types of vessel.

◆ *Arteries*

Arteries are the large vessels which carry blood away from the heart and around the body.

They have a relatively narrow lumen (the hole inside). Because the walls are thick with muscle and elastic tissue, they can stand the high pressure of the blood flowing through them.

Arteries gradually divide and become smaller, being known as **arterioles**. These connect to the capillaries.

◆ *Capillaries*

Capillaries have thin walls and relatively slow moving blood inside them.

The thin walls prevent blood cells and large proteins from leaving the capillaries, but a large proportion of the plasma seeps out through the walls to bathe surrounding cells.

This is given the name **tissue fluid** and it contains the dissolved oxygen and glucose which the cells need in order to respire.

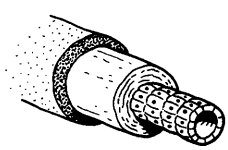
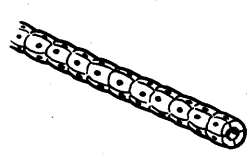
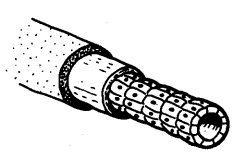
Carbon dioxide and other waste from the cells can diffuse out into the tissue fluid to be collected up into the capillaries and carried away in the blood.

◆ *Veins*

Capillaries join together to form slightly larger vessels called **venules**. Venules merge to produce **veins** which transport blood back to the heart.

Veins have a much wider lumen than arteries, because their walls are a lot thinner. They contain blood at a much lower pressure and have to have valves inside them to prevent the blood flowing in the wrong direction.

Copy out the table and fill in the blanks using information from this sheet.

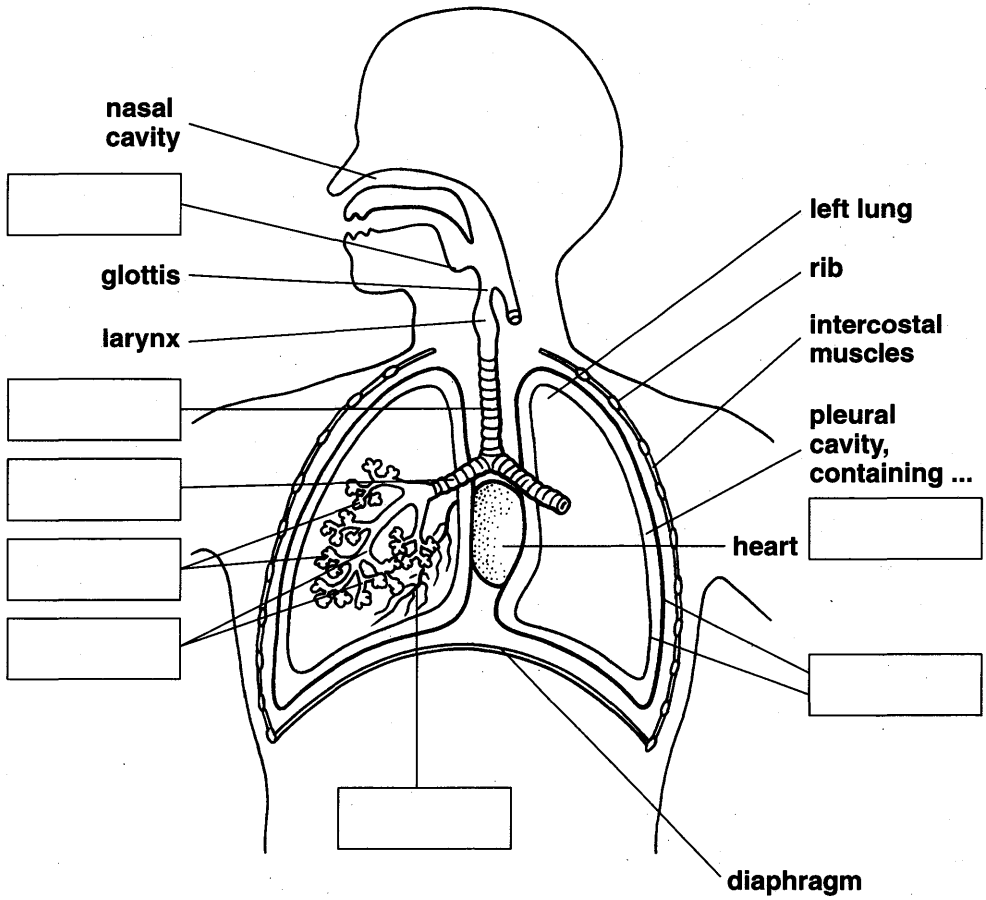
artery	capillary	vein
		
carry blood away from heart		
narrow lumen		
thick walls		
large proportion of elastic fibres		
blood at high pressure		
usually carry oxygenated blood		
blood contains more food		
blood normally contains less carbon dioxide		

© University of York Science Education Group, 1997

The structure of the lungs

Your lungs allow exchange of oxygen and carbon dioxide between the air and your blood.

This diagram shows human lungs. Some of the labels are missing.



Q1 Copy out the labels below in their correct places on the diagram.

Alveoli: coated in a thin layer of mucus-like fluid	**Pleural membranes:** protect the lungs
Capillaries: an extensive network surrounds the lungs	**Epiglottis:** prevents food entering the trachea
Trachea: surrounded by rings of gristle to keep the airway open	**Pleural fluid:** a lubricant allowing membranes to slide smoothly over each other
Bronchus: leads to the lung	**Bronchioles:** branch off and lead to the alveoli

© University of York Science Education Group, 1997

The structure of the lungs

◆ *What happens as you breathe?*

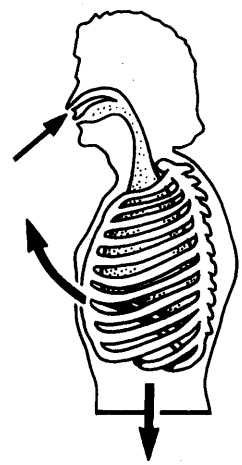
The ribs provide a protective cage round the lungs. Muscles between the ribs – called intercostal muscles – can contract, lifting the ribs up and out. The diaphragm is a stretchy membrane which forms the floor of the cavity that the lungs are in (called the pleural cavity).

◆ *Breathing in*

The intercostal muscles contract, lifting the ribs up and out.

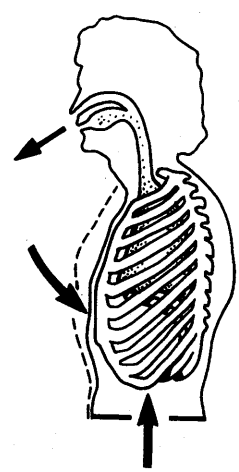
At the same time, the diaphragm moves down.

This *increases* the volume of the cavity. The gas pressure in the cavity falls, and external air pressure pushes air into the lungs so that they expand to fill the larger cavity.



◆ *Breathing out*

Relaxing the intercostal muscles, so that the ribs fall, and raising the diaphragm *decreases* the volume of the pleural cavity and pushes air out of the lungs.



Q2 Fill in the table to show the changes as you breathe in (inspiration) and out (expiration).

	inspiration	expiration
intercostal muscles		
ribs		
diaphragm		
volume of thoracic cavity		
pressure in thoracic cavity		
air movement		

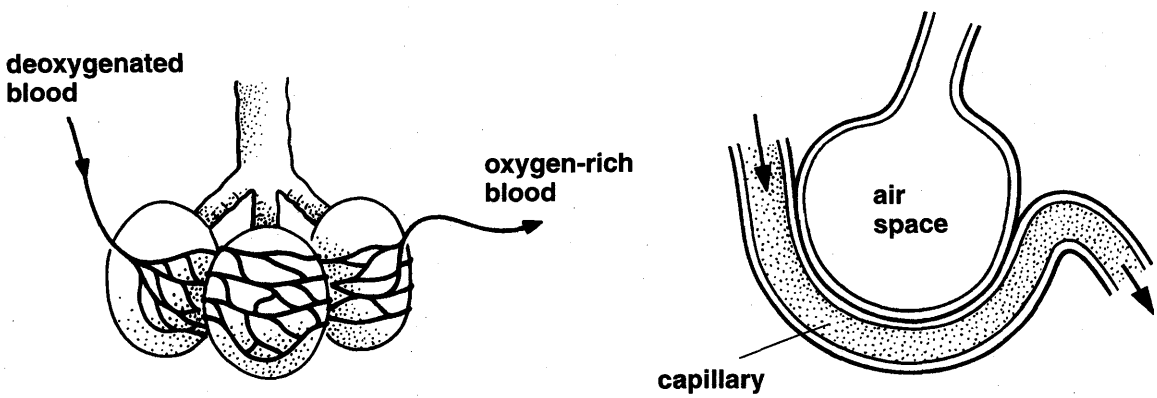
© University of York Science Education Group, 1997

The structure of the lungs

◆ *Gas exchange in the lungs*

Everything about the lungs is designed to make them as good as possible for transferring oxygen from the air in the lungs into the blood.

The pipes which carry air into and out of the lungs divide into smaller and smaller tubes, which end in tiny sacs called alveoli.



Q3 Explain how each of the features listed below helps the lungs to work efficiently (you may need to look at the rest of the information on this sheet to help you):

(a) the alveoli have a very large surface area;

(b) many capillaries carry blood close to the membrane surfaces of the alveoli;

(c) the membranes are very thin;

(d) the membranes are kept moist.

Oxygen from the air in the lungs dissolves in the water which coats the membranes of the alveoli. This dissolved oxygen can pass through the membrane and is then 'captured' by haemoglobin in blood in the capillaries.

Carbon dioxide (waste from respiration) from the blood in the capillaries diffuses the other way through the membranes into the air in the lungs, and so out of the body.

Q4 Complete the table by writing 'high' or 'low' to describe the concentrations of oxygen and carbon dioxide in the blood, and 'increasing' or 'decreasing' for the change in the air in the lungs.

	concentration in		
substance	**blood coming to the lungs**	**air in the lungs**	**blood leaving the lungs**
oxygen			
carbon dioxide			

© University of York Science Education Group, 1997

A living machine!

Students look at the arrangement of bones and muscles and how these function as different types of lever.

3 – 4 lessons

They next consider centre of mass, in the context of high jumping, and evaluate the work done against gravity in various activities.

ACTIVITY	OUTLINE	KEY POINTS
Discussion (Student Sheet 3.1)	Students are reminded about the different types of lever.	Levers function as force multipliers or distance multipliers, depending on the relative positions of the load force, the effort force and the pivot.
Practical work 1 (Student Sheet 3.2)	Students make a model arm and investigate the nature of the levers involved.	The skeleton and muscles form an elaborate system of levers.
Text activity 1 (Student Sheet 3.3)	Students are introduced to the law of moments and use this to calculate the turning forces associated with the biceps muscle.	A force has a turning effect, or *moment*, which depends on the size of the force and its distance from the pivot.
Text activity 2 (Student Sheet 3.4)	Students consider the application of moments to three sporting contexts.	In a stationary lever the sum of the anti-clockwise moments is always equal to the sum of the clockwise moments.
Practical work 2 (Student Sheets 3.5, 3.6 and 3.7)	Students use the law of moments to calculate their centre of mass. They compare situations where the position of the centre of mass leads to instability.	The centre of mass of an object is the point where gravity acts on the object. When the centre of mass moves from over the base then instability occurs.
Text activity 3 (Student Sheet 3.8)	Students read an article about high jump techniques since 1906.	A high centre of mass is useful for sports where jumping higher is important. A low centre of mass is useful for sports where stability is important.
Practical work 3 (Student Sheet 3.9)	Students cut out models of high jumpers and determine the position of their centres of mass.	The centre of mass of an object is not always within the object. Know how to locate the centre of mass of a laminar object.
Text activity 4 (Student Sheet 3.10)	Students calculate their energy expenditure when walking.	Energy expenditure when walking can be calculated from changes in the position of the centre of mass during each stride.

© University of York Science Education Group, 1997

ACTIVITY	REQUIREMENTS FOR THE ACTIVITY
Discussion	Student Sheet 3.1 *Levers*
Practical work 1	Student Sheet 3.2 *A living machine!* *each student group will need:* model arm (see Pre-planner for details) 10, 20, 30, 40 and 50 N weights metre ruler
Text activity 1	Student Sheet 3.3 *Just a moment!*
Text activity 2	Student Sheet 3.4 *Some sporting moments*
Practical work 2	Student Sheet 3.5 *Finding your own centre of mass* plank of wood brick as a support bathroom scales metre rule or tape measure Student Sheet 3.6 *Centre of mass* Student Sheet 3.7 *Touch your toes*
Text activity 3	Student Sheet 3.8 *One giant leap ...*
Practical work 3	Student Sheet 3.9 *How best to jump higher* *each student group will need:* clamp stand optical pin length of cotton small mass
Text activity 4	Student Sheet 3.10 *How much energy do you expend when walking?* *each student group will need:* two metre rules or a tape measure access to bathroom scales

Student book



Thinking about 7: *How do people move?* revises the key ideas of this section.

© University of York Science Education Group, 1997

A living machine!

In this section, students once again compare the working of the human body with that of a machine. The bones in the body provide support and act as levers to move different parts. Muscles provide the forces to generate these movements.

Students first revise ideas about levers from earlier work at Key Stage 3, then consider how muscles operate to produce movement. Most muscles produce turning effects about joints. Students learn how to calculate moments and that equal but opposite moments can produce a balance.

The idea of centre of mass is introduced first in relation to balance, then for a comparison of different high jumping techniques. Finally, students calculate the work done as they walk.

There are opportunities to revise ideas about forces from the unit *Moving On* and ideas about work from Section 1 of this unit.

Discussion: *Levers*

Student Sheet 3.1 accompanies this activity.

This discussion should seek to find out what students already know or remember about levers.

Students may have been introduced to the notion of levers as either force or distance magnifiers during Key Stage 3. This information is revised on *Student Sheet 3.1.*

Practical work 1: *A living machine!*

Student Sheet 3.2 accompanies this activity.

The skeleton and muscles form a complex system of levers which enable people to perform tasks very efficiently. Sports training, by developing the muscles, helps make the levers as effective as possible. The practical work allows students to investigate one of the lever systems in the arm.

In this activity, students make a model arm and investigate which type of lever this forms, and the relationship between the forces and distance involved.

The biceps and bones in the arm form a distance multiplier lever. The majority of lifting levers in the body are of this type. This enables very strong muscles in the body to be used to make very fine and precise movements.

Answers to questions on *Student Sheet 3.2*

Q1 The effort force is greater.

Q2 The load force was furthest from the pivot.

Q3 The arrangement forms a distance multiplier.

Q4 The triceps and bones in the body form a distance multiplying lever.

Text activity 1: *Just a moment!*

Student Sheet 3.3 accompanies this activity.

Students are reintroduced to the law of moments which they met at KS3. The see-saw is the context used to remind students of the method to calculate the turning forces. They are then referred to Practical Work 1 to calculate the turning forces related to their model arm.

© University of York Science Education Group, 1997

Answers to questions on *Student Sheet 3.3*

Q1 The smaller child.

Q2 Her end of the see-saw has gone down.

Q3 400 N × 0.5 m = 200 Nm

Q4 The smaller child (because she is further away from the pivot).

Q5 The see-saw will be turned in the direction of the greater moment.

Q6 Answers will depend on figures obtained on *Student Sheet 3.2.*

Q7 Answers will depend on figures obtained on *Student Sheet 3.2.*

Q8 For each pair of results, the figures should be equal, or close within the limits of experimental error.

Text activity 2: *Some sporting moments*

Student Sheet 3.4 accompanies this activity.

This activity provides additional practice in using the law of moments to solve numerical problems. The calculations are based on sporting situations.

You may wish to emphasise to students that the law of moments applies both at balance (i.e. when a system is stationary) and during controlled movement at a steady speed. In each case there is no net force on the system. (The situation parallels that which students will have encountered in *Moving On*, where it was established that there was no net force on a stationary bicycle or a bicycle moving at constant speed.)

Answers to questions on *Student Sheet 3.4*

Q1 1800 N (300 × 30 = force needed × 5; force needed = 300 × 30/5)

Q2 3600 N (600 × 3 = force × 0.5; force = 600 × 3/0.5)

(Students must ignore the weight of the board!)

Q3 112.5 N (The beam is 5 m long and uniform along its length, so its centre of mass will be 2.5 m from the end, i.e. 2.0 m from the support at the end where Saira has mounted. Saira's weight acts at the end of the beam, i.e. 0.5 m from the support. 450 × 0.5 = weight of beam × 2; weight of beam = 450 × 0.5/2)

Practical work 2: *Finding your own centre of mass*

Student Sheets 3.5, 3.6 and 3.7 accompany this activity.

The purpose of this lesson is to introduce students to the concept of centre of mass and its implications for the stability of objects.

If you are able to provide a suitable plank and bathroom scales, students can make an approximate measurement of the position of their own personal centre of mass, following the instructions given on *Student Sheet 3.5.*

Student Sheet 3.6 links the position of the centre of mass to the stability of an object. Students should discuss the situations shown. They are asked to decide what will happen next. In each case, a person is shown in an unstable position and is about to fall over (intentionally in some cases!).

© University of York Science Education Group, 1997

Student Sheet 3.7 illustrates an activity which will allow students to experience for themselves the result of allowing their centre of mass to move beyond the area they have in contact with the ground.

Students must be cautioned not to try too hard and overstretch. In particular they should not try to get lower by 'bouncing'. A partner should be positioned to support them when they lose their balance.



First, ask the students to touch their toes from a standing position without bending their knees (or get as close as they can!). Then get the students to stand with their backs to a wall, and with their heels touching the wall. If students now try to touch their toes, they will not succeed – unless they cheat!

Students could be asked to suggest reasons for their observations. It is not possible to touch your toes when standing against a wall because of the position of the *centre of mass* of the body.

The centre of mass of an object is the point where gravity appears to act on the object. If an object moves, or is moved, such that a vertical line through the centre of mass falls outside the base of the object, the object will fall over. If you touch your toes, your legs tilt backwards to keep a line through your body's centre of mass over your feet. If your legs are against a wall, this is not possible, and a point is reached where a vertical line through the centre of mass falls outside your feet, and you fall over.

Students could be asked to suggest sports where they think people with low or high centres of mass might have an advantage. For example:

- in jumping sports, where the centre of mass has to be raised as high as possible, a high centre of mass is an advantage;
- in sports where not falling or being pushed over is vital; for example martial arts or the balancing beam in gymnastics, a low centre of mass is an advantage.

Text activity 3: *One giant leap ...*

Student Sheet 3.8 accompanies this activity.

Students read an article about high jump techniques and the Fosbury flop. They are required to respond to some contextual questions. Data related to *World high jump gold medal winners* is provided.

Three different styles used in high jumping are illustrated as a lead-in to the next exercise.

Answers to questions on *Student Sheet 3.8*

Q1 Soft landing beds were introduced. Rules were changed to allow 'head first' jumping.

Q2 1.88 m (6ft 2in), silver medal.

Q3 2.35 m (7ft 8.5in), bronze medal.

Q4 Tall, thin athletes are well suited to the high jump.

Q5 Wrestling, martial arts and the balance beam in gymnastics are all events where a low centre of gravity would be helpful.

Q6 Yes.

© University of York Science Education Group, 1997

Q7 Suggestions may include: improved diet, increased training, new techniques.

Q8 The styles are (a) scissors, (b) western roll and (c) Fosbury flop.

Practical work 3: *How best to jump higher*

Student Sheet 3.9 accompanies this activity.

Student Sheet 3.9 shows a method for locating the centre of mass of a laminar figure. Students use this to find the centre of mass for an athlete as they cross over the bar in different high jump styles.

Students will find that the centre of mass of the 'Fosbury flop' figure lies underneath the back of the figure because of the way the body is bent.

The amount of work done by a high jumper is calculated from the distance the centre of mass rises during the jump. (This is also the increase in gravitational potential energy.) The standard technique requires that the centre of mass passes over the bar. By flexing the body into the Fosbury flop the centre of mass can actually pass under the bar. The Fosbury flop therefore involves less work than the standard jump. This means that, for the same amount of work, an athlete can actually clear a higher bar.

Answers to questions on *Student Sheet 3.9*

Q1 The scissors style of jumping requires the most work because the centre of mass has to be raised higher than in the roll and the Fosbury flop.

Q2 The Fosbury flop has the advantage. The centre of mass is below the athlete's back as they pass over the bar.

Q3 (a) 0.75 m (b) 0.65 m (c) 0.50 m

Q4 (a) 450 Nm (b) 390 Nm (c) 300 Nm

Q5 High jumpers who are tall have the advantage of a high centre of mass and therefore they generally have to do less work than shorter jumpers to clear a jump of the same height. High jumpers who are thin have the additional advantage of a smaller weight to move.

Any handicap system might take account of either the position of the centre of mass of the athlete, or their weight. Some weightlifting events do operate a handicap system in which the score depends on the relation between the weight lifted and the body weight of the lifter. Student opinions may differ on whether such a system would have any value or be workable for other events.

Text activity 4: *How much energy do you expend when walking?*

Student Sheet 3.10 accompanies this activity.

The normal walking action raises and lowers the centre of mass of the body at each stride. This means that work is done against gravity at each stride.

Students estimate this energy based on measurements of their own movement. If this is not possible for any reason, they can use the example data given on *Student Sheet 3.10*.

Answers to questions on *Student Sheet 3.10*

Q1 (a) 25 J ($50 \times 10 \times 0.05 = 25$ J)

(b) 60 000 paces ($30\,000/0.5 = 60\,000$)

© University of York Science Education Group, 1997

(c) 1500 kJ (total work done = 60 000 × 25 = 1500 000 J = 1500 kJ)

(d) 7.5 hr (30 km takes 30 × 15 min = 450 min = 7.5 hr)

(e) 55.6 W (7.5 hr = 27 000 s; power = 1500 000/27 000 = 55.6 W)

Q2 (a) 36 J (60 × 10 × 0.06 = 36 J)

(b) 1800 kJ (no of paces = 30 000/0.6 = 50 000;
total work done = 50 000 × 36 = 1800 000 J = 1800 kJ)

Q3 The rest of the energy released is transferred as the body keeps warm and in repair and growth of body tissues.

© University of York Science Education Group, 1997

Levers

◆ *A reminder*

Levers are machines which help make jobs easier to do.

A lever does one of two jobs.

It is either **a FORCE multiplier** or a **DISTANCE multiplier.**

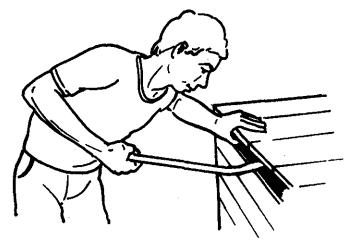
◆ *Force multipliers*

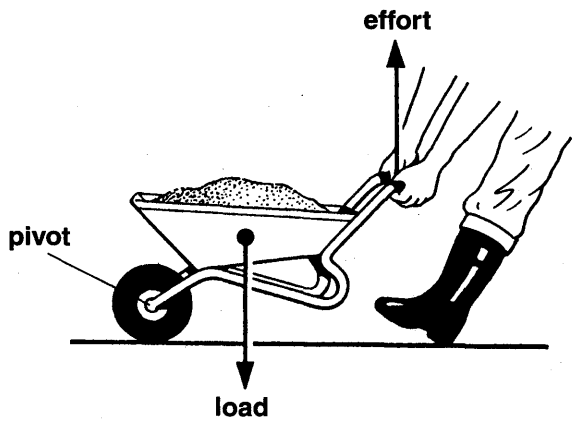
This means that a small effort force (what you put in) will move a larger load force (the job you are trying to do).

If the load force is closer to the pivot than the effort force, the lever is a force multiplier.

A *crowbar* is a simple example of this type of lever.

Here the load force is on the opposite side of the pivot to the effort force.





Sometimes, the load force and effort force are on the same side of the pivot.

If the load force is closer to the pivot than the effort force, the lever is a force multiplier.

A *wheelbarrow* is an example of this type of lever.

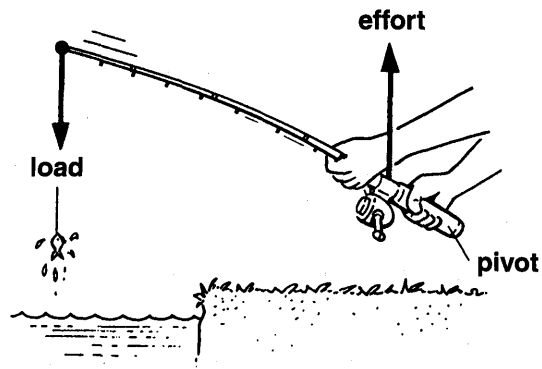
◆ *Distance multipliers*

This means that a small movement by the effort force is turned into a larger movement for the load force.

If the effort force is closer to the pivot than the load force, the lever is a distance multiplier.

A *fishing rod* is one example of this type of lever.

Many of the bones and muscles in your body are also distance multipliers.



© University of York Science Education Group, 1997

A living machine!

You are a machine! Inside your body are over 200 bones and more than 600 muscles.

Muscles are linked to bones by tendons. Together, your muscles and bones make up a huge system of levers which help you to do jobs as efficiently as possible.

◆ *Muscles in action!*

This diagram shows the bones and some of the muscles in your arm.

Notice that there are **two** sets of muscles in your upper arm.

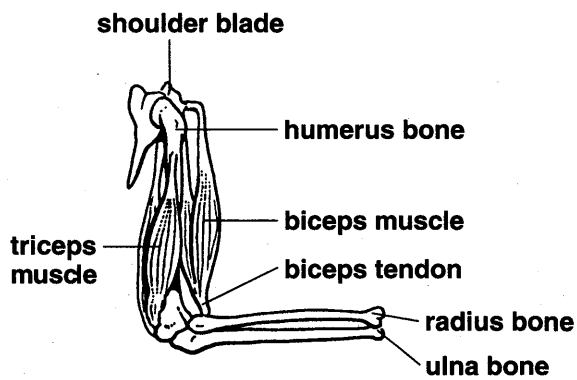
This is because muscles can only exert a force as they contract (get shorter).

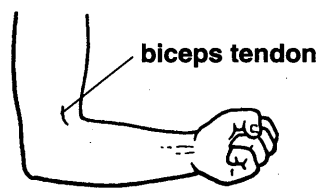
Shade the two sets of muscles different colours.

If you bend your arm, your biceps contracts.

You can feel this, particularly if you try to lift something fairly heavy.

You will also be able to feel the tendon which joins your biceps to your lower arm.





◆ *Muscles usually work in pairs*

Muscles can pull strongly as they contract (get shorter).

A muscle which is fixed to one bone at one end and a different bone at the other end can pull the bones closer together.

Muscles cannot push bones apart.

To reverse the movement of the bones needs a second muscle.

If you only had biceps in your arm, once you had bent your arm, it would stay that way! To straighten your arm, your triceps contracts.

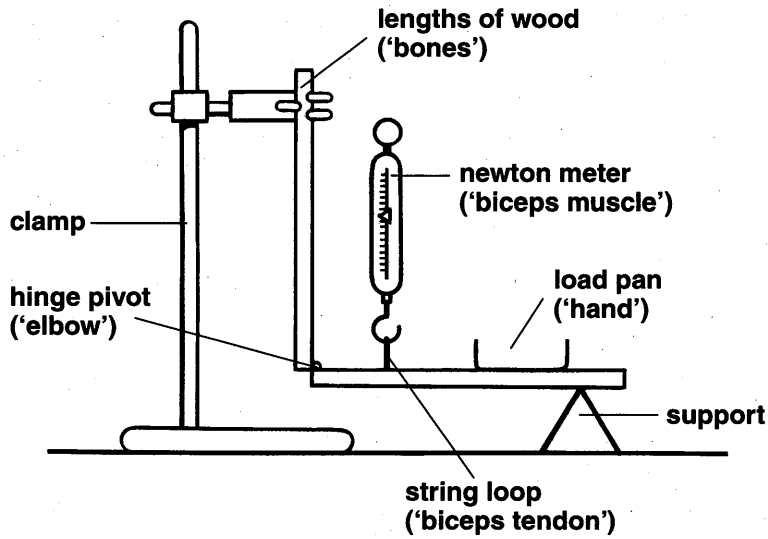
Muscles in the body always work in pairs.

© University of York Science Education Group, 1997

A living machine!

◆ *How strong are your biceps?*

- Set up the apparatus shown in the diagram below:



- Find a volunteer in your group.
- Measure the distance from their hand to their elbow. Make the middle point of the load holder this distance from the hinge.
- Measure the distance from their lower biceps tendon to their elbow. Put the spring balance (the 'biceps') at this distance from the hinge.
- Make a note of these measurements on a results table.
- Put a 5 N weight in the load holder. Pull the spring balance until the 'biceps' just lift the load off the support. Record the reading on the spring balance in your table.
- Repeat this for loads of 10, 15, 20 and 25 N.

◆ *Results table*

Record your results in a table like this:

distance of load holder from hinge =	distance of 'biceps' from hinge =
Load force in load holder (N)	**Effort force needed by 'biceps' (N)**
0	0
10	

◆ *Thinking about the results*

Q1 Which was the greater force, the load or the effort?

Q2 Which force was further from the pivot, the load or the effort?

Q3 Which sort of lever do the biceps and bones in the arm form, a force multiplier or a distance multiplier?

Q4 Imagine you now wanted to use triceps to straighten your arm. What sort of lever do the triceps and bones in the arm form, a force multiplier or a distance multiplier?

© University of York Science Education Group, 1997

Just a moment!

The force exerted by your muscles makes your bones turn around the joint.

◆ *The turning effect of a force*

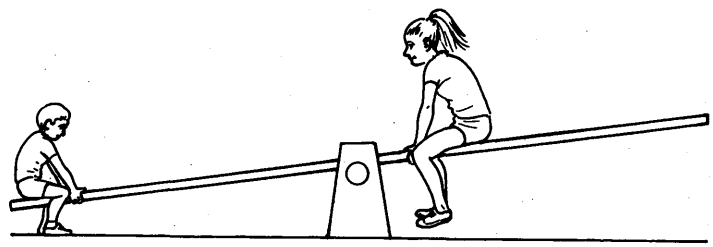
The strength of a turning effect produced by a force is called a **moment**.

The size of a turning effect depends on how large the force is, and on how far away from the pivot it is.

moment of a force = force × distance

◆ *The see-saw*

In this picture, the turning effect of the weight of the small child has lifted the larger child into the air!



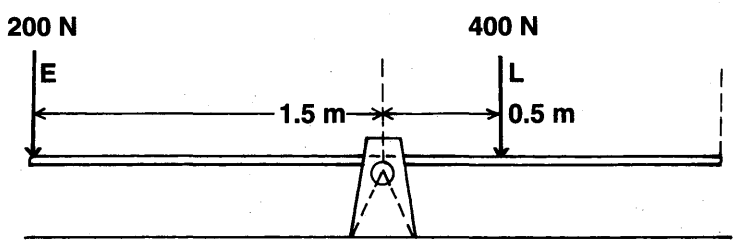
Both of the children are producing a turning effect.

Q1 Which of the children is producing the larger turning effect?

Q2 How do you know?

◆ *The law of moments*

This is a diagram of the see-saw in the picture above.



- The arrow labelled **E** shows where the small child's weight is on the see-saw.
- The arrow labelled **L** shows where the larger child's weight is.
- Mark **P** at the pivot.

The strength of the small child's turning force is

force × distance from the turning point = 200 N × 1.5 m = 300 Nm

Q3 Calculate the turning moment produced by the larger child's weight.

Q4 Which child produces the larger turning moment on the see-saw?

Q5 How does this explain what has happened to the see-saw?

© University of York Science Education Group, 1997

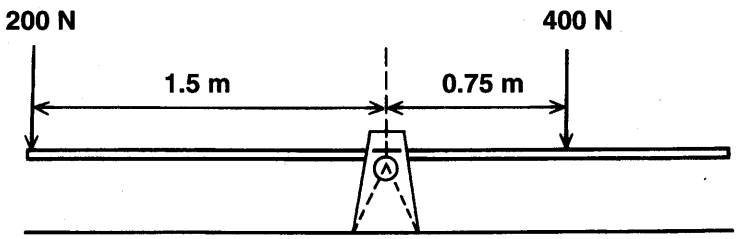
Just a moment!

◆ *Balancing the see-saw*

To balance the see-saw the turning force (moment) both sides of the turning point (pivot) must be equal.

moment (turning anti-clockwise) = moment (turning clockwise)
force × distance from the pivot = force × distance from the pivot

What happens if the larger child moves back and sits 0.75 m from the pivot?



larger child	**smaller child**
force × distance from the pivot	force × distance from the pivot
= 400 N × 0.75 m	= 200 N × 1.5 m
= 300 Nm	= 300 Nm

Now the see-saw will be balanced because the turning moments on each side are equal.

The little bit of extra force as each child in turn pushes against the ground is enough to move the see-saw up and down.

◆ *Moments and the model arm*

Look back at your table of results from when you were measuring the load and effort in your model arm.

Q6 Work out the turning moment of each load you used.

Q7 Work out the turning moment of the effort needed to just hold up each load.

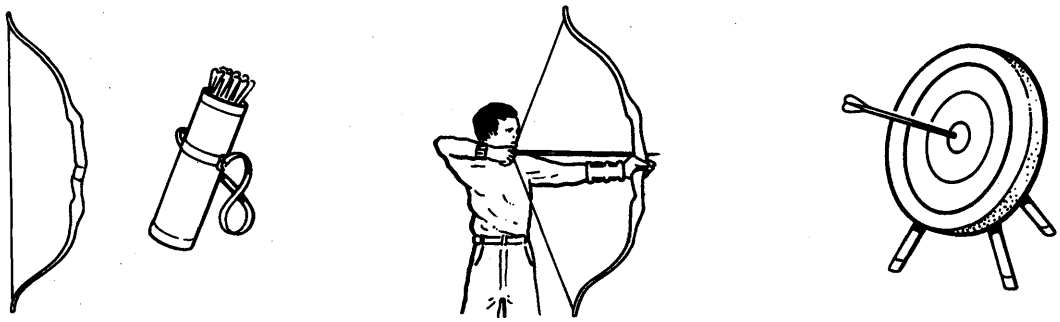
Q8 How do the results compare?

© University of York Science Education Group, 1997

Some sporting moments

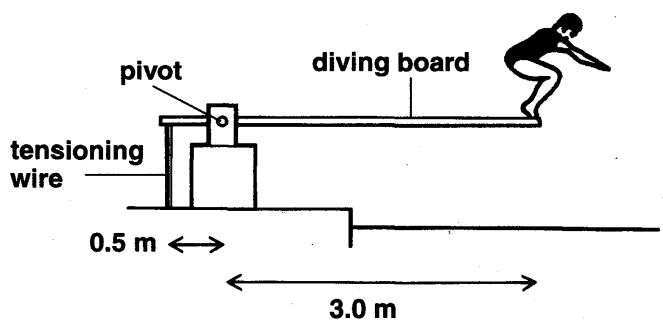
Many sports involve turning forces. Use the law of moments to help you answer the questions below.

Q1 For use in archery competitions, Robin has a bow which requires a force of 300 newtons to draw the string fully back.



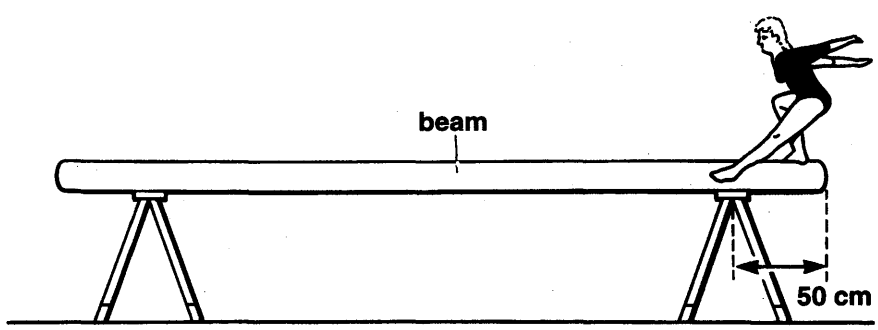
If the distance from his elbow to his hand is 30 cm and his lower biceps ligament is attached 5 cm below the elbow joint, what force must his biceps muscle exert to pull the bowstring back?

Q2 Brenda, who weighs 600 N, is about to dive off the low diving board at her local swimming pool.



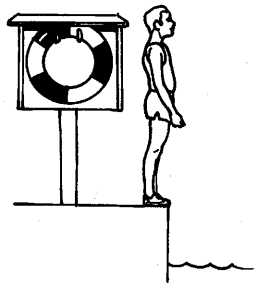
Use the information in the diagram to calculate the force the tensioning wire must exert to stop the diving board tipping over.

Q3 Saira starts her routine on the beam by jumping onto one end of the beam. The beam is 5 m long, and supported by legs 50 cm from each end. Saira has a weight of 450 N. Find out the *minimum* weight the beam would have to be to make sure it did not tip up as Saira jumps on. [Hint: remember the weight of the beam will appear to come from where gravity acts on its centre of mass.]

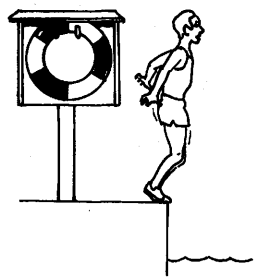


© University of York Science Education Group, 1997

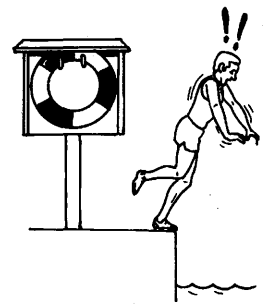
Finding your own centre of mass



Have you ever leaned over too far and fallen off a platform or step?



You can lean just so far, and still get back, even though part of you is beyond the edge.



But if you lean too far, over you go!

It is as though all of your weight was at just one point, somewhere in the middle of you.

For the purpose of calculations the total mass of an object can be considered to act at a single point known as the **centre of mass** (sometimes called the **centre of gravity**).

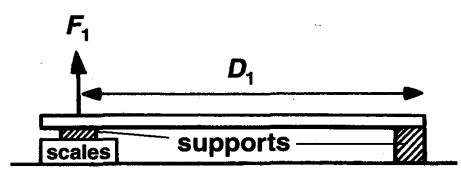
◆ *Your own centre of mass*

Use the law of moments to find your own centre of mass. The diagrams below show how the measurements were taken for Katie. Try them yourself.

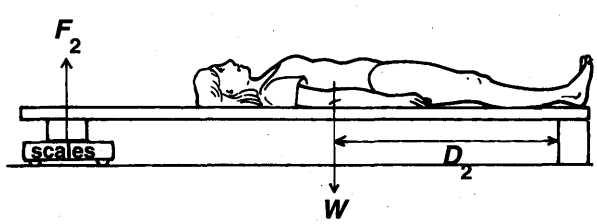
Step 1: Find your weight in newtons.

Step 2: Balance a plank with one end on a pair of bathroom scales.

Measure the length of the plank and the reading on the scales.



Step 3: Lie on the plank as shown. Get your partner to read the scales.



Extra force needed to hold you up = $F_2 - F_1 = F$

Using the law of moments:

$F \times D_1$ = your weight (W) $\times D_2$

So, $D_2 = \frac{F \times D_1}{W}$

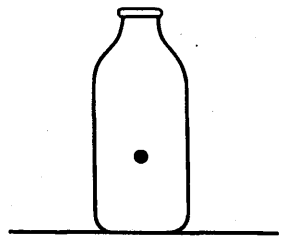
So now you know how far your centre of mass is from your feet!

© University of York Science Education Group, 1997

Centre of mass

The centre of mass of an object is the point where gravity appears to act on an object.

◆ *Where is the centre of mass?*

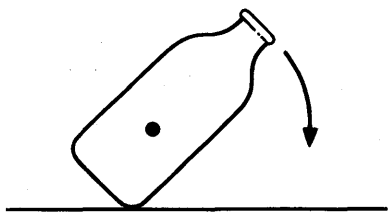


This object is **stable**.

It does not topple over.

Draw a vertical line through the centre of mass.

Q1 What do you notice?



This object is **unstable**.

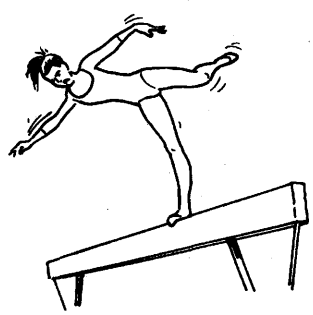
Unless supported, it will topple over.

Draw a vertical line through the centre of mass.

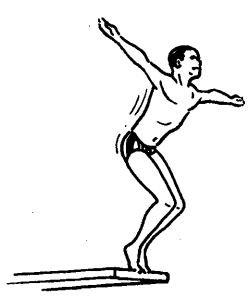
Q2 What do you notice?

◆ *Sydney 2000*

Here are four situations. What do you think will happen next?









© University of York Science Education Group, 1997

Touch your toes

Here is a challenge for you to try!

Step 1

- Stand up straight where you have some free space all round you.
- Bend forward and touch your toes – keep your legs straight.

CARE! Do NOT try too hard, or bounce your upper body up and down as you might damage your muscles.

Step 2

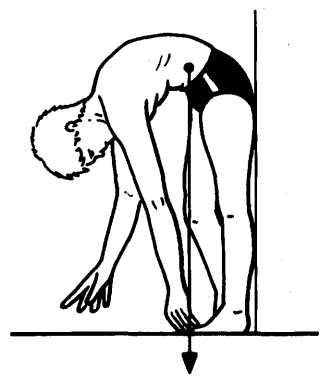
- Now stand firmly upright against a wall with your heels touching the wall.
- Bend and touch your toes.

Did you have problems?

Use the two diagrams below to help you explain why it was impossible.



line through centre of mass passes through feet



line through centre of mass does not pass through feet

© University of York Science Education Group, 1997

One giant leap ...

In the Olympic games of 1996, a British athlete, Steve Smith, won a bronze medal for the high jump by clearing the bar at a height of 2.35 m.

You can read how one newspaper reacted to his success on the next page.

Q1 What changes in the event happened in the 1960s?

Q2 How high did Leahy jump in 1908? What medal did he win?

Q3 How high did Smith jump in Atlanta in 1996? What medal did he win?

Q4 In high jumping a high centre of mass is desirable. Can you give a physical description of an athlete whose body shape is suited to the high jump event?

Q5 In which sport would a low centre of gravity be useful?

◆ *World high jump records*

date	athlete	jump style	height/m
1880	Patrick Davin (IRL)	front roll	1.90
1912	George Horine (USA)	western roll	2.00
1941	Lester Steers (USA)	straddle	2.10
1960	John C Thomas (USA)	straddle	2.22
1973	Dwight E Stones (USA)	flop	2.30
1978	Volodomir Yashchenko (URS)	straddle	2.34
1983	Zhu Jianhua (CHN)	flop	2.38
1988	Carlo Thränhardt (FRG)	flop	2.42
1993	Javier Sotomayor (CUB)	flop	2.45

Q6 Plot the results as a line graph. Is there a trend?

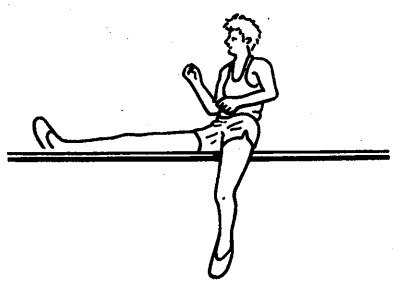
Q7 Discuss possible reasons for this trend.

◆ *Name the high jump styles*

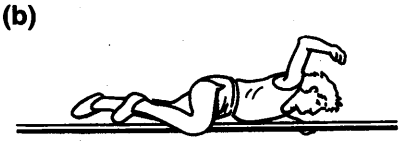
These pictures show three different high jump styles.

Q8 What is the name of each style?

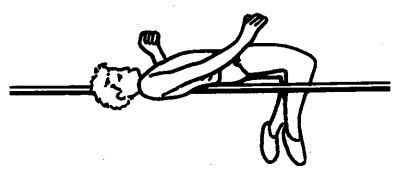
(a)



(b)



(c)



© University of York Science Education Group, 1997

One giant leap ...

One giant leap for Britain finally clears Olympic gap for 88 years

by ROBIN YOUNG

BRITISH athletes yesterday celebrated closing a gap of 88 years and 1ft $6\frac{1}{2}$in over the last time they won an Olympic medal for the high jump.

Steve Smith won his bronze in Atlanta by clearing 7ft $8\frac{1}{2}$ in (2.35m). Long before the Fosbury flop had been invented – or would indeed have been considered legal – Britain picked up a silver at the 1908 Games in London when Cornelius (Con) Leahy jumped a mere 6ft 2in (1.88m).

The long stretch of time emphasised not only changing styles, but challenging national boundaries. Leahy was from Co Cork, now part of the Irish Public.

He was one of seven sporting brothers, four of whom won jumping titles. There was a great tradition of Irish jumping in the early days of international sport, because jumping of all sorts had always figured largely in Irish village games. Leahy excelled at long and triple jumps as well as high. Born in 1876, he won the high jump in the 1906 intercalated Olympics – so called because they were held after a two-year interval before the four year cycle was established. In 1908, he shared the silver with a Frenchman, Georges André, and a Hungarian, Istvan Somody, while the gold went to an American, Harry Porter, who cleared 6ft 3in (1.905m).

Leahy and M André's jumps would have been good enough for gold in 1904, when the Olympic winner, Samuel Jones, managed only 5ft 9in. Con's lifetime best was 6ft $4\frac{1}{2}$in, also in 1904, but outside Olympic competition. Leahy died in America in 1921, 12 years after emigrating with his brother Pat in 1909.

In high jump, Leahy used a variant of the scissors method, in which the upper torso was held nearly upright while first the right leg and then the left crossed the bar. Although the scissors jump has now almost disappeared from international competition, it is still used in schools and youth competitions where landing beds are not available.

In the early 1960s, the introduction of landing beds and abolition of a rule which required that jumps be performed feet first made possible the Fosbury flop, named after Dick Fosbury, the US gold medal medalist of 1968.

The flop, in which jumpers go head first and land on their backs, was employed by Steve Smith and all his opponents this year, having replaced not only the scissors, but also other techniques such as the eastern cut-off, the western roll (introduced by George Horine of the USA in 1912), and the straddle.

Smith's leap, four centimetres higher than his season's best, added an Olympic bronze to the silvers he has won at the European Championship and Commonwealth Games. After his triumph, he said: "I have got 22 relatives here: my two brothers, my mum and dad, all my aunties, uncles and cousins and my girlfriend. I think it's going to be Scousers on the rampage."

Sport, page 39

Extract from *The Times*, 30 July 1996.

© University of York Science Education Group, 1997

How best to jump higher

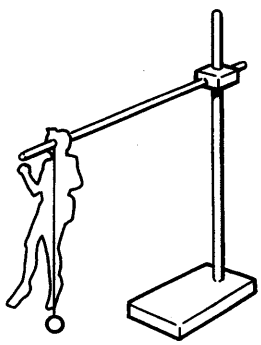
Does it make any difference which style a high jumper uses?

◆ *Where is the high jumper's centre of mass?*

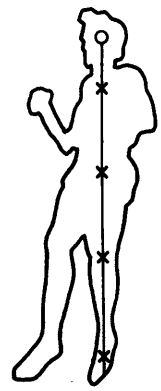
An object which is hung from a single support always hangs so that its centre of mass is directly below the support.

Follow these steps to find the centre of mass of any flat cut out shape:

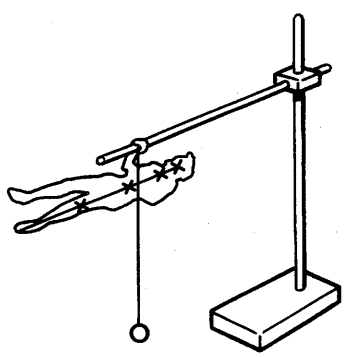
Step 1: Hang up your shape.



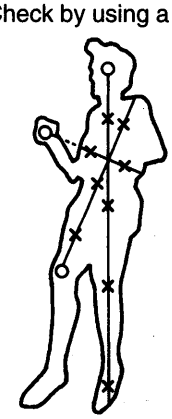
Step 2: Mark the position of the cotton with two or three pencil crosses.



Step 3: Hang the shape from a different point and mark the new position of the cotton.

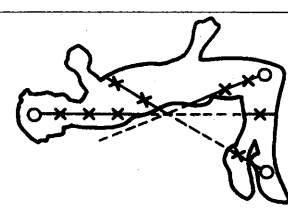


Step 4: Check by using a third position.



The centre of mass of a shape does not always lie within the shape.

If the lines do not cross on the shape, lay it on a piece of paper and extend the lines until they cross.



Cut out shapes showing the position of high jumpers as they cross the bar in each of three different jumping styles.

Use this method to find the centre of mass of each figure.

Now look at the pictures showing each style in action.

Q1 In which style does the jumper have to lift their centre of mass to the highest level to get over the bar?

Q2 Which style has the advantage in terms of the height to which the jumper must lift their centre of mass?

© University of York Science Education Group, 1997

How best to jump higher

◆ *How much work do high jumpers do?*

If a high jumper who is using the scissors style just clears the bar, they must lift their centre of mass 0.25 m above the bar.

For a jumper using the western roll method, the centre of mass must be at least 0.15 m above the bar.

When a jumper uses the Fosbury flop method, the centre of gravity only needs to be lifted to just the height of the bar.

- Assume that a jumper has centre of mass 1 m above the ground when standing.

Q3 How far would this jumper have to raise their centre of mass to clear a bar set at 1.5 m, using

(a) the scissors (b) the western roll (c) the Fosbury flop?

- Assume that the jumper has a mass of 60 kg and so weighs 600 N.

Q4 What is the minimum amount of work the jumper will have to do against the force of gravity to clear the bar, using

(a) the scissors (b) the western roll (c) the Fosbury flop?

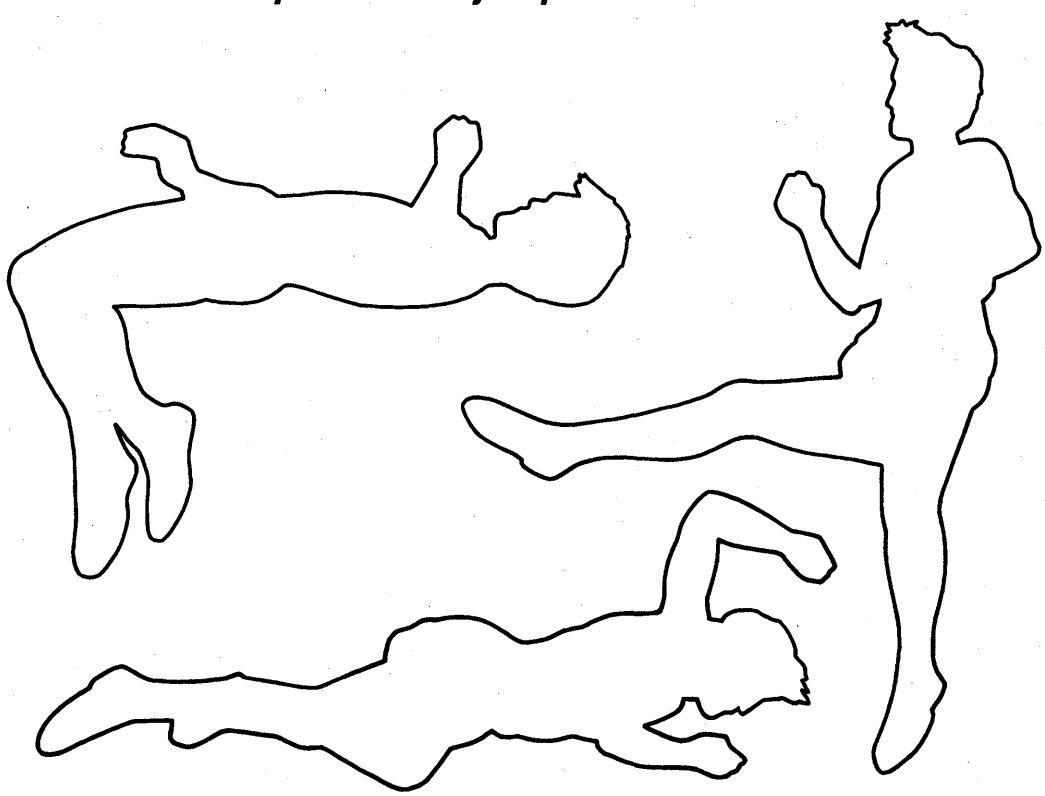
Remember, use this formula:

work done = force × distance moved

- Suppose that the next competitor in the event also weighs 600 N, but is much taller and thinner.

Q5 What difference will this make to the amount of work they have to do to clear the bar? Discuss whether it would be possible to devise a 'handicap' system for the high jump which would cancel out any advantage due to the shape of the jumper.

◆ *Cut-out shapes for the jumpers*



© University of York Science Education Group, 1997

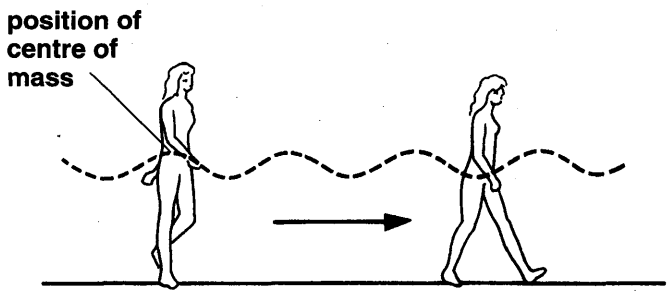
How much energy do you expend when walking?

It isn't only high jumpers who do work against gravity!

◆ *Walking to work*

How much energy do you expend if you walk a distance of 1 km over level ground?

When you are walking, you are continuously raising and lowering your centre of mass. Most of the energy you expend comes from the work you have to do to raise your centre of mass in each step:



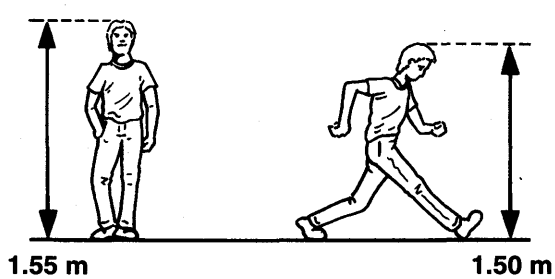
There are several stages involved in measuring how much work you do (i.e. your energy expenditure) as you walk 1 km.

Stage 1: How much does your centre of mass go up and down?

- measure your height

standing normally

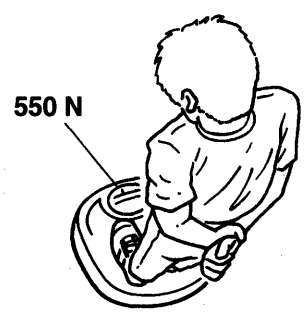
in the middle of a step



difference = 1.55 – 1.50 = 0.05 m

Stage 2: How much work for each step?

- Measure your weight



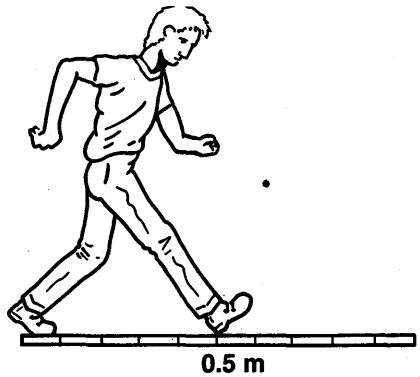
work done per step = height difference × weight
= 0.05 × 550
= 27.5 J

© University of York Science Education Group, 1997

How much energy do you expend when walking?

Stage 3: How many steps in 1 km?

- measure the length of one stride



- divide this into 1000 m
  1000/0.5 = 2000 steps

Stage 4: Total amount of work

- to find the total amount of work done, multiply the number of steps by the work done for each step

2000 × 27.5 = 55 000 J = 55 kJ

Compare the amount of work done by different people in your class.

Can you see any patterns in the results?

◆ *Long distance walking!*

Q1 Sian is taking part in a sponsored walk over a distance of 30 km.

(a) If Sian has a mass of 50 kg and her centre of mass rises 5 cm each time she takes a step, how much work does she do each time she makes a step? (Be careful with units!)

(b) If Sian's average step length is 50 cm, how many steps does she make on the walk?

(c) How much work does she do on the walk?

(d) If Sian walks on average 1 km in 15 minutes, how long will the walk take her?

(e) What power does she develop as she is walking? (Again, be careful with units!)

Q2 David took part in the same sponsored walk. He has a mass of 60 kg, a 60 cm step length and his centre of mass rises by 6 cm each time he makes a step.

(a) How much work does he do each time he makes a step?

(b) How much work does he do during the walk?

Q3 The average daily energy requirements from food for teenage girls and boys are 9600 kJ and 11 400 kJ, respectively. Even a 30 km walk needs only a fraction of this energy! What do you think happens to the energy which is not expended while walking?

© University of York Science Education Group, 1997

Faster and higher

This section introduces students to ideas about kinetic and potential energy. **2 lessons**

The ideas are applied in the context of the pole vault.

Analysis of data about free fall parachuting leads to ideas of acceleration due to gravity and the limiting effect of air resistance.

The principle of conservation of energy is also formalised.

ACTIVITY	OUTLINE	KEY POINTS
Practical work (Student Sheet 4.1)	Students measure kinetic and potential energies in a variety of simple tasks.	Kinetic energy (KE) is associated with movement. Gravitational potential energy (PE) is associated with height above the ground. KE = $^1/_2mv^2$ PE = mgh. Many sports involve increasing kinetic or potential energy.
Text activity 1 (Student Sheet 4.2)	Students apply their knowledge of KE, PE and energy conservation to energy changes in the pole vault. This leads to a discussion of conservation of energy.	Energy cannot be created or destroyed, only converted from one form to another. Often a non-useful energy transfer accompanies a useful one. Some of the energy ends up in non-useful, spread out forms.
Text activity 2 (Student Sheet 4.3)	Students consider data from free fall parachuting.	Falling objects accelerate downwards due to gravity. Air resistance limits the rate of fall.
Text activity 3 (Student Sheet 4.4)	Students' ideas about representing energy transfers are revised.	Energy flow arrow diagrams can be used to represent energy transfers.

ACTIVITY	REQUIREMENTS FOR THE ACTIVITY
Practical work	Student Sheet 4.1 *How fast, how high?* meter rulers stop clocks bathroom scales or newton scales
Text activity 1	Student Sheet 4.2 *Faster and higher?* graph paper
Text activity 2	Student Sheet 4.3 *Free for all*
Text activity 3	Student Sheet 4.4 *Energy transfers in sport*

Student book



Looking at: *Jumping and vaulting* reinforces many of the ideas in this section.

Thinking about 5: *What are kinetic and potential energy?* revises the key ideas in the section.

© University of York Science Education Group, 1997

Faster and higher

The purpose of this section is to introduce students to the terms kinetic energy (KE) and potential energy (PE), and how they may be calculated. Further exploration of these ideas leads to the principle of conservation of energy and revision of energy flow arrow diagrams as a means of showing energy transfers.

Practical work: *How fast, how high?*

Student Sheet 4.1 accompanies this activity.

In this fairly short practical exercise, students calculate kinetic and potential energies for a selection of simple tasks. If students appear to need more practice, you can add other, similar tasks. Students may need to be reminded of ideas studied in the unit *Moving On*, in particular that velocities are calculated from measurements of distance *and* time, and are measured in units of m/s.

Point out to students the similarity in the methods of calculating gravitational PE and work done: gravitational PE is calculated as a weight (i.e. a force) mg is moved through a distance h. If necessary, remind students again that on Earth weight is mass × 10 (the acceleration due to gravity).

Questions 3, 9 and 10 lead towards implicit assumptions of conservation of energy, but this will not be formally discussed until the next activity.

Answers to questions on *Student Sheet 4.1*

Q1 (a) 10 m/s

(b) 3250 J

Q2 (a) (i) 1000 J

(ii) 4000 J

(iii) 16 000 J

(b) If the speed is doubled, the kinetic energy goes up four times. At higher speeds there is more energy involved in any collision, so more damage is likely to be done.

Q3 (a) 577.5 J

(b) (i) It is progressively converted into kinetic energy.

(ii) Most of the energy is absorbed in squashing the landing bed. Small amounts may be converted to heat or sound.

(c) It is possible to calculate the velocity at landing. Necessary assumptions include that energy is conserved, so that all of the potential energy has been converted to the same amount of kinetic energy, and that air resistance is negligible.

Q4/5/6 Answers will depend on the mass of the bag and height of the stool and table.

Q7 The answer to question 6 should equal the sum of the answers to questions 4 and 5.

Q8 Answers will vary. Check the method of calculation.

Q9 The velocity should be based on the answer to question 6.

Q10 Assumptions are the same as for question 3(c).

© University of York Science Education Group, 1997

Text activity 1: *Faster and higher?*

Student Sheet 4.2 accompanies this activity.

This activity requires students to apply the ideas encountered so far in the lesson to data and questions on pole vaulting.

During this activity, students again consider conversion of energy from one form to another. Taken together with the previous activity, this provides an opportunity to point out that the total amount of energy remains constant, although it can be transferred from one form to another.

This is the first time that students have met this principle formally, though the idea of conservation of energy has been implicit in material covered in the unit *Energy Matters*.

The energy arrow notation encountered in *Energy Matters* also implies conservation of energy. The principle of conservation of energy is also encountered in the units *Balancing Acts* and *Energy Today and Tomorrow*.

For your information

> The principle of conservation of energy is an idea which many students find hard to grasp, in part because of the different ways in which the word *conservation* is used in connection with energy. Students will have heard about the need for energy conservation in the home, and will have come across the notion of world energy supplies 'running out'. These ideas conflict with the use of the word in the term *principle of conservation of energy*.
>
> It is helpful if the different uses of the word *conservation* can be acknowledged and explained to students.

Answers to questions on *Student Sheet 4.2*

Q1 The record has increased fairly steadily, with a rapid rise between 1960 and 1970.

Q2 **(a)** Fibreglass poles were introduced in the 1960s, and caused a significant increase in the record.

(b) Properties mentioned may include strength and flexibility, as well as the need to be good at storing and transferring energy.

Q3 **(a)** 3500 J ($70 \times 10 \times 5$)

(b) 10 m/s ($v^2 = 2 \times 3500/70$; $v = 10$)

Text activity 2: *Free for all*

Student Sheet 4.3 accompanies this activity.

Students discuss data for the rate of fall of a free fall parachutist at various stages in her descent. They are asked for comments about her movement at the following stages:

A – Leaving the aeroplane.

B – Reaching maximum speed, terminal velocity.

C – Opening the parachute.

D – Steady speed of descent with the parachute open.

E – Landing.

F – Standing up after landing.

The downwards force of gravity on the parachutist (her weight) is the same at all stages of the drop.

© University of York Science Education Group, 1997

The force due to air resistance gets larger as she goes faster. When air resistance and gravitational force are equal a steady speed is attained. The students should be reminded that they first met this idea of balancing driving force and counter forces in *Moving On.*

Answers to questions on *Student Sheet 4.3*

Q1 A Jackie jumps out of the plane. Just before she jumps, she has maximum potential energy. As she falls, the effect of gravity begins to convert this to kinetic energy and her rate of fall increases.

B As Jackie falls faster, the counter force of wind resistance grows. At point B, the wind resistance just balances the pull of gravity and Jackie reaches terminal velocity.

C After falling at a steady speed for some time, Jackie opens her parachute. The increased air resistance slows her fall.

D She now continues to fall at a slower rate as she approaches the ground.

E She touches the ground. By flexing her knees she spreads the final impact, reducing the force on her body (remind students of work done on safety belts in the unit *Moving On*).

F Jackie is stationary on the ground.

Q2 The force of gravity (her weight).

Q3 The counter force was air resistance.

Q4 (a) The downward force remains constant.

(b) The counter force increases as her rate of fall increases.

Q5 The forces are equal but opposite.

Q6 The parachute offers greatly increased air resistance.

Text activity 3: *Energy transfers in sport*

Student Sheet 4.4 accompanies this activity.

Students should be reminded of the use they have made in earlier units of energy flow arrow diagrams. The significance of the constant width of the arrows should now be apparent as a means of showing conservation of energy.

Students discuss different activities and select energy arrow diagrams which describe the energy transfers taking place. With more able students, you may wish to consider simply issuing the sheet with the pictures (page 69), and asking students to draw in all of the arrows.

Answers to questions on *Student Sheet 4.4*

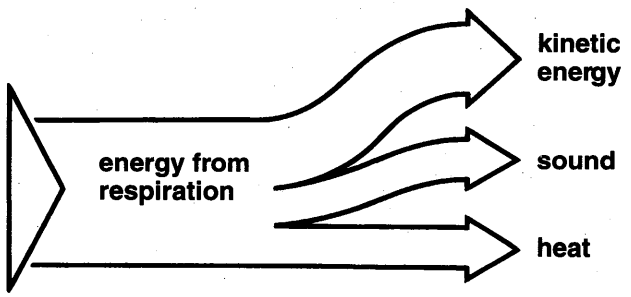
Energy arrow A goes with picture 2.

Energy arrow B goes with picture 5.

Energy arrow C goes with picture 1.

Energy arrow D goes with picture 4.

The energy arrow drawn by students to go with picture 3 should be similar to the one shown below.



© University of York Science Education Group, 1997

How fast, how high?

Many sports are concerned with going faster or higher. From a science point of view, this means the sports person is interested in increasing:

- their **kinetic energy** (the energy something has when it is moving);
- their **gravitational potential energy** (the energy something has when it is raised above the ground).

◆ *Kinetic energy*

The kinetic energy (KE) of an object can be calculated from its mass (m, measured in kg) and its velocity (v, measured in m/s).

Like all quantities of energy, kinetic energy is measured in joules, J.

$$\text{KE} = {}^1/_2\, mv^2$$

Q1 A top athlete can run 100 m in 10 s.
- (a) What is his velocity during the race?
- (b) If he has a mass of 65 kg, what is his KE when running?

Q2 A cyclist and his bike together have a mass of 80 kg.
- (a) Calculate their kinetic energy when cycling at
  - (i) 5 metres per second
  - (ii) 10 metres per second
  - (iii) 20 metres per second
- (b) Use your answers to help you explain why injuries are often more severe in high speed crashes than in ones at lower speeds.

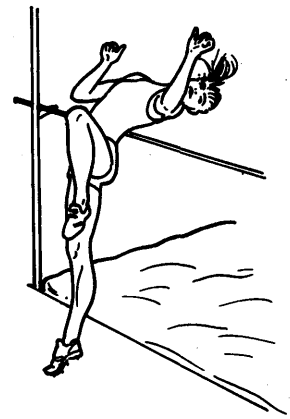
◆ *Gravitational potential energy*

The gravitational potential energy (PE) of an object can be calculated from its mass (m, measured in kg), the effect of gravity (g = 10 m/s^2) and its height above the ground (h, measured in m).

Like all energy, gravitational potential energy is measured in joules, J.

$$\text{gravitational PE} = mgh$$

Q3 Susan is a high jumper. When standing, her centre of mass is 0.85 m above the ground. In winning a competition, she lifted her centre of mass to a height of 1.9 m.
- (a) If she has a mass of 55 kg, how much PE has she gained as she goes over the jump?
- (b) What do you think happens to this PE:
  - (i) as she begins to come down from the jump?
  - (ii) as she lands?
- (c) Do you think it is possible to work out the velocity with which she hits the mat at the other side of the jump? Explain your answer.



© University of York Science Education Group, 1997

How fast, how high?

◆ *Working out your own energy*

Many of the things you do each day cause changes in kinetic energy or potential energy.

Here are some activities for which you can calculate the energy transfers.

You will need to measure the mass of objects you use – and your own mass.

To calculate velocity, you need two measurements: how far the object moves, and how long it takes.

◆ *Lifting and lowering*

- Measure the mass of your school bag.
- Measure the height of
  (a) a stool in the laboratory
  (b) a table

Q4 Calculate how much potential energy is gained by your school bag as you lift it from the floor to the bench.

Q5 How much potential energy does the bag gain if you lift it from the stool onto the table?

Q6 How much potential energy does the bag gain if you lift it directly from the floor to the table in one movement?

Q7 What do you notice about your answers to questions 4, 5 and 6?

◆ *Energy on the move*

- Measure the mass of each person in your group.
- Mark out a known distance (say 5 metres) and time each person in your group as they walk across this distance at their normal walking speed.

Q8 Calculate how much kinetic energy each person in your group has when walking.

◆ *Energy in one form or another*

In question 6, you calculated how much potential energy your school bag gains as you lift it from the floor to the table.

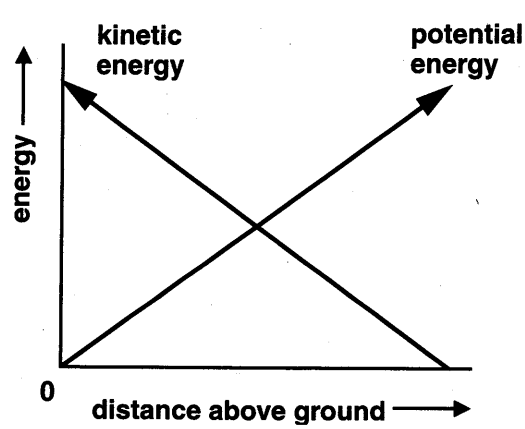
Q9 Suppose that the bag falls off the table. Calculate how fast it would be moving when it hit the floor?

Q10 What did you have to assume in order to answer question 9?

Objects have potential energy because of the force of gravity pulling them down.

As an object falls, its potential energy gets less, and it begins to build up kinetic energy.

The total of both kinds of energy remains constant.

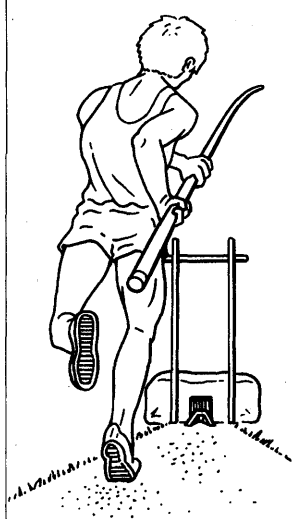
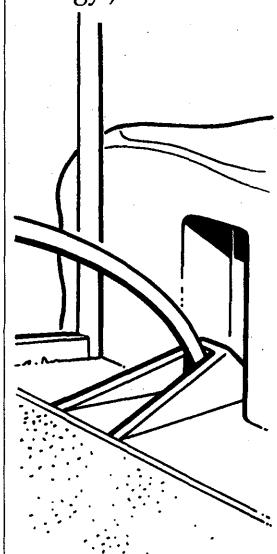
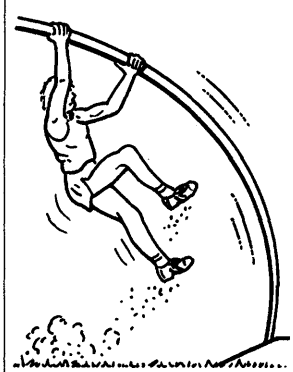
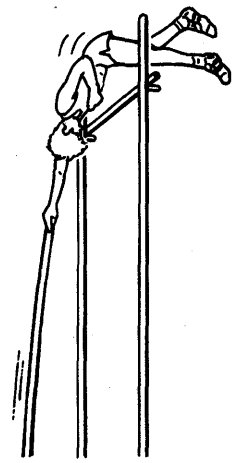


© University of York Science Education Group, 1997

Faster and higher?

Energy transfers are very important to pole vaulters. There are four main energy transfers in the pole vault.

◆ *Pole vaulting*

The vaulter runs as fast as possible at the jump.	The pole is dug into the ground. The kinetic energy from the run is transferred to the pole as the pole bends. (This is actually called *elastic* potential energy.)	The energy stored in the pole is transferred to the vaulter as the pole straightens.	As the vaulter reaches the top of the jump, the maximum **gravitational** potential energy is gained. This is converted to kinetic energy as the vaulter comes down.
			

◆ *Records*

Look at the data below, which shows how the men's world pole vault record has altered in the twentieth century.

year	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990
height (m)	3.6	3.9	4.1	4.3	4.5	4.7	4.8	5.5	5.8	5.9

- Plot a graph of these results and use it to help you answer these questions.

Q1 What does your graph tell you about how the pole vault record has changed this century?

© University of York Science Education Group, 1997

Faster and higher?

Q2 At the beginning of the century, pole vaulters used wooden poles. Today, pole vaulters generally use fibreglass poles.

(a) In which decade do you think fibreglass poles were introduced? Explain your answer.

(b) What do you think would be the most important properties of materials used to make the poles?

Q3 (a) How much potential energy would a 70 kg pole vaulter have gained at the top of a 5 m jump?

(b) If all this energy was transferred to kinetic energy, what would be his velocity as he hit the mat at the other side of the jump?

◆ *Conservation of energy*

In some sports, such as pole vaulting, athletes start off by increasing their kinetic energy, but then reach a point where they want to convert this into gravitational potential energy. For these athletes, though they may not realise it, the **principle of conservation of energy** is very important.

FACT FILE
The principle of conservation of energy says that energy cannot be created or destroyed, only changed from one form to another.

◆ *Non-useful energy*

Most things you do involve transfers of energy.

Usually, you want to transfer all of the energy into one useful form (e.g. pole vaulters want to transfer all of their kinetic energy into potential energy).

Unfortunately, it is rarely possible to do this. Usually, some of the energy is transferred to non-useful forms.

There is still the same total amount of energy there – it is **conserved** – but it often ends up being transferred as spread out energy, e.g. for warming the surroundings. You may also remember that energy arrow diagrams can be used to show how the energy is transferred.

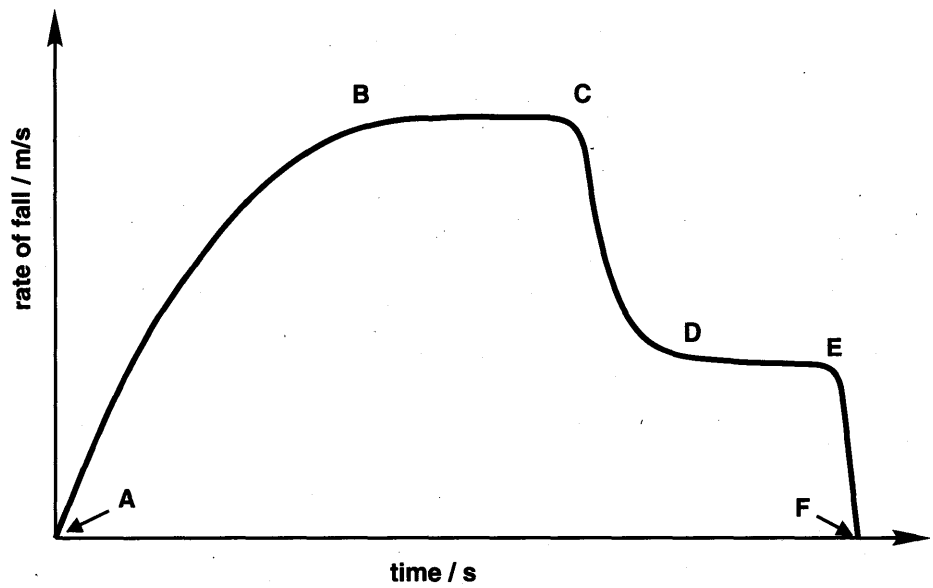
For example, if you are running to school because you are late, you want to change the chemical energy from your food into kinetic energy. You probably notice you are getting warm as well – but this is not particularly useful for getting you to school on time!

© University of York Science Education Group, 1997

Free for all

Jackie's sport is free fall parachuting. Having jumped from an aeroplane Jackie has lots of gravitational potential energy which is quickly converted to kinetic energy due to the gravity force acting on her body.

◆ *Descent data*



The diagram shows how Jackie's rate of fall alters throughout a typical jump.

Q1 Describe what is happening at each of points A to F on the diagram?

Q2 What force was pulling Jackie downwards?

Q3 As Jackie fell, what counter forces were acting to slow her fall?

Q4 Describe what happens to

(a) the downward force, (b) the counter forces,

as Jackie falls faster and faster.

Q5 What can you say about the downward force and the counter forces during the time when Jackie was falling at constant speed.

Q6 Explain why Jackie falls more slowly after her parachute has opened.

Objects falling through the atmosphere fall faster and faster until they reach a final steady speed. This speed is called the **terminal velocity**.

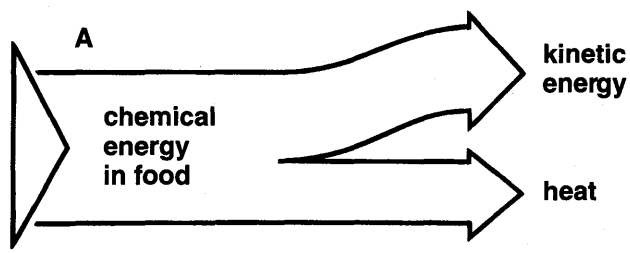
© University of York Science Education Group, 1997

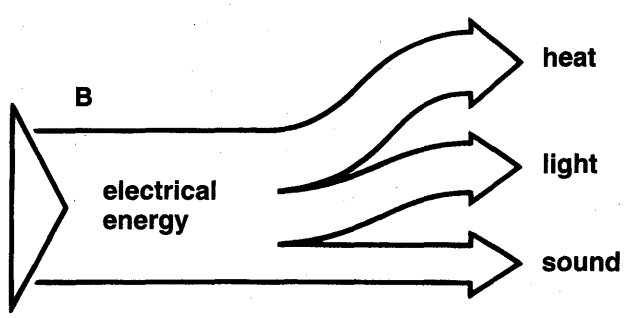
Energy transfers in sport

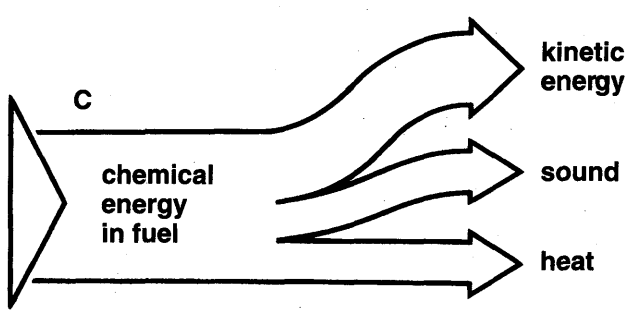
In other parts of your science course, you have used arrow diagrams to represent energy changes. These are sometimes called Sankey diagrams. They can be used to describe changes in sporting situations as well as all the other uses you have seen.

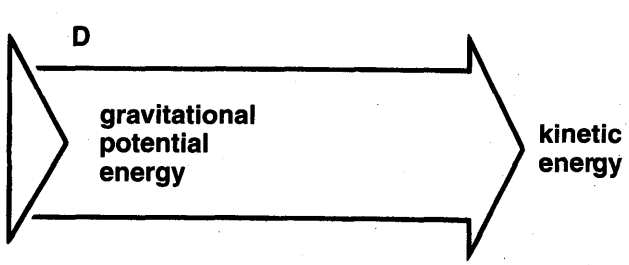
◆ *What energy transfers happen in these situations?*

- Look carefully at the sequence of pictures on page 69, which show some events in a tennis player's day.
- Cut out the energy arrow diagrams below. These show the main energy transfers in *four* of the pictures in the sequence.
- Match each diagram to the appropriate picture. You will be left with one picture which does not match with any of the arrows.
- Complete the chart by drawing an energy arrow diagram for the remaining picture.





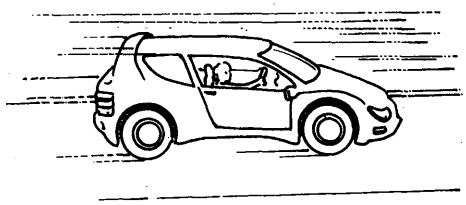
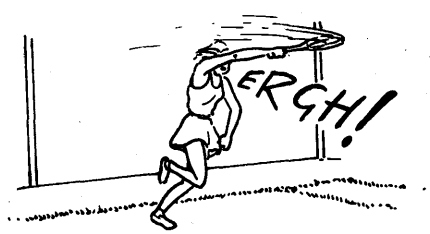
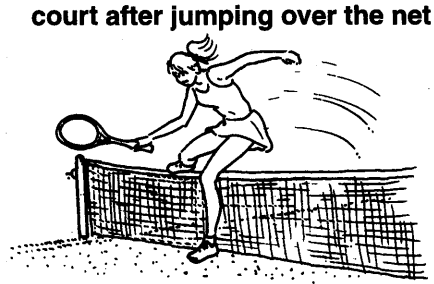
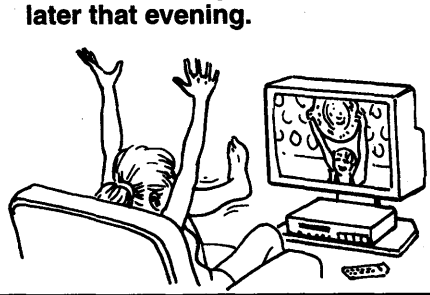




© University of York Science Education Group, 1997

Energy transfers in sport

◆ *Anyone for tennis?*

Event	Energy changes
1. Driving to the tennis court ... 	
2. ... playing the match ... 	
3. ... smashing home a shot ... 	
4. ... landing on the other side of the court after jumping over the net ... 	
5. ... and watching the victory on TV later that evening. 	

© University of York Science Education Group, 1997

science

THE SALTERS' APPROACH

GCSE Unit Guides

The Salters' Approach begins with familiar materials and issues from everyday life and uses these to explore the underlying scientific concepts. This flexible course is delivered through 23 contextual units over the two years.

The photocopiable Unit Guides provide the framework of the course and are complemented by the two textbooks, one volume for each Year.

Each Unit Guide provides a wealth of teacher support material both for preparation and for direct student use:

Each unit has:
- **Overview** which summarises the key objectives of the unit
- **Overall plan** which divides the unit into sub-sections and recommended lessons
- **Preplanner** indicating less readily available materials to assist with planning
- **Cross reference** to syllabus outcomes

as well as:
- **Targetted worksheets** for the student.

Each section within the unit:
- **Outline**s the activities and their key points
- Lists **special requirements** needed for that section
- Provides **teachers' notes** for background and advice on teaching each activity.

The 23 units are:

Year 10
Moving On
Energy Matters
Transporting Chemicals
Construction Materials
Keeping Healthy
Food for Thought
Electricity in the Home
Mining & Minerals
Restless Earth
The Atmosphere
Communicating Information
Balancing Acts

Year 11
Burning & Bonding
Controlling Change*
Staying Alive*
The Earth in Space
Energy Today & Tomorrow
Evolution
Making Use of Oil
Seeing Inside the Body
Sound Reproduction
Sports Science
Waste Not, Want Not

* these replace the units Controlling Change in Animals and Controlling Change in Plants

ISBN 0 435 630423

Heinemann

ISBN 0-435-63042-3

9 780435 630423