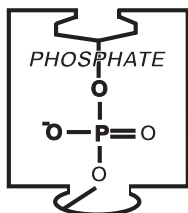
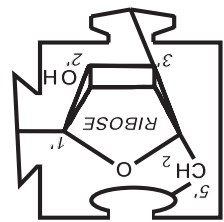
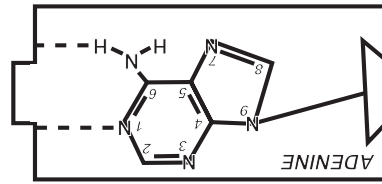
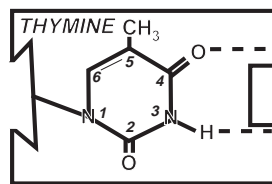
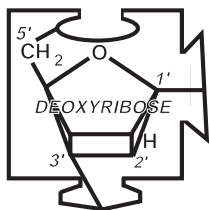
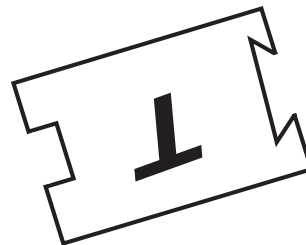
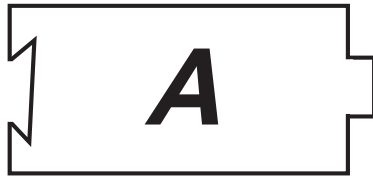
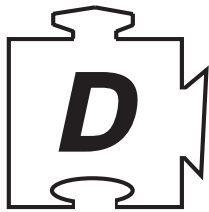
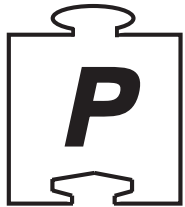
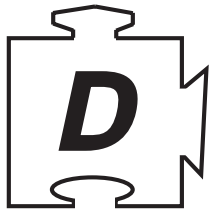
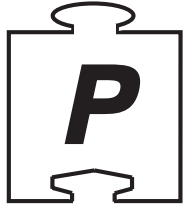
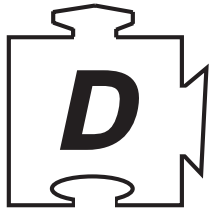


DNA model

STRUCTURE
REPLICATION
TRANSCRIPTION

GUIDE



Devised and designed by

J.W.Garvin



The Queen's University of Belfast



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This model has been widely trialled, particularly by teachers, in Northern Ireland, elsewhere in the UK, the Republic of Ireland, and a number of European countries. To all those teachers, lecturers, pupils and students who trialled the prototype I am particularly grateful.

This kit could not have been produced without financial assistance so I am grateful to Unilever and the European Initiative for Biotechnology Education (EIBE) for their sponsorship.

If you have any suggestions for improving this Guide, the author would be interested in hearing from you. His address is given above; telephone, fax and email are :

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INTRODUCTION - to the teacher

DNA appears on the media virtually every day. For a chemical substance with an abbreviated title to be a household name is somewhat unusual. Why is there so much interest in this chemical? What is it, what does it actually do, and why is it so important?

All living things, from bacteria to plants, animals and ourselves, contain the same basic DNA (there are a few viruses that contain a related molecule RNA of which more later).

Curiosity alone drove James Watson, an American biologist, and Francis Crick, an English physicist, both working at the Cavendish Laboratory in Cambridge University, to team up to work out the structure of DNA and thus hopefully to find out how it operated. They didn't actually carry out any experimental work on DNA, but they tried to find out all they could about it from other scientists' work. When they had garnered all the available information, they built models so that they could see what they were imagining more clearly. They finally succeeded in devising a structure that fitted all the data, and published their findings in *Nature*, a most prestigious scientific journal, in 1953. They eventually received the Nobel Prize in 1962, together with Maurice Wilkins who supplied them with critical X-ray diffraction patterns.

DNA is the molecule of life - it is the information technology of living things. It must therefore be able to :

- (i) carry genetic information, and
- (ii) make copies of itself so that this information can be passed on during cell division and from generation to generation

In recent years, because of our increasing knowledge and understanding of DNA and its related molecule RNA, it has been possible to work with this genetic information and to use it for our own benefit - a process known as *genetic modification*, which is the underlying basis of the new biotechnologies. These are now changing many aspects of our lives, and undoubtedly will have even greater impact in the future - strong evidence for applications arising out of pure research!

This model kit has been specifically designed to aid learning and understanding about DNA (and RNA). Starting with *no prior knowledge* the student constructs the relatively simple model by following carefully sequenced instructions when the structure and function are revealed. Since the pieces have been specially shaped and coloured, the senses of sight and touch are both employed.

Since most science syllabuses and courses at various levels include DNA, this model has been designed as a '*two-in-one*'. The *basic model* is printed on one side of the pieces with large letters (the first letters of the names of the chemical molecules) and is appropriate for use particularly at the secondary level - it could even be used at the late primary level and in non-science courses. The *advanced model* is printed on the other side and shows details of the structures of the molecules - it can therefore be used for A-level and introductory courses at College or University. The two models could even be used in sequence - moving from basic to advanced - **see inside back cover**.

This model is intended as an educational medium, to be used in your courses in whatever way you find most appropriate. Adapt or even change the activity sheets if you wish. The model also lends itself to extension work - this will depend entirely on your creativity. Examples that spring immediately to mind are mutation, restriction enzymes, hybridisation, probes, PCR etc. - I am sure there are plenty of others. A continuation model on protein synthesis will also be available.

CONTENTS OF THE KIT

The kit consists of 180 pieces, arranged in 15 compartments labelled with the appropriate letters, and each containing 12 pieces - it is therefore a simple matter to check that all pieces have been returned at the end of an activity. The pieces, and their positions, are as follows :

Letter	G	C	A	T	<i>U</i>
Name	Guanine	Cytosine	Adenine	Thymine	Uracil
Colour	<i>green</i>	<i>gold</i>	<i>red</i>	<i>light blue</i>	<i>dark blue</i>
Number	12	12	12	12	12
Letter	D	D	P	P	<i>R</i>
Name	Deoxyribose	Deoxyribose	Phosphate	Phosphate	Ribose
Number	12	12	12	12	12
Letter	D	D	P	P	<i>R</i>
Colour	<i>grey</i>	<i>grey</i>	<i>yellow</i>	<i>yellow</i>	<i>black</i>
Number	12	12	12	12	12

The total number of pieces is therefore :

Deoxyribose	4 x 12 = 48	Guanine	12	Cytosine	12
Phosphate	4 x 12 = 48	Adenine	12	Thymine	12
Ribose	2 x 12 = 24	Uracil	12		

One kit is suitable for use with a class of 24 students - they can be divided into 4 groups of 6 students, when the model will be 6 base-pairs long; alternatively you can have 6 groups of 4 students, when the model will be 4 base-pairs long. Smaller groups and/or longer molecules can be arranged by obtaining further kits.

The pieces are printed on both sides - letters on one side (the **basic** model) and molecular structures on the other (the **advanced** model). When in use only one side is normally used.

If any of the pieces get lost or damaged, replacements can be purchased from the NCBE who will quote prices for what you require. Their address, telephone, fax and email are as follows :

National Centre for Biotechnology Education

The University of Reading
PO Box 228, Whiteknights,
READING, RG6 6AJ.
England.

Tel : +44 (0) 118 9873743
Fax : +44 (0) 118 9750140
email : C.Shearer@reading.ac.uk

See also WWW site : <http://www.reading.ac.uk/NCBE>

The Guide contains student activity sheets with appropriate questions, teacher notes with answers, and overhead masters, both at basic and advanced levels. Basic model sheets are in a different typeface (**Helvetica**) from the Advanced model sheets (**Times**) so that they can be readily distinguished from one another and each sheet has at the top an identifying basic or advanced logo.

CONTENTS of the BOOKLET

	Page
INTRODUCTION	3
1 THE STRUCTURE OF DNA	
<i>1.1 Basic Model</i>	
1.1.1 Student Activity	6
1.1.2 Teacher Notes	7
1.1.3 Overhead Transparency Master	8
<i>1.2 Advanced Model</i>	
1.2.1 Student Activity	9
1.2.2 Teacher Notes	11
1.2.3 Overhead Transparency Masters (2)	13
2 THE REPLICATION OF DNA	
<i>2.1 Basic Model</i>	
2.1.1 Student Activity	15
2.1.2 Teacher Notes	16
2.1.3 Overhead Transparency Master	17
<i>2.2 Advanced Model</i>	
2.2.1 Student Activity	18
2.2.2 Teacher Notes	19
2.2.3 Overhead Transparency Master	20
3 THE TRANSCRIPTION OF RNA from DNA	
<i>3.1 Basic Model</i>	
3.1.1 Student Activity	21
3.1.2 Teacher Notes	22
3.1.3 Overhead Transparency Master	23
<i>3.2 Advanced Model</i>	
3.2.1 Student Activity	24
3.2.2 Teacher Notes	25
3.2.3 Overhead Transparency Master	26

1

THE STRUCTURE OF DNA

1 Basic Model



1 Student activity

Follow the instructions carefully and answer ALL the questions

Place all the pieces that you have been given on the bench and arrange them so that only the large letters are showing. Each piece represents a molecule.

Q1 *Make a list of the different kinds of pieces (molecules).*

Place pieces (molecules) of the same letter (and colour) in groups. Count how many there are of each type.

Q2 *Write down the numbers of each kind of molecule. Are any of the numbers the same? Find as many similarities as you can.*

Examine the pieces carefully and find out which pieces fit together.

Q3 *Write down what pieces fit together.*

Now join all the pieces (molecules) together to make a very large molecule (macro-molecule). This represents a short length of **Deoxyribo Nucleic Acid (DNA** for short).

Q4 *Make a simple drawing of your DNA molecule. Describe anything unusual you found when you were putting the DNA molecule together?*

Compare your DNA molecule with those made by other students.

Q5 *In what ways is your DNA molecule similar to those of others? In what ways is it different?*

If you look carefully you will find that your DNA molecule is made up of repeating units (building blocks), each of which is made up of three pieces.

Q6 *What are the three pieces (molecules) that make up one of these repeating units which is called a nucleotide.*

The model that you have constructed is very much larger than an actual DNA molecule, which is about 2 nanometres wide (1mm = 1 million nanometres).

Q7 *How many times larger is the model than an actual DNA molecule?*

If you wish you can join your DNA molecule to those of other groups to make as long a length of DNA as possible. How many base-pairs long is it? The DNA molecule is not actually flat but twisted in a spiral form known as a **double helix**. Look at diagrams or models which show this three-dimensional structure.

1

THE STRUCTURE OF DNA

1 Basic Model



2 Teacher Notes

The number and kinds of pieces that you give out depends on the class size, the number of kits available, and the number and size of groups of students that you want to have. If, for example, your class consisted of 24 students and you had 1 kit, then you could have 4 groups of 6 students each, or 6 groups of 4 students each, when the numbers of the pieces per group would be :

4 groups of 6 students		6 groups of 4 students	
2 groups would each get	2 groups would each get	3 groups would each get	3 groups would each get
D - 12	D - 12	D - 8	D - 8
P - 12	P - 12	P - 8	P - 8
A - 4	A - 2	A - 3	A - 1
T - 4	T - 2	T - 3	T - 1
G - 2	G - 4	G - 1	G - 3
C - 2	C - 4	C - 1	C - 3

NOTE : The following should always apply no matter what groups you decided upon :

The number of Ds = the number of Ps; the number of As = the number of Ts;
the number of Gs = the number of Cs; the number of Ds (or Ps) = the number of As+Ts+Gs+Cs,
but the number of As and Ts should not equal the number of Gs and Cs.

Naturally, if you have a smaller class, or more kits, then the groups can be smaller.

Q1 D, P, A, T, G and C

Q2 This will depend on the numbers you have given out - see above.

Q3 D with P (or P with D); A,T,G, and C with D; A with T (or T with A); G with C (or C with G).

Q4 There is only one basic way that it fits together properly, although half of the letters have to be placed upside-down - check that they have fitted all the pieces together so that it looks like a ladder - the Ds and Ps form the 'uprights' and the As, Ts, Gs and Cs form the 'rungs'. A will only pair with T, and G with C - this is known as the **base-pairing rule**. The molecule is in two 'halves' or 'strands' running in opposite directions (anti-parallel) - see overhead master on the next page.

Q5 All the DNA molecules will look basically the same in overall structure. Closer examination will however reveal that the order or 'sequence' of the As, Ts, Gs and Cs will differ. There are many permutations possible in this base sequence. The information in DNA is to be found in this sequence of bases - 3 consecutive bases being known as a **triplet codon**.

Q6 A **nucleotide** (the basic building block) consists of a D, a P and one of A, T, G or C.

Q7 You can skip this question if you think that it is too difficult. The width of the model is about 220 mm. If 1 mm = 1 million nanometres then 220 mm = 220 million nanometres. The real molecule is 2 nanometres wide, so we have to multiply 2 nanometres by 110 million to get 220 million nanometres. The model is therefore 110 million times bigger!

There is a simple double helix paper model in Unit 1 - **Microbes and Molecules**, by the European Initiative for Biotechnology Education, pages 6 and 7. This can be downloaded via the World Wide Web - site location : <http://www.reading.ac.uk/NCBE>. See also next page.

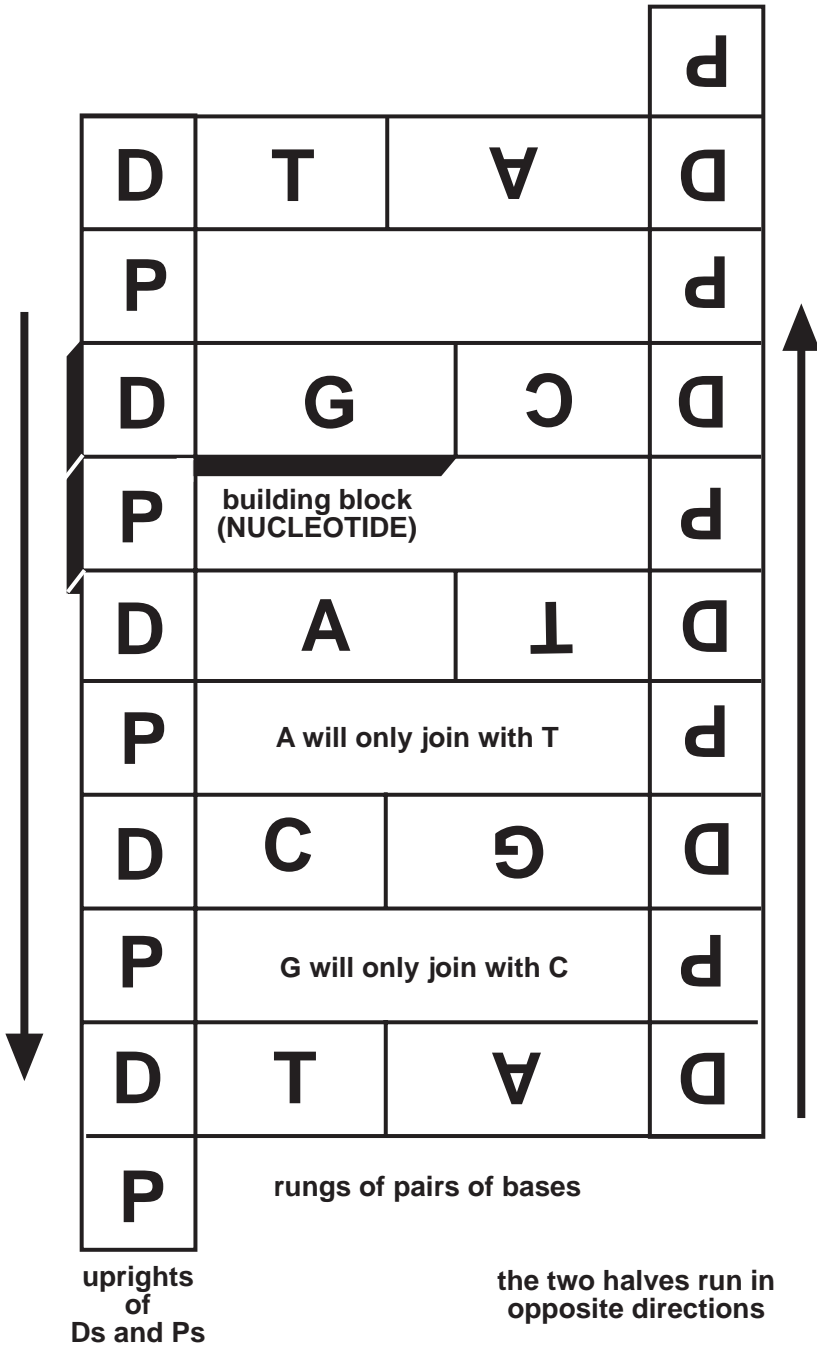
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THE STRUCTURE OF DNA

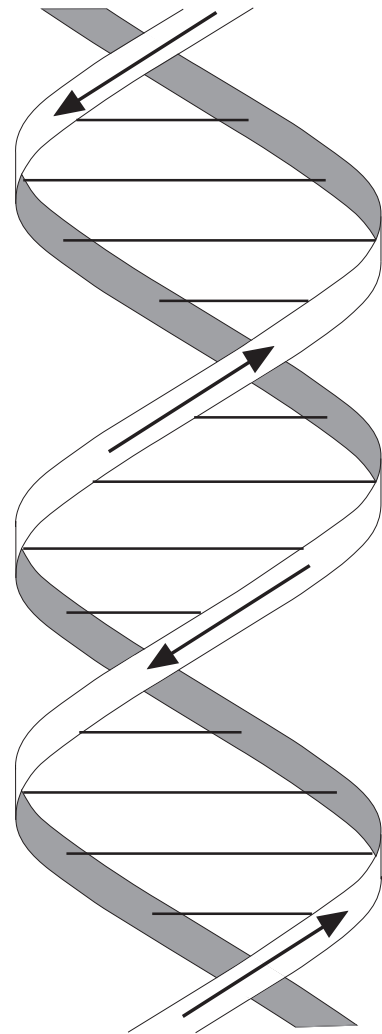
1 Basic Model



3 Overhead



DNA 'ladder'



DNA 'double helix'

1

THE STRUCTURE OF DNA

2 Advanced Model



1 Student Activity

Arrange all the pieces that you have been given on the bench so that all the molecular structures (and not the large letters) are facing upwards.

Q1 *Make a list of the names of the different kinds of molecules.*

Place similar molecules in groups. Make a note of the numbers of each type of molecule.

Q2 *Can you find any relationships between the numbers of each kind of molecule?*

Erwin Chargaff was the first person to analyse DNA carefully using paper chromatography to determine the concentrations of the four bases. Some of his data published in the early 1950s are given in the table below, which shows the molar quantities of the nitrogenous bases in DNA - expressed as moles for 100 gramme atoms of phosphorus in combination with them.

SOURCE	PURINES		PYRIMIDINES	
	Adenine	Guanine	Cytosine	Thymine
Man	30.4	19.6	19.9	30.1
Ox	29.0	21.2	21.2	28.7
Salmon sperm	29.7	20.8	20.4	29.1
Wheat germ	28.1	21.8	22.7	27.4
<i>E.coli</i>	26.0	24.9	25.2	23.9
Sheep liver	29.3	20.7	20.8	29.2

Examine Chargaff's data.

Q3 *Can you find any relationships between the molar quantities of the different bases?*

Q4 *Calculate the ratio of the molar quantity of adenine to the molar quantity of thymine for the different sources. What are these ratios and what do they mean?*

Q5 *Calculate the ratios for the molar quantities of guanine and cytosine? Are they similar to the ratios that you found in Q4? What does this mean?*

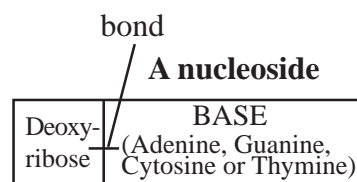
Q6 *Are the relationships that you found in question 2 above the same as those determined in questions 4 and 5?*

The DNA is made up of repeating units. Let us examine these units more closely.

First of all, a bond is formed between a nitrogenous base and a deoxyribose sugar molecule to form what is called a **NUCLEOSIDE** - this bond is termed a **β -N-glycosidic bond**.

Construct as many nucleosides as possible from the pieces that you have been given.

Note : the carbon atoms have been omitted but they are numbered

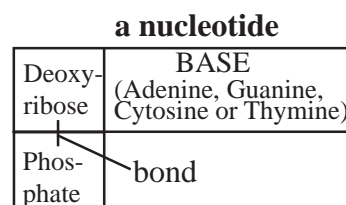


Q7 *Between which numbered atoms of the deoxyribose and base molecules is this bond formed*

- (a) *with the purine bases*
 (b) *with the pyrimidine bases?*

Secondly a bond is formed between a deoxyribose sugar and a phosphate molecule. This is termed a **covalent phosphodiester bond** and forms what is called a **NUCLEOTIDE**.

Construct as many nucleotides as possible from the pieces that you have been given by adding the phosphates to the nucleosides. You should now have used up all the pieces.



Q8 *Between which atoms does the phosphodiester bond form?*

The nucleotide is the 'building block' of DNA. Join two nucleotides together making another phosphodiester bond.

Q9 *Between which atoms is this new phosphodiester bond formed?*

Now add two further nucleotides but in this case do **not** use phosphodiester bonds.

Q10 *Between which atoms are these new bonds formed? These are weak hydrogen bonds. Describe in detail all you can about them.*

Continue joining nucleotides together until they are all used up. Use all the types of bonds described above. When complete you will have constructed a very short length of DNA.

Q11 *Describe briefly in words what your DNA molecule looks like.*

Q12 *Make a note of any unusual or particular features that you noticed when you were constructing the DNA molecule.*

Compare your DNA molecule with that constructed by other students.

Q13 *In what ways is it similar? In what ways is it different?*

This model is of course very highly magnified compared with an actual DNA molecule. The DNA molecule is about 2 nanometres wide. (1 mm = 1 million nm).

Q14 *How many times larger is this model than an actual DNA molecule?*

The model was constructed in such a way that you could work with it on a flat bench - it is however actually twisted in a 3D configuration in what is known as a **DOUBLE HELIX**. Examine a diagram of the 3-dimensional arrangement, or even construct a simple paper model to show this.

This structure of DNA was first described in the journal *Nature* in 1953 by James Watson (an American biologist) and Francis Crick (an English physicist).

1

THE STRUCTURE OF DNA

2 Advanced Model



2 Teacher Notes

The number and kinds of pieces that you give out depends on a number of factors, for example, class size, the number of kits available, the number of student groups etc. If, for example, you had a class of 24 students and one kit, then you could divide the class into 4 groups of 6 students each, when each group would have a model 6 base-pairs long. Alternatively you could have 6 groups of 4 students each, when each group would have a model 4 base-pairs long. The numbers of pieces given to each group would be as follows :

MOLECULE	4 groups of 6 students each		6 groups of 4 students each	
	2 groups would each get	2 groups would each get	3 groups would each get	3 groups would each get
deoxyribose	12	12	8	8
phosphate	12	12	8	8
adenine	4	2	3	1
thymine	4	2	3	1
guanine	2	4	1	3
cytosine	2	4	1	3

NOTE : The following should always apply no matter what groups you decide upon :

the number of Ds = the number of Ps;
the number of As = the number of Ts;
the number of Gs = the number of Cs;
the number of Ds (or Ps) = the number of As+Ts+Gs+Cs,
but the number of As and Ts should not equal the number of Gs and Cs.

Naturally, if you had a smaller class, or more kits, then the groups could be smaller.

- Q1** Deoxyribose, phosphate, adenine, thymine, guanine and cytosine.
- Q2** This will depend on the numbers you have given out - see above.
- Q3** The molar quantities of adenine and thymine are roughly the same, as are the molar quantities of guanine and cytosine, while other comparisons are quite different.
- Q4** Adenine/thymine (or T/A) approximates to 1. This means that adenine probably combines with thymine.
- Q5** G/C (or C/G) also approximates to 1 - guanine probably combines with cytosine.
- Q6** Yes - numbers and molar quantities of particular molecules are the same.
- Q7** (a) Between C1' of the deoxyribose and N9 of the purine base (adenine or guanine).
(b) Between C1' of the deoxyribose and N1 of the pyrimidine base (thymine or cytosine).

Q8 Between C3' of the deoxyribose and an O of the phosphate.

Q9 Between C5' of the deoxyribose and an O of the phosphate.

The carbon atoms of the deoxyribose (and ribose) sugars are given a dash or *prime* (3') to distinguish them from the atoms making up the rings of the nitrogenous bases. None of the molecular structures actually show the C atoms since they would become too complicated - if an atom is missing but numbered, and there are 4 bonds, assume that it is a carbon atom.

Q10 The bonds between the bases are weak hydrogen bonds - shown in the model as dotted lines. There are two between adenine and thymine (N1-H and H-O), and three between guanine and cytosine (H-O, H-N and O-H). These can be more easily broken than the glycosidic and phosphodiester bonds - in the model they slide apart. These bonds have virtually the same dimensions so that everything fits neatly together - see overhead master on the next page.

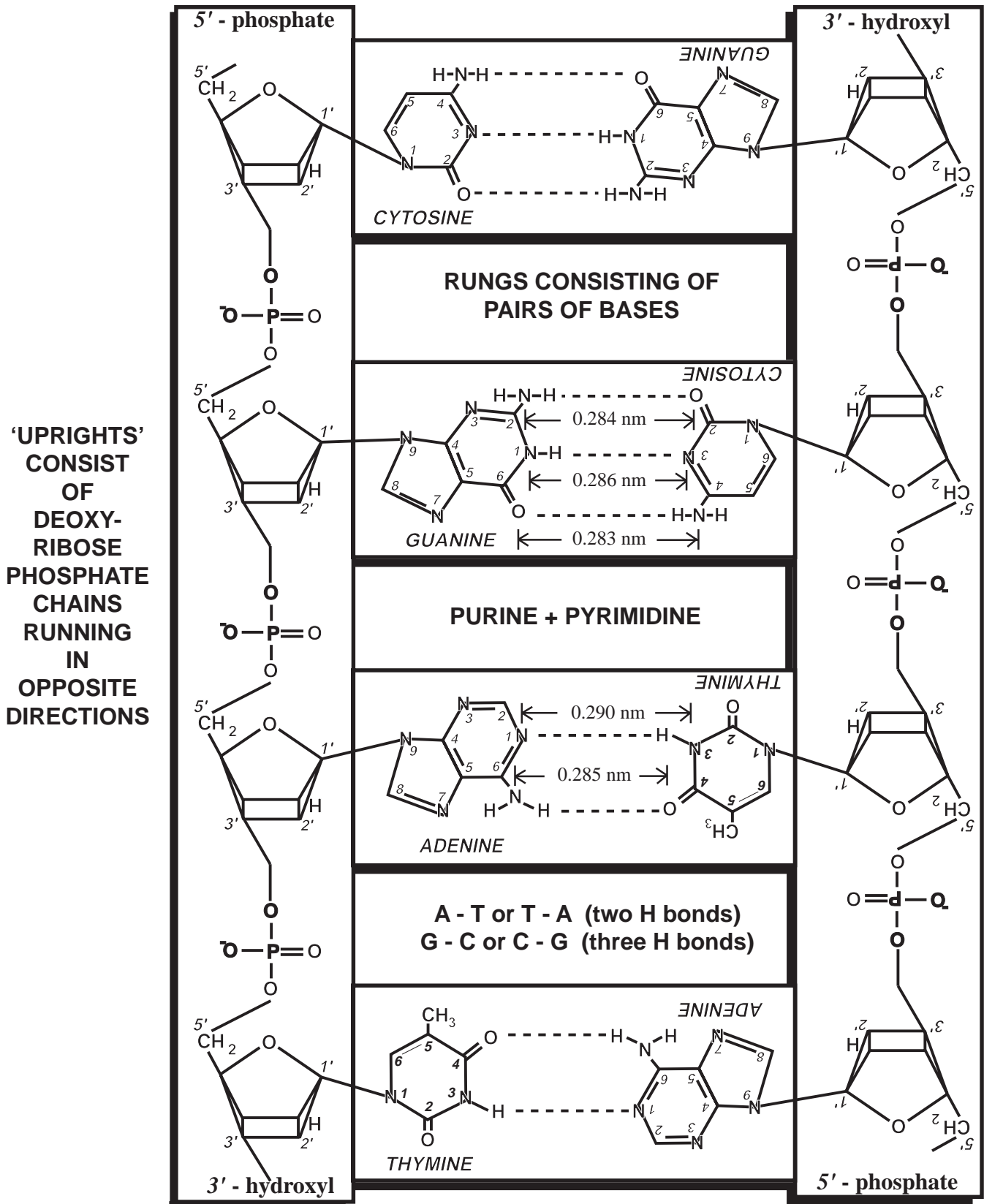
Q11 It looks like a ladder, with the deoxyribose sugars and the phosphates forming the 'uprights' and the pairs of bases forming the 'rungs'.

Q12 Adenine can hydrogen bond specifically only with thymine, while guanine can hydrogen bond only with cytosine. These bondings are described as **base-pairing** and the paired bases are said to be **complementary**. The complete molecule consists of two halves called '**strands**' - going in opposite directions - this is known as an '**anti-parallel**' or '**bi-directional**' arrangement. Since students have to consciously turn half of the molecules 'upside-down' to get the pieces to fit, they are more likely to remember this important feature (it is interesting to note that one rarely, if ever, finds the DNA molecule shown this way in book illustrations).

Q13 Similar basic ladder structure. Differences will occur however in the sequence (order) of the bases - thus giving virtually infinite variability. It would be an interesting probability exercise for the mathematically inclined in the class to work out the number of possible base-sequence permutations that are possible with say a 6bp long molecule - 4 A-Ts and 2 G-Cs. Remember that apart from the actual sequence the pairs can be either way around. The length of a DNA molecule is described in terms of the number of base-pairs (abbreviated to bps) e.g. it is 120 bps long. Since the number of paired bases ranges from about 5,000 for the simplest known virus up to an estimated 3 billion in the 23 chromosomes of humans, the possible variations are astronomical - DNA is well suited to explain the immense diversity among living things. (The complete DNA sequence of brewer's yeast took 7 years to work out - it was completed in 1996, and contains 12.071 million base-pairs - making up some 6000 genes).

Q14 110 million times larger. The measured width of the model is about 220 mm. Since 1 mm = 1 million nanometres, then 220 mm = 220 million nm. The real DNA molecule is about 2 nm wide - we have to multiply this by 110 million to get 220 million nm. The model is therefore 110 million times larger.

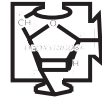
With respect to the 3-dimensional structure of DNA, this is not necessary for understanding of the basic structure of DNA and relating this to its function, but students should know that it is in the form of a **double helix**. Most textbooks illustrate this in some way - see overhead master on the next page. Alternatively you could show them a 3-D model. You can even get them to make up their own simple 3-D model - a good example of which can be found in Unit 1 - Microbes and Molecules, by the European Initiative for Biotechnology Education, pages 6 and 7. This can be downloaded via the World Wide Web - site location - <http://www.reading.ac.uk/NCBE>.



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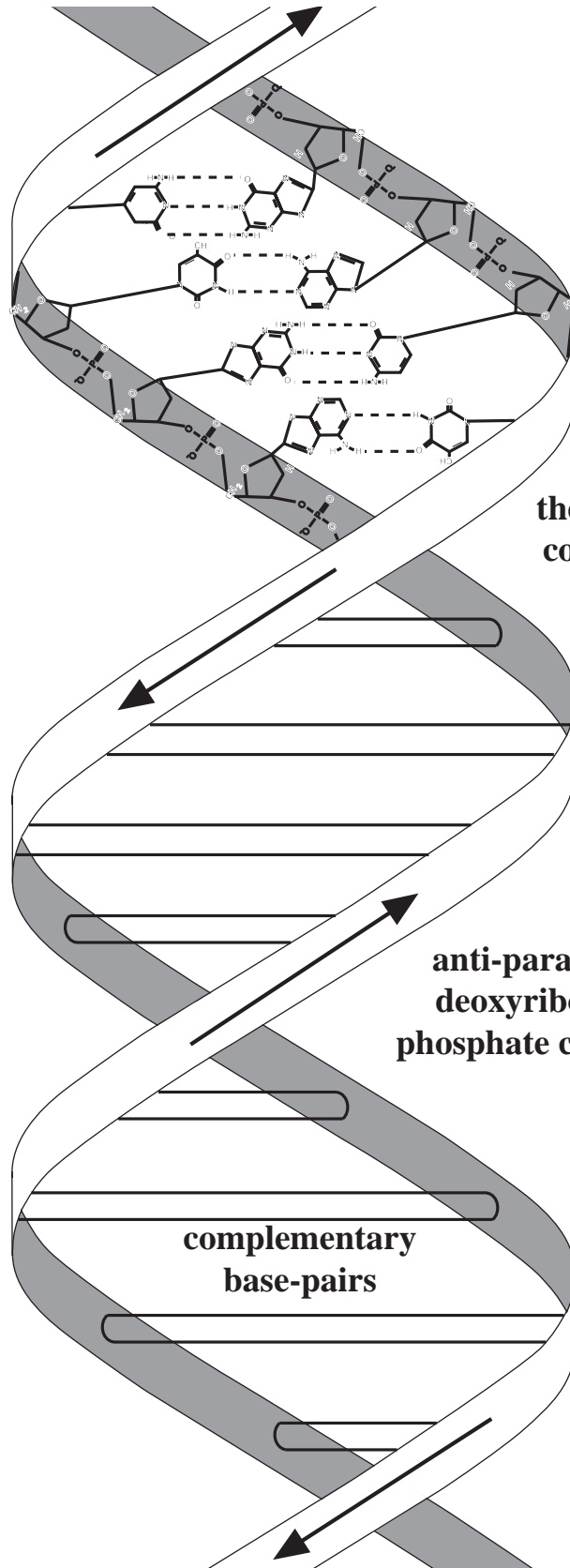
THE STRUCTURE OF DNA

2 Advanced Model



3 Overhead 2

The DOUBLE HELIX of DNA



there are 10 base pairs per complete turn of the helix

anti-parallel
deoxyribose
phosphate chains

complementary
base-pairs

2

THE REPLICATION OF DNA

1 Basic Model



1 Student Activity

Follow the instructions carefully and answer ALL the questions

Place all the pieces that you have been given on the bench with only the large letters facing upwards. Join all these pieces together to make a DNA molecule.

Q1 *Make a simple drawing of this molecule, making sure that you show the order of the bases in the rungs of the 'ladder'. Label your drawing 'parent' DNA.*

'Unzip' this 'parent' DNA molecule by pulling the pairs of bases apart gently until the molecule is divided into two single strands of DNA.

Now take the second set of pieces that you have been given; make sure only the large letters are showing, and arrange them into nucleotides of three pieces each.

Now place these nucleotides, wherever they will fit, into the two single strands of DNA. Continue until all the nucleotides, and thus all the pieces, have been used up.

You should now have two double-stranded DNA molecules - these are known as '**daughter**' DNA molecules.

Q2 *Look carefully at the two daughter DNA molecules. What do you find?*

Q3 *Compare the daughter DNA with the drawing that you made of the parent DNA. What do you find?*

Q4 *Write down in words how DNA molecules make exact copies of themselves.*

This property of DNA is very important since DNA must be passed from 'parent' to 'daughter' cells during cell division and so it must be able to make copies of itself. The term for this exact copying of DNA is known as **replication**. DNA must also be passed from generation to generation.

This ability of DNA to replicate is used nowadays by scientists in many situations. In forensic science, for example, extremely tiny amounts of DNA, such as that in a minute smear of blood found at the scene of a crime, can be doubled time and time again until there is enough for analysis. All that is needed, apart from the original DNA, is a source of nucleotides, a special enzyme and some other special conditions, and the DNA will happily multiply in a tube. This process is known as the Polymerase Chain Reaction (PCR for short). If you need more of a particular type of DNA for research or other scientific work, there is no problem since you can obtain as much you need in a few hours.

2

THE REPLICATION OF DNA

1 Basic Model



2 Teacher Notes

Each group of students will need two sets of pieces. You will therefore need to halve the number of groups or alternatively you can obtain more kits. The first set of pieces given out is exactly the same as that given out for activity 1.1.1, so you can simply continue on from that activity if you wish - see inside back cover.

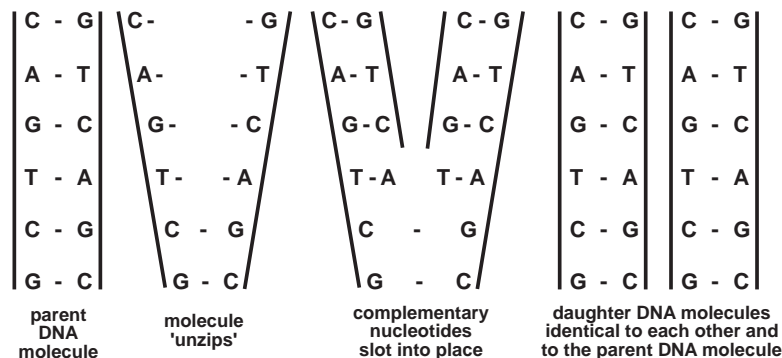
Q1 A very simple drawing is all that is required - see example below.

The second set of pieces given out to each group should be identical to the first set of pieces.

Q2 They are identical.

Q3 They are exactly the same. The sequence of bases is faithfully replicated, because of the specific base-pairing rule - A-T or T-A, and G-C or C-G.

The following simple diagram illustrates this clearly.



This type of replication is known as **semi-conservative replication**, since each strand of the molecule acts as a template or pattern for the two new strands.

A classic experiment was devised by Meselson and Stahl in 1958 to find out if this was the way replication actually took place. They grew the bacterium *E. coli* in a medium containing a heavy type of nitrogen until all the ordinary nitrogen in the DNA had been replaced with the heavy type. They then returned the bacteria to a medium containing ordinary nitrogen and at each new generation they took samples, isolated the DNA and determined its density. They found that the density of the first generation DNA was exactly halfway between that of the heavy parent DNA and that of ordinary 'light' DNA and that each generation contained more and more light DNA - clear evidence that semi-conservative replication did occur and that Watson and Crick's model was correct.

DNA can be artificially multiplied - a process first devised by Kary Mullis and known as PCR (Polymerase Chain Reaction) - it can now be carried out very simply using a PCR machine. This process is used in any situation where only minute amounts of DNA are available, so that enough DNA can be obtained for analysis.

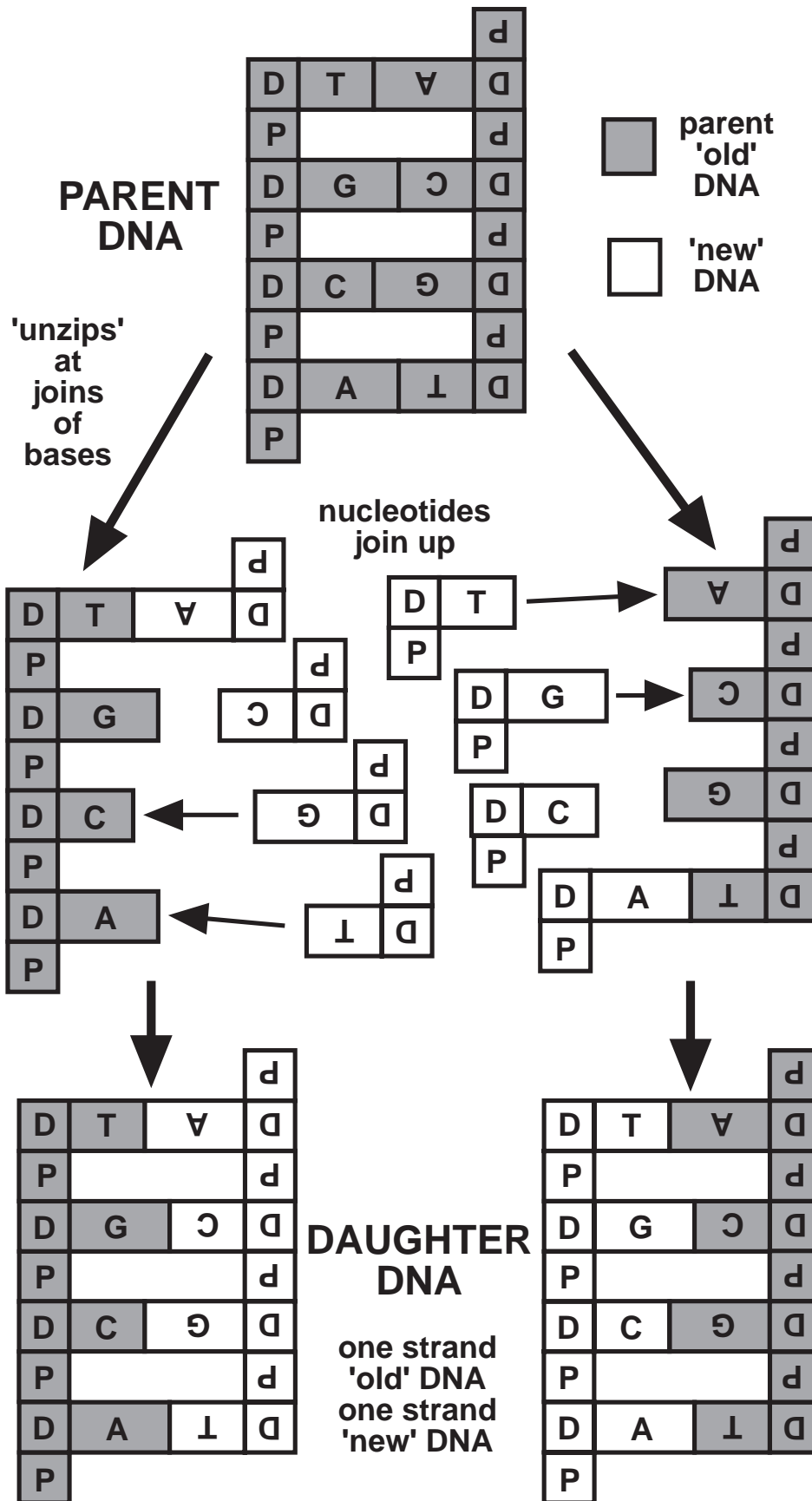
2

THE REPLICATION OF DNA

1 Basic Model



3 Overhead

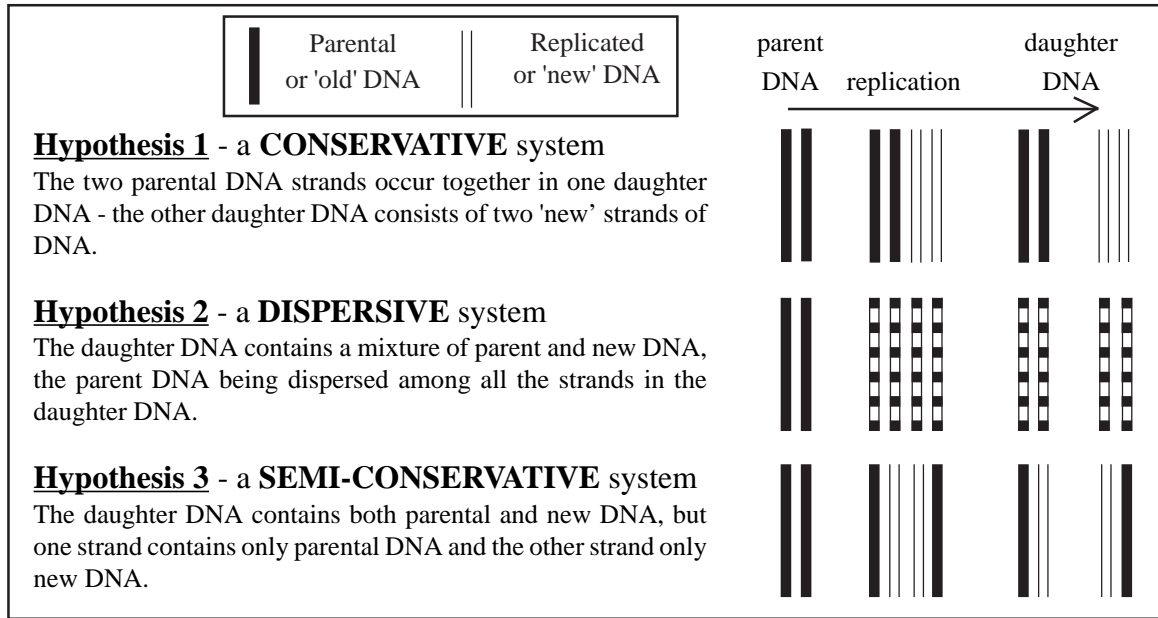


2 Advanced Model



1 Student Activity

The second requirement of DNA is that it should be able to make exact copies of itself so that the genetic information can be passed on during cell division. Making exact copies is termed **replication**. In theory this could take place in one of the following three ways :



Arrange the pieces that you have been given on the bench so that only the molecular structures are facing upwards. From these pieces construct a short length of double stranded DNA.

Q1 *Make a simple drawing of this molecule, noting in particular the sequence of bases. Label your drawing 'parent' DNA.*

Now gradually 'unzip' the DNA molecule by sliding apart the weak hydrogen bonds holding the bases together. Continue unzipping until you have two single strands of DNA.

Arrange the second set of pieces so that the molecular structures are facing upwards and make them up into nucleotides. Now slot all of these nucleotides into place, fitting the new nucleotides together in the direction 5' to 3' of the carbon atoms in the deoxyribose molecules. Continue until all the nucleotides and thus the pieces have been used up.

Q2 *What do you end up with?*

These molecules are known as '*daughter*' DNA molecules.

Q3 *Examine the daughter DNA molecules carefully. What do you notice?*

Q4 *Compare the structure of the daughter molecules with your drawing of the parent molecule. What do you notice?*

Q5 *What does each double-stranded daughter molecule consist of in terms of DNA strands?*

Q6 *Which of the three hypotheses above is the correct one?*

2 Advanced Model

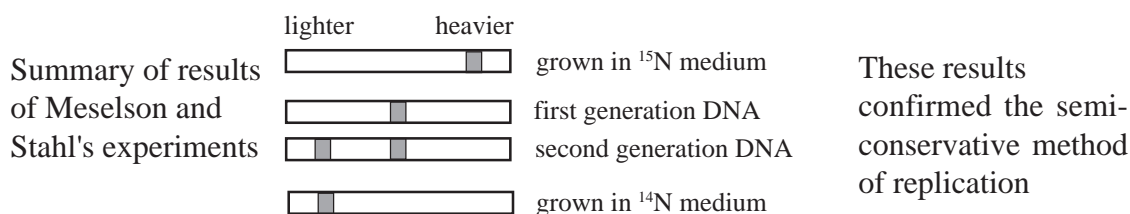
2 Teacher Notes

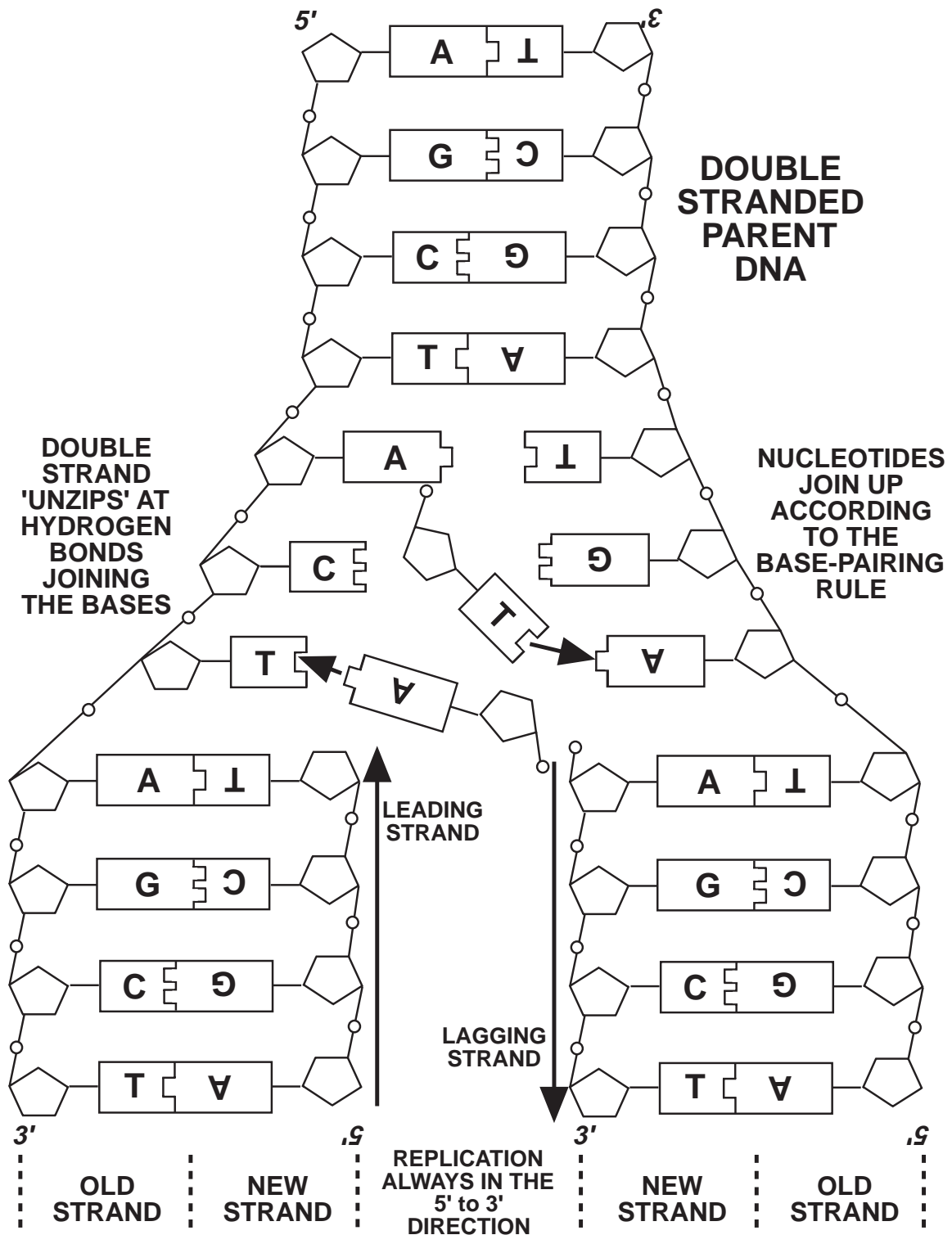
Watson and Crick, in their original article in *Nature* (171:737; 1953) were well aware of the need for DNA to self replicate when they stated, or rather understated, 'It has not escaped our notice that the specific pairing [of bases of DNA] we have postulated immediately suggests a possible copying mechanism for the genetic material.'

For this activity each group will require two identical sets of pieces, each set containing the appropriate pieces to make up a short length of double-stranded DNA - you can, if you have time, continue from activity 1.2.1 (see inside back cover), using the DNA already constructed.

- Q1** Their drawing of the 'parent' DNA should be very simple, concentrating on the base sequences and using only the letters A, T, G and C for the bases.
- Q2** They should end up with two double-stranded 'daughter' DNA molecules.
- Q3** The two 'daughter' DNA molecules are identical.
- Q4** Each 'daughter' DNA molecule is identical to the 'parent' DNA molecule - they have been faithfully replicated.
- Q5** It contains one strand (the template) from the 'parent' DNA and a 'new' replicated strand.
- Q6** Hypothesis 3 - semi-conservative replication (see overhead on the next page).

This form of replication was confirmed by an ingenious experiment carried out by Matthew Meselson and Franklin Stahl at the California Institute of Technology in 1958. They grew the bacterium *E.coli* for several generations in a medium where all the available nitrogen was in the form of the isotope ^{15}N (heavy nitrogen), so that over time the ordinary form of nitrogen (^{14}N) was replaced by the heavy form, and the DNA formed thus had a higher molecular weight and density than that of normal DNA. The bacteria containing the heavy DNA were then transferred to a medium containing normal nitrogen (^{14}N) so that any new DNA which was replicated would have to be made using this normal nitrogen. They were left long enough for the DNA to replicate once - this was determined by a doubling in the number of cells. The DNA was extracted and spun in an ultracentrifuge at an extremely high speed with caesium chloride. The caesium chloride sediments partially to form a density gradient, so that any mixture of molecules dissolved in it would settle into bands according to their density. The density of this first generation DNA was found to be exactly halfway between that of the heavy parent DNA and that of ordinary light DNA - as it would be if each molecule contained one old (heavy) strand and one new (light) strand, as predicted by Watson and Crick. Further generations were then grown in the ^{14}N medium and its DNA ultracentrifuged. Their results were as follows :





DOUBLE STRANDED DAUGHTER DNA (IDENTICAL TO EACH OTHER AND TO THE PARENTAL DNA)

3

THE TRANSCRIPTION OF DNA

1 Basic Model



1 Student Activity

Follow the instructions carefully and answer ALL the questions

From the pieces that you have been given make up a **single strand** of DNA (not the usual double-stranded DNA) with the letters facing upwards.

Q1 *How many bases long is your DNA strand?*

Keeping your single strand of DNA together, take the pieces of RNA (Ribose Nucleic Acid) that you have been given, and compare them with the pieces of DNA.

Q2 *What similarities and differences between the DNA and RNA pieces can you find? Construct a table listing the similarities and differences.*

Make up all the RNA pieces that you have been given into nucleotides.

Join up these nucleotides of RNA to the DNA strand that you have made. You should now have no pieces left. The DNA strand acts as a pattern or **template**, converting the sequence of bases of DNA into a sequence of bases of RNA. This process is called **transcription**.

Q3 *Write down the complementary base pairs of DNA and RNA.*

Your double stranded molecule should now consist of a strand of DNA and a strand of RNA. Separate the RNA and DNA strands by 'unzipping' them where the bases join.

The separated RNA strand is now known as **messenger RNA** or **mRNA** for short, so called because it carries the message or code contained in the order of the bases of DNA from the nucleus to the cytoplasm of the cell.

Q4 *Make a simple drawing of your mRNA strand.*

The messenger RNA passes out of the cell nucleus, carrying the information contained in its order of bases. This information is eventually translated as a long series of **triplet codons** (sequences of three bases beside each other) by another form of RNA called **transfer RNA** or **tRNA**. Because of this double copying (DNA to mRNA to tRNA) the original order of the bases in DNA is restored except for one difference.

Q5 *What is this difference?*

The order of the bases (in threes) on the transfer RNA tells the cell what proteins to make. All the proteins made are thus determined by the original order or sequence of the bases in the DNA. The cell nucleus contains enough DNA to code for all the proteins.

3

THE TRANSCRIPTION OF DNA

1 Basic Model



2 Teacher Notes

Give out enough DNA pieces to each group of students to make a single-stranded DNA molecule, say 6 bases long, that is, half the usual number of pieces. Remember that you can use the DNA from a previous activity - see inside back cover.

Once they have constructed the DNA strand give out the second set of pieces. This RNA set should be complimentary to the first DNA set except that R (black with white letter) is in place of D, and U (dark blue with white letter) is in place of T.

Q2

	DNA	RNA
Similarities	P A G C	P A G C
Differences	D T	R U

Q3 This depends on the bases you have given out.

After question 4 you can stop if you think that the rest of the activity is too difficult. This section simply informs the student of the relevance of the code and what it is used for.

Q5 With reference to the bases, U is in place of T. Of course R also replaces D. Note that the molecules in RNA which are different from those in DNA are printed in white.

3

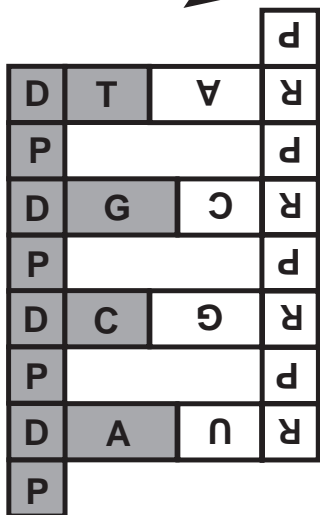
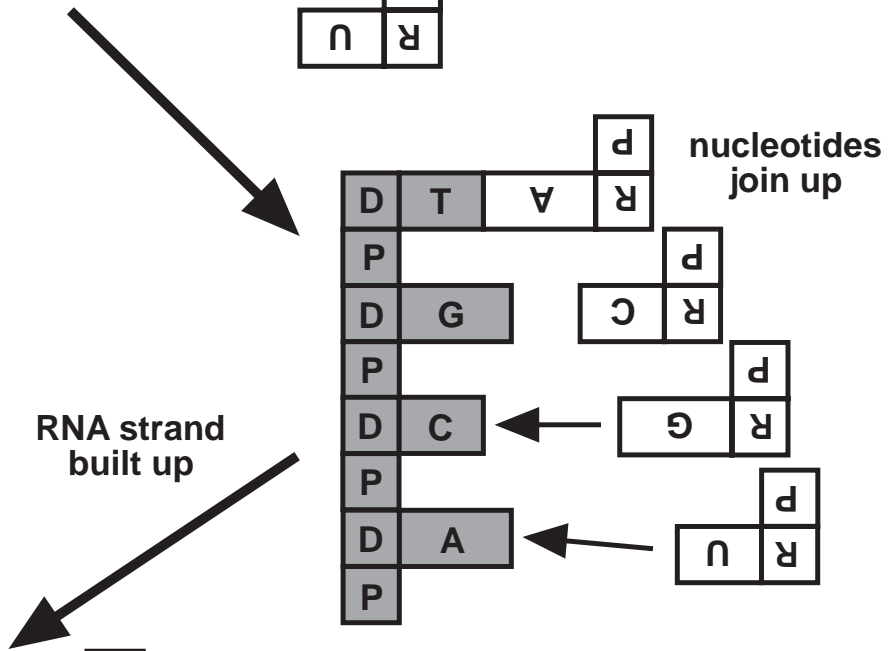
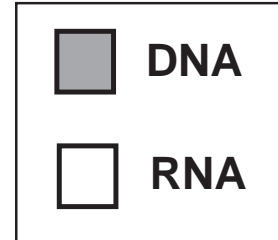
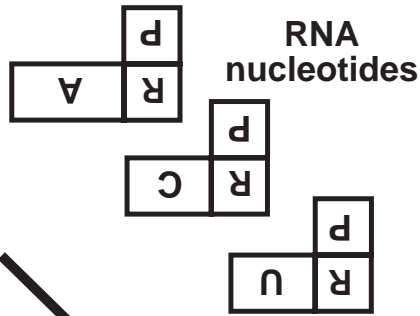
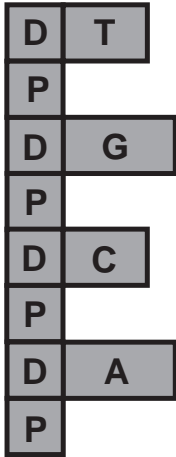
THE TRANSCRIPTION OF DNA

1 Basic Model

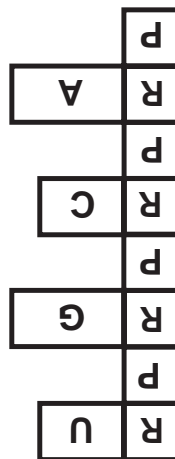


3 Overhead

DNA STRAND



RNA strand separates



moves out of the nucleus into the cytoplasm

DNA strand

RNA strand

messenger RNA (mRNA)

3

THE TRANSCRIPTION OF DNA

2 Advanced Model



1 Student Activity

You have found that genetic information lies in the sequence of bases in DNA, and that this sequence can be faithfully replicated. If this is so, how is this genetic information used? Cells and organisms differ mainly in their proteins, and they arise from the multitude of reactions which take place in the cytoplasm of the cells. These reactions are controlled by enzymes which are all proteins. It would be a reasonable assumption therefore that the information coded in DNA would be in the form of instructions to produce particular proteins. The genetic information contained in the DNA must therefore get from the nucleus of the cell out into the cytoplasm.

Arrange the DNA pieces you have been given on the bench so that only the molecular structures are facing upwards. From these pieces construct a **single strand** of DNA. Move this to the side when you are finished, but keep it intact.

Now take the second set of pieces that you have been given and again arrange them so that only the molecular structures are facing upwards.

Q1 *Examine the new pieces carefully. List as many similarities and differences as you can find between the DNA pieces and the new pieces? Note in particular any similarities and differences in chemical structure.*

Make up the new pieces into nucleotides. Join up these nucleotides to the DNA strand that you have constructed. The DNA strand acts as a template so that a specific strand of the new pieces is formed. This new strand is called **Ribo Nucleic Acid** (RNA for short).

Q2 *Why do you think it is called Ribo Nucleic Acid?*

This process of converting a strand of DNA into a strand of RNA is called **transcription**.

Separate the RNA strand from the DNA strand by 'unzipping' the hydrogen bonds holding pairs of bases together. The single strand of RNA is now known as **messenger RNA (mRNA)** for short) since it can move out of the nucleus through pores in the nuclear membrane into the cytoplasm, carrying the transcribed base sequence message.

Since this message is in the form of a linear sequence of bases, and since proteins consist of a linear sequence of amino acids, it was thought that there might be a relationship between the two? It was discovered that a particular sequence of 3 bases - known as a **triplet codon**, codes for a particular amino acid. Proteins consist of basically only 20 amino acids - it is the number and types, and particularly the sequence of amino acids that determines the type of protein. Triplet codons have been deciphered for all 20 amino acids. A long length of mRNA would therefore have enough information to code for all the amino acids in a protein and thus control its formation.

There must be enough mRNA in any cell of an organism to code for all the proteins that it requires - this would obviously be a very large amount of information.

3

THE TRANSCRIPTION OF DNA

2 Advanced Model



2 Teacher Notes

Give out enough DNA pieces to each group of students so that they can construct a single-stranded DNA molecule - they could use one of the strands they constructed from the previous activity if you have time. Make sure that you have ready for each group an equivalent number and types of RNA pieces to make a complementary strand.

Once they have constructed their single strand of DNA, give out the RNA pieces.

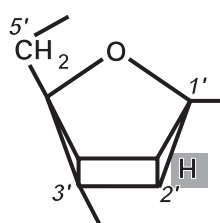
Q1 Similarities between DNA and the new pieces :

They both have phosphate, adenine, guanine and cytosine.

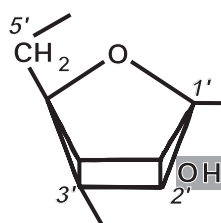
Differences : DNA has deoxyribose while the new pieces contain ribose - note that ribose is black and that the printing is in white.

The new pieces contain the base uracil in place of thymine - dark blue in place of light blue and again the printing is in white.

Close examination of ribose and deoxyribose shows that the only difference between them is that ribose has an OH group at C2' whereas deoxyribose has only an H atom - this is why *deoxy-* (without oxygen) ribose nucleic acid is so called.

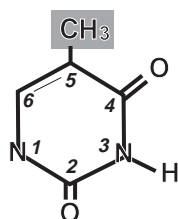


DEOXYRIBOSE

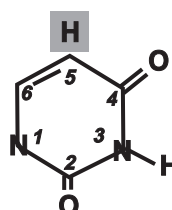


RIBOSE

Uracil differs from thymine in that the CH₃ group at C5 is replaced with an H atom.



THYMINE



URACIL

Q2 Because it contains ribose in place of deoxyribose.

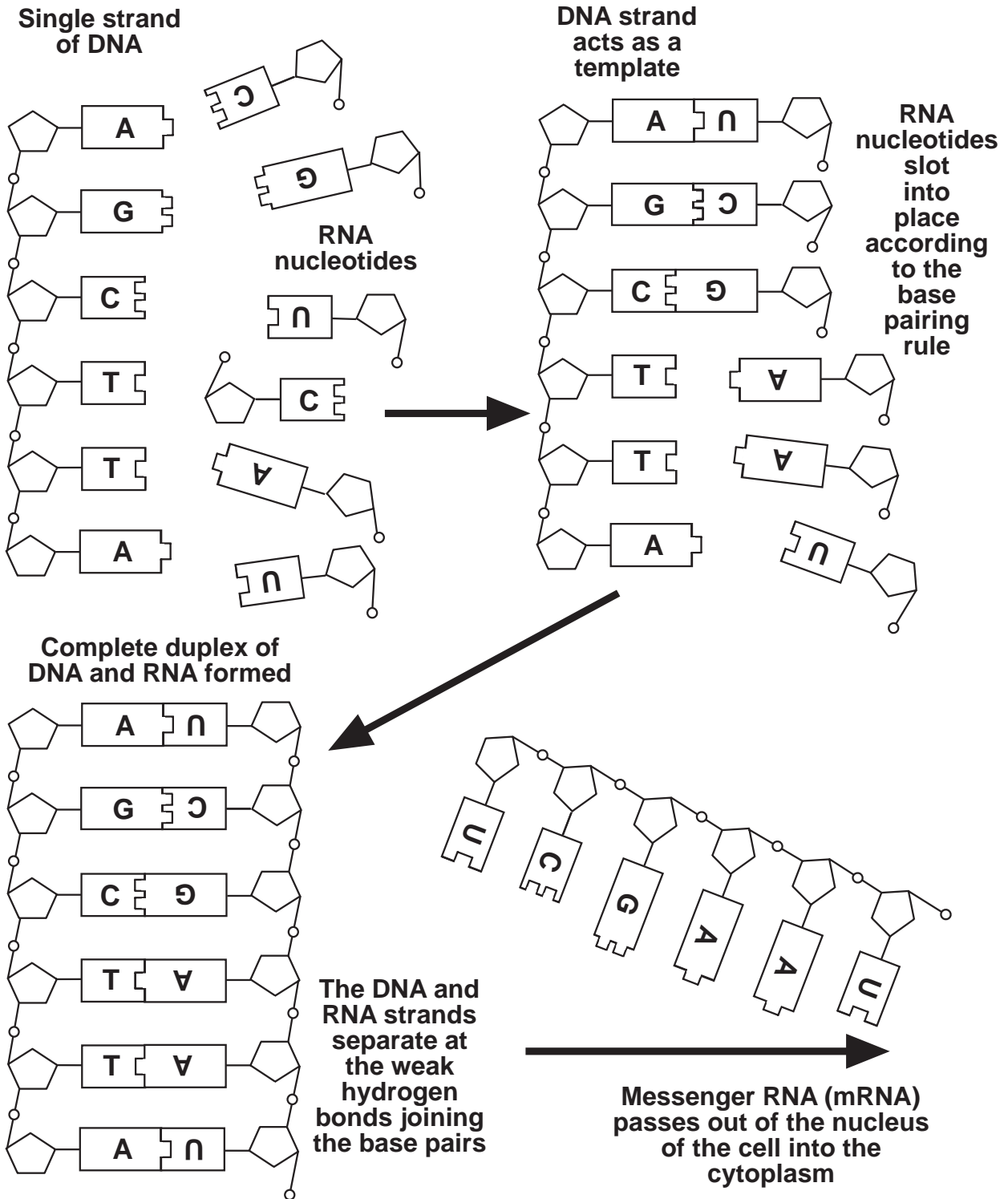
The model ends at transcription. You can go on to explain how translation of the mRNA code brings about protein synthesis by being in the form of **triplet codons**. A continuation model dealing with translation and protein synthesis is being developed at present.

THE TRANSCRIPTION OF DNA

2 Advanced Model



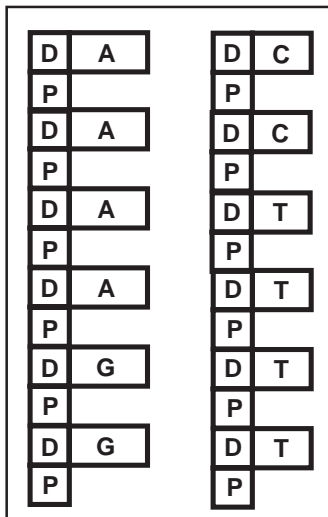
3 Overhead



SEQUENCING THE ACTIVITIES

Pieces shown for one group - molecule 6 base-pairs long

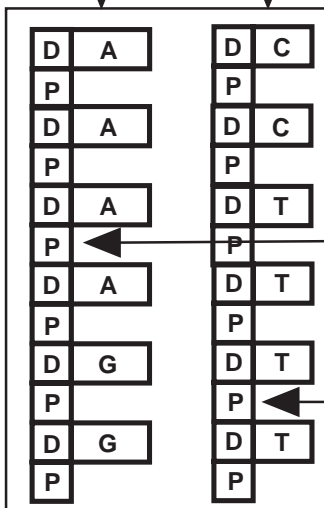
ACTIVITY 1 - STRUCTURE



Appropriate pieces to make a double-stranded DNA molecule 6 base-pairs long

This double-stranded DNA molecule can then be used for the next activity

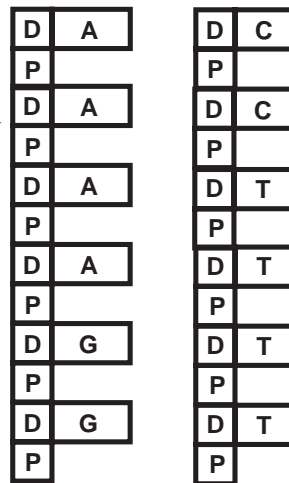
ACTIVITY 2 - REPLICATION



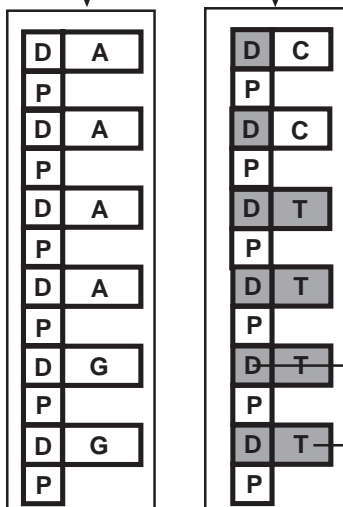
Each group requires a duplicate set of pieces

One strand of this DNA can be used for the next activity

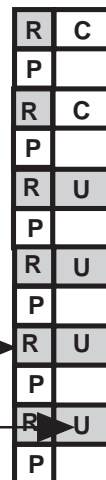
Another strand can easily be modified



ACTIVITY 3 - TRANSCRIPTION



The Ds (deoxyriboses) in the second strand are replaced by Rs (riboses) and the Ts (thymines) by Us (uracils)



You can therefore teach all three activities in one lesson if you have time

Wilbert Garvin was for many years a biology teacher. He is currently lecturer in Education (Biosciences) at the Queen's University of Belfast. He is Director of the Northern Ireland Centre for School Biosciences and a founder member of the European Initiative for Biotechnology Education.

In 1995 he was awarded the Unilever Prize for *Teacher Training in Biotechnology* under the Partnership Award scheme commending innovation in teaching and learning in Higher Education.

He is the author of a number of books, including three volumes of a *Skills in Advanced Biology* series published by Stanley Thornes Ltd. of Cheltenham.

<i>Vol.1</i>	<i>Dealing with data</i>
<i>Vol.2</i>	<i>Observing, recording and interpreting</i>
<i>Vol.3</i>	<i>Investigating</i>