Work, Power and Efficiency

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SIEMENS AKTIENGESELLSCHAFT
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Heyden & Son Ltd., Spectrum House, Hillview Gardens, London NW4 2JQ, UK.
Heyden & Son Inc., 247 South 41st Street, Philadelphia, Pennsylvania 19104, USA.
Heyden & Son GmbH, Münsterstrasse 22, 4440 Rheine, West Germany.

Title of German original edition:
Arbeit, Leistung, Wirkungsgrad (PU 34)
Von Alois Koller
Siemens Aktiengesellschaft 1977
ISBN 3-8009-4034-5

ISBN 3-8009-4734-X Siemens AG, Berlin and München
ISBN 0-85501-511-X Heyden & Son Ltd, London

Typeset in Great Britain by The Universities Press, Belfast

Printed in Great Britain by Kelsi Print Co., London

Introduction

This programmed instruction (pi) book explains why we make electrical appliances, and how every appliance helps us to perform certain types of work. It describes the concept of work, how it is measured and assessed, how much it costs, and how different types of work may be compared. It is intended principally for use at technical college level. It is also suitable for secondary school use, as a refresher for students of advanced technology and for adult education.

When you have successfully worked through the course you should be able to describe:

How the physical concept of 'work' began;
The relationships between work, power, energy, force and efficiency;
The units in which these quantities are measured;
What is meant by the rating values stated on electrical appliances;
What a kilowatthour (kwh) is;
What efficiency can be achieved in telecommunications systems and in power stations.

This programme is the basis for later work on more advanced subjects. However, knowledge of the following programmes would be helpful before starting the course: *Structure of Matter* (pi 08); *Current, Voltage and Resistance* (pi 09); *Kirchhoff's Laws* (pi 06); *The Electric Circuit* (pi 10).

The programmed instruction method means that the material is divided into small steps and by answering the questions asked after each step you can easily check your progress. You can work at your own speed and if you do not understand a step you should repeat it until it is clear.

You should use the book in the following manner:

1. Work thoroughly through each Lesson.
2. Answer the Question at the end of each lesson.
3. Check that your Answer agrees with that given on the next page. If it does not agree work through the lesson again and find out where you made a mistake.
4. Answer the questions in the Intermediate Tests and the Final Test.
5. Check your answers with those provided and repeat any lessons that you did not fully understand.

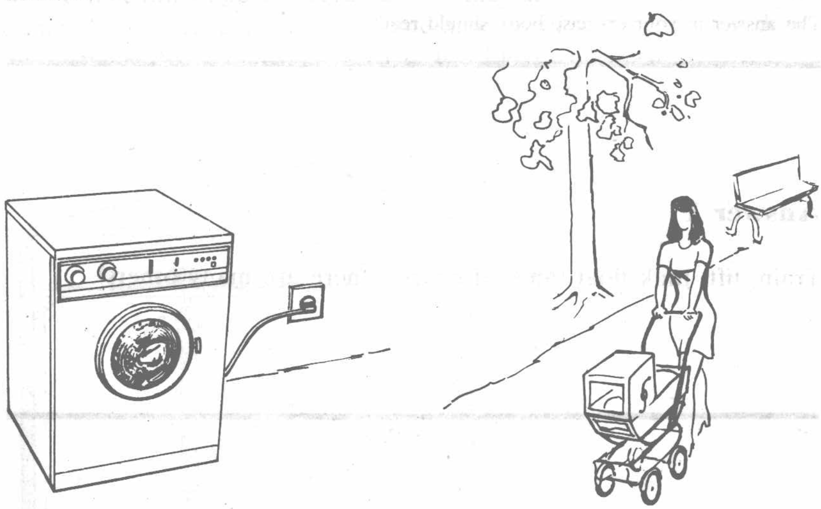
Some of the technical terms in this book are explained briefly in the Appendix (p. 63).

THE PUBLISHERS

Electrical machinery performs work **Lesson 1**

Electrical machinery and appliances save much drudgery: they do the laundry, wash the dishes, grind coffee, drill holes, cut and sand wood and other materials, drive machine tools, transport people and freight, cook, provide light, supply information on call and entertain us with radio, television, cinema etc.

The time they save us can be used for more pleasant and interesting activities. Our lives would be much duller without these electrical devices.



Automatic washing machine at work — while — Young mother takes her baby for a walk

QUESTION 1

Name three examples of an electrical device moving people or things.

Think about it! If you know the answer write in your exercise book (not in this instruction book) Answer and the lesson number shown at the top of this page, followed by the answer you have found, thus:

Answer 1

Compare your answer with the solution on the other side of this page only after having answered the question.

The answer in your exercise book should read:

Answer 1

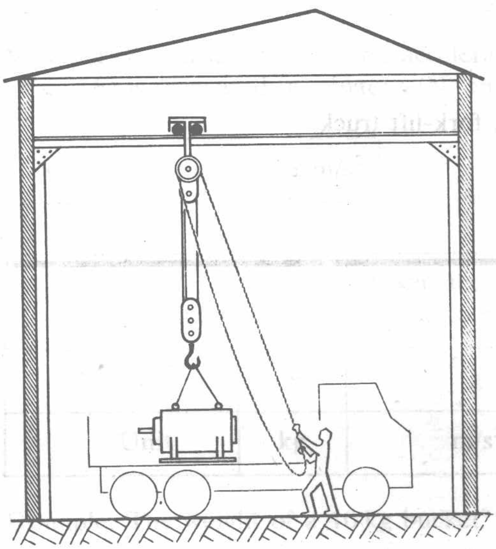
Train, lift, milk float (and, of course, there are many others).

No doubt your answer was correct and so your exercise book now contains the first correct entry. Enter subsequent answers in it, in a similar way, one beneath the other.

Lifting loads

It is desirable to be able to measure all types of *work;* we must pay for work and need a basis for calculating the cost. Let us, therefore, take as an example the most elementary form of work: lifting a load.

In ancient times heavy loads had to be lifted for building pyramids, castles, bridges, cathedrals, etc. This work had to be done using manpower or animals. Thousands of slaves had to work for many years to erect a large building. Man's ingenuity began to evolve simple machines like the lever and lifting tackle to make this work easier. It was realized that the same amount of work could be done by a smaller force if it was applied at a longer distance.



A heavy load is lifted with block and tackle

QUESTION 2

Give three examples where people or goods are lifted by electrical machinery.

Answer 2

Goods lift, overhead crane, fork-lift truck.

A force is necessary to lift a load. Of course, a larger force is required for heavier loads. The required *force* (F), which must counteract the force of gravity, also called weight (W), is the product of mass (m) and the local acceleration due to gravity (g). On our Earth $g = 9.8060665$ m/s^2, or, when rounded up 9.81 m/s^2.

Loads are lighter on the Moon, because there $g = 1.62$ m/s^2 and their weights will thus be only $\frac{1}{6}$ of those on Earth.

This can be written as:

Force = weight = mass × gravitational acceleration $F = W = m \times g$

Mass (m) is measured in kg and acceleration (a) in m/s^2.
Force (F) is measured in newtons (N) and we have:

$$1\ \text{N} = 1\ \text{kg} \times 1\ \text{m/s}^2 = 1\ \text{kg m/s}^2$$

Quantity	Mass	Local acceleration due to gravity	Force (weight)
Symbol	m	g	F
Unit	kg	m/s^2	N

Example: The weight of a 10 kg bucket* is:

$$F = 10\ \text{kg} \times 9.81\ \text{m/s}^2 = 98.1\ \text{kg m/s}^2 = 98.1\ \text{N}$$

* In common parlance weight is sometimes expressed in kg force, i.e. weight in N divided by g. Thus the same bucket also weighs 10 kg.f, although the latter is now seldom used.

QUESTION 3

What lifting force is required by a weightlifter for lifting 200 kg? (The world record is now 238 kg, using both arms.)

Answer 3

Given: $m = 200$ kg and $g = 9.81$ m/s^2
To be determined: F

$$F = m \times g$$

Calculation: force $= 200 \text{ kg} \times 9.81 \text{ m/s}^2 = 1962 \text{ N}$

Comparison of work done in lifting

It is a fundamental rule in mechanics that the same amount of work can be done with a smaller force if it is applied at a longer distance. this can be simply explained without using even the most primitive machine (like a lever or a roller) as an example. It will be shown that the following three examples give equal values of work:

(a) Lifting 30 kg to a height of 1 m
$F = 30 \times 9.81$ N, distance $s = 1$ m

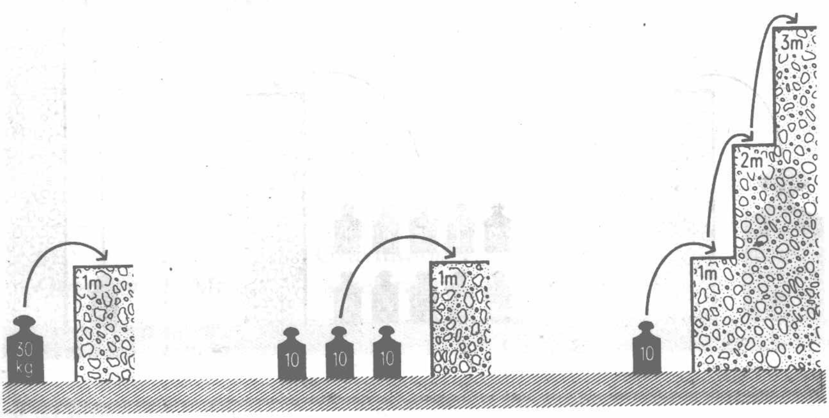
(b) Lifting 10 kg, 3 times to a height of 1 m
$F = 3 \times 10 \times 9.81$ N, distance $s = 1$ m

(c) Lifting 10 kg to a height of 3 m
$F = 10 \times 9.81$ N, distance $s = 3$ m

The product of *force* × *distance* ($F \times s$) is identical in the three cases:

$$3 \times 10 \times 9.81 \text{ Nm} = 294.3 \text{ Nm}$$

The product $F \times s$ gives the work done in each example.



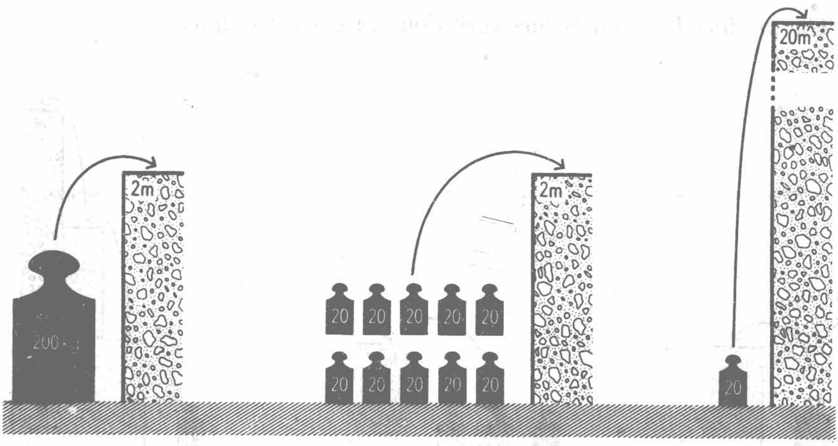
QUESTION 4

A weightlifter raises 200 kg to a height of 2 m. What weight would he have to lift 20 m high, for the same amount of work to be done?

Make a sketch, similar to the one above.

Answer 4

To lift 20 kg 10 times to 2 m requires the same amount of work as to lift 20 kg 10 times up to 2 m or once up to 20 m.



Work = force × distance

Lesson 5

Work (W) equals the product of force (F) and distance (s):

Work = force × distance = mass × gravitational acceleration × distance
$W = F \times s$

We assume here that the force always acts in the direction in which the distance (s) is measured.

If force is measured in newtons and distance in metres, *the product will be given in joules* (J).

$$1\ \text{J} = 1\ \text{N} \times \text{m} = 1\ \text{kg m}^2/\text{s}^2$$

$$1000\ \text{J} = 1\text{kJ};\ 10^6\ \text{J} = 1\ \text{MJ} = 1\ \text{megajoule}$$

Example: A light aircraft weighing 1000 kg increases its altitude by 1000 m. What work is done to reach this altitude?

Given:

$$m = 1000\ \text{kg};\ g = 9.81\ \text{m/s}^2;\ s = 1000\ \text{m}$$

$$W = m \times g \times s$$

Calculation:

$$W = 1000\ \text{kg} \times 9.81\ \text{m/s}^2 \times 1000\ \text{m} = 9.81 \times 10^6\ \text{kg m}^2/\text{s}^2$$

$$W = 9.81\ \text{MJ}$$

Quantity	Mass	Gravitational acceleration	Force	Work
Symbol	m	g	F	W
SI unit	kg	m/s^2	N	J

QUESTION 5

What work is performed by a weightlifter, raising 200 kg to a height of 2 m?

Answer 5

Given:

$$m = 200\ \text{kg};\ g = 9.81\ \text{m/s}^2 \text{ and } s = 2\ \text{m}$$

To be determined: W

$$W = m \times g \times s$$

Calculation:

$$W = 200\ \text{kg} \times 9.81\ \text{m/s}^2 \times 2\ \text{m} = 3924\ \text{J} = 3.924\ \text{kJ}$$

Intermediate Test 1

The questions in this test deal with the subject matter of the preceding lessons. If you are unable to answer all the questions you are advised to work through the lessons again.

1 From what sort of activity did the concept of 'work' develop?

2 What is the formula for determining the force required to lift a body?

3 Why is everything lighter on the Moon than it is on Earth?

4 Show the difference between force and work, using moving and lifting as examples.

5 What is the technical definition of work?

6 Which unit is used for force?

7 What force is necessary to carry 1 kg?

8 Which unit is used for work?

9 How much work is done when lifting 1 kg a height of 1 m?

Answers to Intermediate Test 1

1 Lifting loads. (Lessons 2 and 3)

2 Force = mass × gravitational acceleration. (Lesson 3)

3 Because the gravitational acceleration (g) on the Moon is $\frac{1}{6}$ that on Earth.

$g_{Moon} \approx \frac{1}{6} g_{Earth}$ (Lesson 3)

4 Force is needed to move a body, but it has to be lifted for work to be done. (Lesson 5)

5 Work = directional force × distance.

$W = F \times s$ (Lesson 5)

6 The newton is the unit of force.

$1\ N = 1\ kg \times 1\ m/s^2$ (Lesson 3)

7 given:

$m = 1\ kg;\ g = 9.81\ m/s^2$

To be determined: F

$F = m \times g$

Calculation:

$F = 1\ kg \times 9.81\ m/s^2 = \mathbf{9.81\ N}$ (Lesson 3)

8 The joule is the unit of work

$1\ J = 1\ Nm$ (Lesson 3)

9 Given:

$m = 1\ kg;\ g = 9.81\ m/s^2;\ s = 1\ m$

To be determined: W

$W = m \times g \times s$

Calculation:

$W = 1\ kg \times 9.81\ m/s^2 \times 1\ m = \mathbf{9.81\ J}$ (Lesson 5)