BIOTECHNOLOGY

Ordinary Level

(Syllabus NP04)

CONTENTS

INTRODUCTION

Biotechnology is a multi-disciplinary science that engages knowledge in biology and technological applications to improve human lives and the environment. This syllabus allows students to develop a range of interests in biotechnology and it provides the foundation for further studies in biotechnology and related fields.

Students will be introduced to the principles and applications of various areas of biotechnology. They will gain an understanding of gene technology, microbial biotechnology, animal cell culture and plant biotechnology. The subject will also encompass the applications of biotechnology in the fields of forensic science, medicine and the environment.

This subject is suitable for upper secondary school students with no prior knowledge in biotechnology.

AIMS

The aims are to:

1. equip students with fundamental knowledge in biotechnology to enable them to understand its applications,

2. provide experiential learning opportunities for students to conduct hands-on experiments, projects and research in the many areas of biotechnology, and

3. equip students with an understanding of recent advances in biotechnology and its ethical and social implications.

ASSESSMENT OBJECTIVES

A. Knowledge with Understanding (30%)

Students should be able to demonstrate knowledge and understanding in relation to:

1. biotechnological phenomena, facts, laws, definitions, concepts, theories;
2. biotechnological vocabulary, terminology, conventions (including symbols, quantities and units);
3. scientific instruments and apparatus used in biotechnology, including techniques of operation and aspects of safety;
4. scientific quantities and their determination;
5. biotechnological applications with their ethical, social and environmental implications.

The subject content defines the factual knowledge that candidates may be required to recall and explain. Questions testing those objectives will often begin with one of the following words: *define, state, describe, explain* or *outline*. (See the glossary of terms.)

B. Handling Information and Solving Problems (40%)

Students should be able to – in words or by using symbolic, graphical and numerical forms of presentation:

1. search, select, organise and present information from a variety of sources;
2. interpret, critique, analyse and evaluate data to solve problems;
3. use information to identify patterns, report trends and draw inferences;
4. present reasoned explanations for phenomena, patterns and relationships;
5. make predictions and propose hypotheses.

These assessment objectives cannot be precisely specified in the subject content because questions testing such skills may be based on information which is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a novel situation. Questions testing these objectives will often begin with one of the following words: *predict, suggest, calculate* or *determine*. (See the glossary of terms.)

C. Experimental Skills and Investigations (30%)

Students should able to:

1. follow a sequence of instructions;
2. use techniques, apparatus and materials;
3. make and record observations, measurements and estimates;
4. interpret and evaluate observations and experimental results;
5. plan investigations, choose techniques, apparatus and materials;
6. evaluate methods and suggest possible improvements.

WEIGHTING OF ASSESSMENT OBJECTIVES

Theory Papers (Papers 1 and 2)

A Knowledge with Understanding, approximately **45%** of the marks.

B Handling Information and Solving Problems, approximately **55%** of the marks.

Structured Project (Paper 3)

C Experimental Skills and Investigations, **100%** of the marks.

USE OF CALCULATORS

An approved calculator may be used in all papers.

SCHEME OF ASSESSMENT

Candidates are required to enter for Papers 1, 2 and 3.

Paper	Type	Marks	Weighting	Duration
1	Multiple choice questions	30	20%	45 min
2	Structured Questions	80	50%	1 h 45 min
3	Structured Project	100	30%	15 h

Paper 1

This written paper consists of 30 compulsory multiple choice questions with 4 options.

Paper 2

This paper consists of a variable number of structured questions. Candidates must answer all the questions.

Paper 3

This structured project is carried out over a period of 15 hours in Secondary 4. It comprises three inter-related components and assesses appropriate aspects of objectives C1 to C6.

a) <u>The Project Plan (15 marks)</u>
Candidates will have 3 hours to prepare their experimental plans and timeline in their logbooks.

b) <u>Experimental Skills (45 marks)</u>
Candidates will have 3 scheduled lab sessions to carry out their experiments and record their procedures in their logbooks.

c) <u>Report (40 marks)</u>
Candidates will report on the results, analyse their data, and evaluate their planning and design of experiment.

(Refer to Appendix A for *Assessment Scheme for Structured Project*)

KEY AREAS COVERED

The specific areas are:

S/N	Scope
1.	Introduction to Biotechnology
2.	Gene Technology
3.	Microbial Technology
4.	Animal Cell Culture
5.	Plant Biotechnology
6.	Biotechnology Applications

SUBJECT CONTENT AND LEARNING OUTCOMES

1. Introduction to Biotechnology

Content

1.1 The Cell

Learning Outcomes:

Upon completion of this unit the student will be able to

(a) identify bacteria as typical prokaryotic cells and state functions of their cellular structures: surface structures (flagella, pili, fimbriae), glycocalyx, cell wall, cell membrane, ribosomes, cytoplasm, plasmids, nucleoid and endospore
(b) identify cellular structures (including organelles) of typical eukaryotic cells and state their functions: cell membrane, cell wall, cytoplasm, cell vacuoles, nucleus, smooth and rough endoplasmic reticulum, mitochondria, chloroplasts, Golgi body and ribosomes
(c) compare the structures of typical prokaryotic (bacteria) and eukaryotic cells (plant and animal)

Use the knowledge gained in this section in new situations or to solve related problems.

2. Gene Technology

Content

2.1 DNA to RNA, RNA to Proteins
2.2 Recombinant DNA Technology
2.3 Genomics and the Human Genome Project

Learning Outcomes:

Upon completion of this unit the student will be able to

(a) outline the relationships between DNA, genes, chromosomes and genome
(b) compare DNA and RNA in terms of composition, structure and location
(c) state the rule of complementary base pairing and outline its role in the transfer of genetic information from:
    i. DNA to DNA (semi-conservative replication)
    ii. DNA to RNA
    iii. RNA to proteins, which are polymers of amino acids (Processes and enzymes are not required)

(d) state that genes can be inserted into cells to produce recombinant cells with new traits (such as the production of recombinant proteins, transgenic organisms)
(e) state the main features of plasmids such as multiple cloning sites (MCS) containing specific recognition sites for restriction enzymes, origin of replication and antibiotic resistance gene and their use in cloning genes
(f) explain how DNA is amplified using polymerase chain reaction (PCR)
(g) outline the principles and process of cloning a recombinant DNA molecule:
    i. digestion of DNA and plasmid using restriction enzymes
    ii. ligation, transformation and selection of recombinant cells
(h) explain how agarose gel electrophoresis is used to analyse DNA fragments
(i) outline the principles and process of purification of recombinant proteins using size-exclusion chromatography
(j) explain how polyacrylamide gel electrophoresis (SDS-PAGE) is used to analyse proteins
(k) determine, using spectrophotometry
    i. the quantity and quality of DNA
    ii. the quantity of proteins
(l) describe the *Human Genome Project* (HGP) as a multi-national collaboration to identify and map all the genes in human DNA and use the results obtained from the HGP in studying diseases
(m) state the use of model organisms e.g. mouse and zebrafish in understanding the human genome
(n) state that bioinformatics tools are used to analyse biological data (e.g. sequence alignment using BLAST)

Use the knowledge gained in this section in new situations or to solve related problems.

3. Microbial Biotechnology

Content

3.1 Bacteria

Learning Outcomes:

Upon completion of this unit the student will be able to

(a) state the effects of cell wall inhibitors (antibiotics e.g. penicillin) on bacteria
(b) describe the stages of the bacterial growth curve in culture
(c) classify bacteria based on
    i. morphology
    ii. nutrient requirements and nutritional types
(d) state the different environmental conditions (e.g. temperature, pH, oxygen) that bacteria can grow
(e) outline the tests used to characterise bacteria (e.g. Gram stain and biochemical tests)
(f) state and perform basic microbiological procedures
    i. preparation of agar and broth cultures
    ii. serial dilution and determination of bacteria density
    iii. determination of culture purity
(g) discuss the applications of bacteria in
    i. food (fermentation, probiotics)
    ii. industry (production of enzymes)
    iii. agriculture (nitrogen fixation)

Use the knowledge gained in this section in new situations or to solve related problems.

4. Animal Cell Culture

Content

4.1 Types of Animal Cell Cultures
4.2 Cell Culture Medium
4.3 Growth and Maintenance of Cells in Culture

Learning Outcomes:

Upon completion of this unit the student will be able to

(a) define the following in terms of *in vitro* culture of animal cells
    i. primary cell culture
    ii. cell lines (adherent and suspension cell lines)
    iii. subculture
(b) state the uses of the following equipment and materials used in animal cell culture: biological safety cabinet, cell culture incubator, inverted microscope, haemocytometer, liquid nitrogen (for cryopreservation) and vessels for cell culture (e.g. Petri dish, flask, bioreactor)
(c) outline the functions of various components of the cell culture medium: water, amino acids, carbohydrates, serum, antibiotics, sodium bicarbonate and pH indicator (e.g. phenol red)
(d) perform calculations to prepare cell culture medium and phosphate buffered saline using the concepts
    i. molarity (moles of solute/litre of solution) and relative molecular mass of chemicals
    ii. percent concentration (%w/v, %v/v)
    iii. dilution of stock solutions
    iv. $C_1V_1 = C_2V_2$ where C refers to concentration of a solution and V refers to the volume
(e) describe the following cell culture techniques and procedures that are used in subculturing cells
    i. trypsinisation
    ii. determination of cell density and viability
    iii. calculation of seeding density

Use the knowledge gained in this section in new situations or to solve related problems

5. Plant Biotechnology

Content

5.1 Plant Tissue Culture
5.2 Genetically Engineered Plants

Learning Outcomes:

Upon completion of this unit the student will be able to

(a) explain the concept of cell totipotency and morphogenesis in plant tissue culture
(b) state the different types of plant tissue cultures and their applications
(c) outline the types of sterilisation techniques (e.g. autoclaving, filtration, gamma-irradiation and chemical sterilisation) and their uses
(d) describe the effects of the following on plant tissue cultures
    i. culture conditions (e.g. light, temperature)
    ii. growth medium (e.g. macronutrients, micronutrients, carbon source, auxins, cytokinins)
(e) describe and perform the stages of micropropagation
    i. preparation of media with different plant growth regulators
    ii. Micropropagation - Stages I, II, III and IV
(f) outline the method of plant transformation using *Agrobacterium* with transferred DNA (T-DNA) from the tumour inducing (Ti) plasmid
(g) state the applications of plant genetic engineering and discuss ethical and social issues regarding genetically-modified crops with respect to
    i. crop improvement e.g. *BT* gene
    ii. enhanced nutritional quality
    iii. molecular farming

Use the knowledge gained in this section in new situations or to solve related problems.

6. Biotechnology Applications

6A. Forensic Science

Content

6.1 DNA Profiling

Learning Outcomes:

Upon completion of this unit the student will be able to

(a) describe *short tandem repeats* (STRs) in humans as a form of repetitive DNA
(b) outline the method of DNA profiling using STRs and analyse the results in applications such as forensic science, paternity testing and disease diagnosis

Use the knowledge gained in this section in new situations or to solve related problems.

6B. Transgenic Animals

Content

6.2 Gene Transfer in Animal Cells
6.3 Transgenic Animals and their Applications

Learning Outcomes:

Upon completion of this unit the student will be able to

(a) describe the process of gene transfer into animal cells using microinjection
(b) list the types of transgenic animals and state their uses: sheep (e.g. pharm animals), mice and pigs

Use the knowledge gained in this section in new situations or to solve related problems.

6C. Medical Biotechnology

Content

6.4 Biologics

Learning Outcomes:

Upon completion of this unit the student will be able to

(a) define *biologics* as biological products synthesised by living organisms through biotechnology methods
(b) compare the use of prokaryotic and eukaryotic cells for the production of biologics
(c) outline the production of biologics by recombinant
    i. bacteria
    ii. Chinese hamster ovary (CHO) cells

Use the knowledge gained in this section in new situations or to solve related problems.

6D. Environmental Biotechnology

Content

6.5 Bioremediation

6.6 Fermentation and Biofuels

Learning Outcomes:

Upon completion of this unit the student will be able to

(a) describe *bioremediation* as the use of using living organisms (microbes and plants) to alleviate environmental problems
   i. bacteria that digest oil
   ii. plants that extract heavy metals from water or soil
(b) outline the process of alcohol fermentation and describe its application in the production of biofuels

Use the knowledge gained in this section in new situations or to solve related problems.

SUMMARY OF KEY QUANTITIES, SYMBOLS AND UNITS

The following list illustrates the common symbols and units that will be used in Biotechnology and the question papers and is not meant to be exhaustive. Some of the units used, such as for volume and concentration, may differ from those used in Biology and Chemistry.

Quantity	**Symbol**	**Unit**
length	*l*	µm, mm, cm, m
area	*A*	cm^2, m^2
volume	*V*	µ*l*, m*l*, L
mass	*m*	µg, mg, g, kg
concentration	*C*	µM, mM, M, %v/v, %w/v
time	*t*	s, min, h, d
pH	pH	-
temperature	*T*	ºC

Glossary of Terms used in Biotechnology Papers

This glossary provides a description of the meanings of the terms which the candidates may encounter in the exam papers. It is to be used a guide and it is neither exhaustive nor definitive. Candidates should appreciate that the meaning of a term must depend in part on its context.

1. *Calculate* is used when a numerical answer is required. In general, working should be shown, especially where two or more steps are involved.
2. *Comment* is intended as an open-ended instruction, inviting candidates to recall or infer points of interest relevant to the context of the question, taking account of the number of marks available.
3. *Compare* requires candidates to provide both similarities and differences between things or concepts.
4. *Define* (*the term(s)* …) is intended literally, only a formal statement or equivalent paraphrase being required.
5. *Describe* requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. In the former instance, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena.
6. *Determine* often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula.
7. *Discuss* requires candidates to give a critical account of the points involved in the topic.
8. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned, making such simplifying assumptions as may be necessary about the points of principle and about the values of quantities not otherwise included in the question.
9. *Explain* may imply reasoning or some reference to theory, depending on the context.
10. *Find* is a general term that may be variously interpreted as calculate, measure, determine etc.
11. *List* requires a number of points, generally each of one word, with no elaboration. Where a given number of points is specified, this should not be exceeded.
12. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or mass, using a balance.
13. *Outline* implies brevity, i.e. restricting the answer to giving essentials.
14. *Predict* or *deduce* implies that the candidate is not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted from an earlier part of the question.
15. *Sketch*, when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct, but candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value.
16. S*ketch*, when applied to diagrams, implies that a simple, freehand drawing is acceptable; nevertheless, care should be taken over proportions and the clear exposition of important details.
17. *State* implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained “by inspection”.
18. *Suggest* is used in two main contexts, i.e. either to imply that there is no unique answer, or to imply that candidates are expected to apply their general knowledge to a “novel” situation, one that may be formally “not in the syllabus”.
19. *What is meant by (the term(s) ...)* normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment intended should be interpreted in light of the indicated mark value.

APPENDIX A

ASSESSMENT SCHEME FOR STRUCTURED PROJECT

Project Plan			
Timeline	A clear timeline is shown, with experiments spread out over the project duration.	1	3
	Plan takes into account the time required for individual experiments and when the data will be collected.	1	
	Time is allocated for repeating experiments.	1	
Experimental plan / design	Appropriate tests are chosen to meet all project objectives	6	12
	Appropriate controls are included for each tests	4	
	Replicates are included	2	
Experimental Skills			
Logbook	Procedures / modifications to plan are recorded in the logbook	2	4
	Observations and results are recorded in the logbook	2	
Experimental skills	Experimental work is well organised and systematic	3	9
	Experiments are executed according to set procedures / protocols	5	
	Correct handling of equipment such as micropipettors, microscopes etc.	1	
Safety	Use of laboratory coat, gloves and personal protective equipment where appropriate (e.g. safety goggles)	1	2
	Appropriate disposal of waste (e.g. biohazard waste in autoclave bags, normal waste in appropriate waste container)	1	
Report			
	Observation of results, handling of data, evaluation and analysis of data, making inference	28	28
	Modification / evaluation / improvement of experiment	4	4
	Design of experiment (new scenario)	8	8