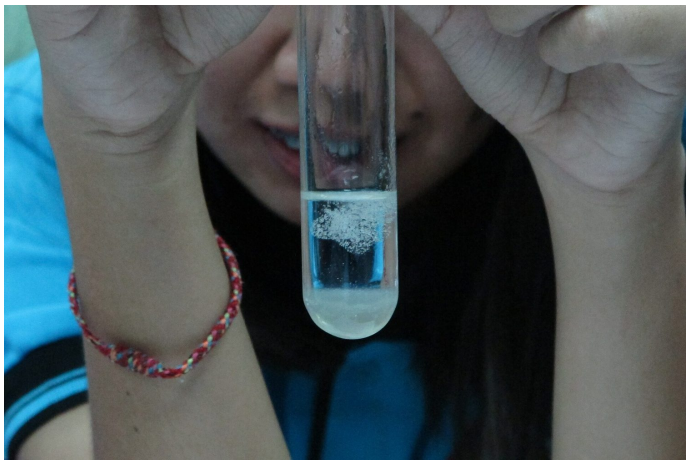
Gene Expression and Regulation

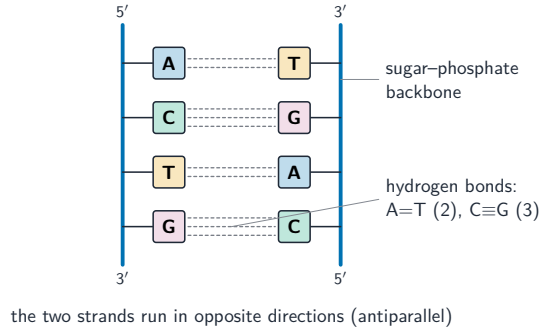
AP Biology

DNA and RNA Structure



Spooling precipitated DNA from a cell extract — DNA is a real, visible molecule

DNA carries genetic information as a **double helix** 双螺旋 of two strands. Its **nucleotides** 核苷酸 pair by rule – A with T, G with C (**complementary base pairing** 互补配对) – so one strand specifies the other. The strands run **antiparallel** 反平行. **RNA** is single-stranded, uses **uracil** (U) instead of thymine, and has ribose sugar.



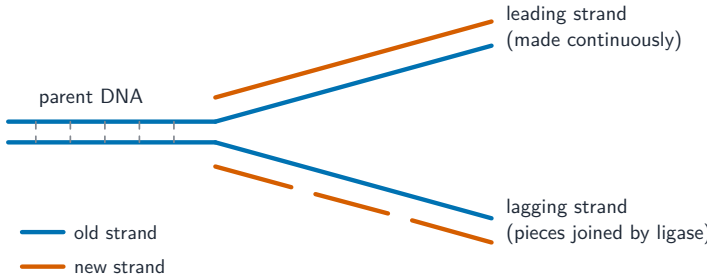
DNA: two antiparallel strands held by complementary base pairs

How the DNA is packaged differs between the domains, and the CED asks for both.

- **Prokaryotic** organisms typically have a **single circular chromosome** 环状染色体 in the cytoplasm, often with extra small circles called plasmids.
- **Eukaryotic** organisms typically have **multiple linear chromosomes** 线性染色体, and each is **condensed by wrapping around proteins called histones** 组蛋白. That packing is what fits two metres of DNA into a nucleus a few micrometres across — and because a tightly wound region is hard for the transcription machinery to reach, the packing is itself a level of gene regulation.

DNA Replication

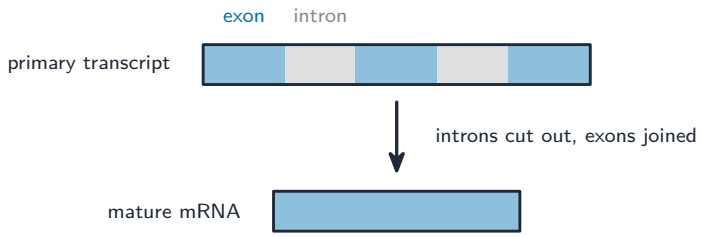
Before a cell divides, DNA is copied **semiconservatively** 半保留复制: the helix unwinds and each old strand templates a new one, so each daughter helix has one old and one new strand. **DNA polymerase** 聚合酶 adds nucleotides following base-pairing rules, building the new strand and proofreading as it goes.



Semi-conservative DNA replication at a replication fork

Transcription and RNA Processing

Transcription 转录 copies a gene's DNA into **messenger RNA** 信使 RNA (mRNA). **RNA polymerase** reads the template strand and builds a complementary RNA. In eukaryotes the mRNA is then **processed**: a cap and tail are added, and **introns** 内含子 (non-coding parts) are spliced out, leaving the **exons** 外显子.

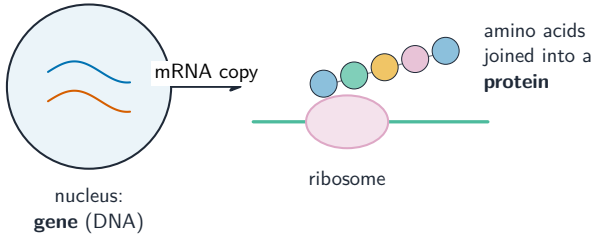


Introns are removed and exons joined to make mature mRNA

The **5′ cap** added during processing is a modified guanine nucleotide — a **GTP cap** — and its job is recognition: it **helps the ribosome recognise and bind the mRNA**, as well as protecting the transcript from degradation as it leaves the nucleus.

Translation

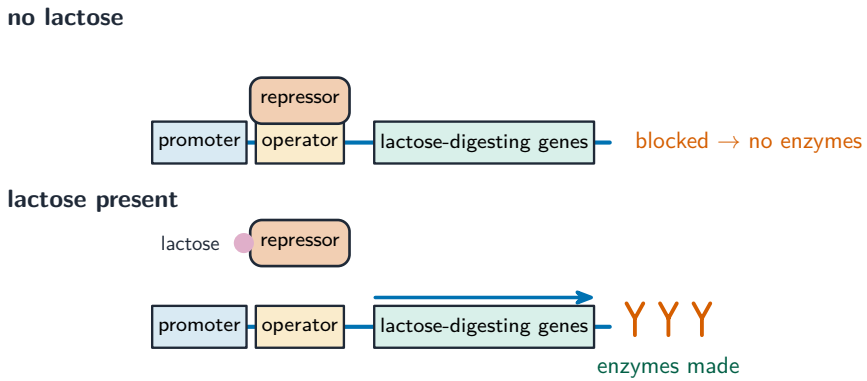
Translation 翻译 builds a protein from the mRNA at the **ribosome** 核糖体. The mRNA is read in three-base **codons** 密码子, each specifying one amino acid (the genetic code). **Transfer RNA** 转运 RNA brings the matching amino acid, and the ribosome links them into a polypeptide until a stop codon ends it. This is the "central dogma": DNA → RNA → protein.



mRNA is read by a ribosome to build a protein from amino acids

Regulation of Gene Expression

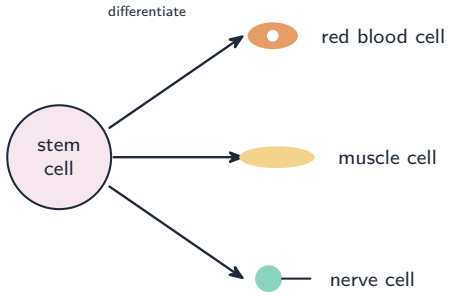
Cells control **which** genes are expressed and **when**. In prokaryotes, **operons** 操纵子 switch groups of genes on or off. In eukaryotes, regulation happens at many levels – which genes are transcribed (transcription factors, promoters, enhancers), RNA processing, and after translation. This lets a cell respond to its environment without changing its DNA.



The lac operon switches genes on only when lactose is present

Gene Expression and Cell Specialization

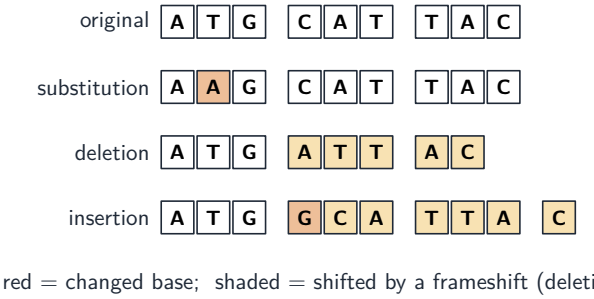
Every cell in a body has the **same** DNA, yet cells differ because they express **different** genes – **differential gene expression** 差异表达. This is how one fertilized egg produces many specialized cell types (muscle, nerve, skin); signals during development turn specific genes on and off.



A stem cell differentiates into specialised cell types

Mutations

A **mutation** 突变 is a change in the DNA sequence. **Point mutations** change one base (silent, missense, or nonsense); **insertions/deletions** can cause a **frameshift** 移码 that garbles everything downstream. Mutations in gametes are heritable; they may be harmful, neutral, or beneficial – and beneficial ones supply the variation for natural selection.

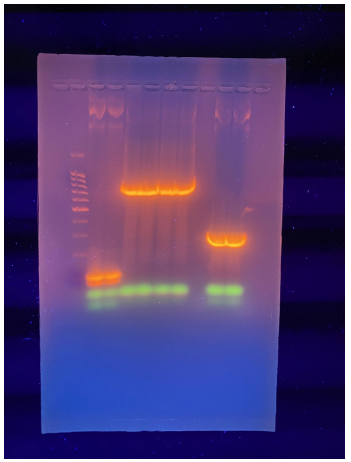


Substitution, deletion, and insertion mutations

Whole-chromosome errors change the phenotype too. Mutation is not only a change of base: **errors in mitosis or meiosis can result in changes in phenotype**. If chromosomes fail to separate — **nondisjunction** 不分离 — a gamete receives an extra copy or none, and the resulting zygote has an abnormal chromosome number (**aneuploidy** 非整倍性). Trisomy 21 is the familiar example. Because a whole chromosome carries hundreds of genes, the phenotypic effect is far broader than a point mutation's.

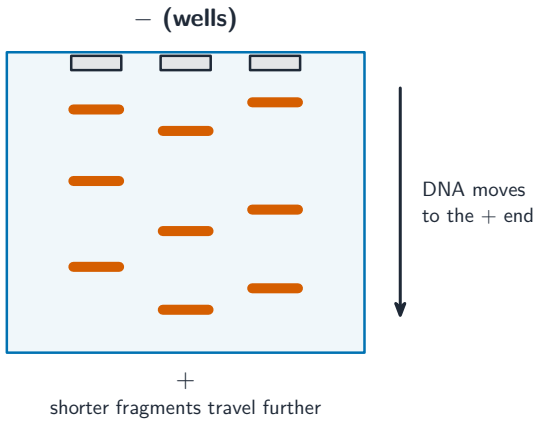
Biotechnology

A thermal cycler repeatedly heats and cools samples to amplify DNA (PCR)

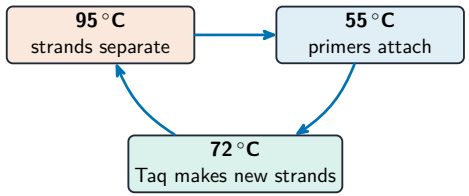


Agarose gel under UV light: DNA fragments separate by size as bright bands

Biotechnology 生物技术 tools manipulate genetic material: **PCR** 聚合酶链反应 copies DNA, **gel electrophoresis** 凝胶电泳 separates DNA fragments by size, **restriction enzymes** and cloning move genes between organisms, and **CRISPR** edits sequences. These techniques enable genetic testing, engineered organisms, and medical treatments.



Gel electrophoresis separates DNA fragments by length



The polymerase chain reaction doubles the DNA each cycle

Worked example. A template DNA strand `3'-TAC GGA TTC-5'` is transcribed into mRNA `5'-AUG CCU AAG-3'`. A ribosome reads three codons: AUG = Met (start), CCU = Pro, AAG = Lys — coding for **Met–Pro–Lys**. Changing the third base of a codon often gives the same amino acid, because the genetic code is **degenerate**, which softens the effect of many mutations.

Reading DNA identifies individuals. Because the number of repeats at certain non-coding loci varies from person to person, **analysis of DNA can be used for forensic identification**: amplify those regions by PCR, separate the fragments by gel electrophoresis, and compare the pattern of band positions with a reference sample. A match is a statement about probability rather than certainty, which is why several loci are tested rather than one.

Exam tips

- Know the **central dogma** DNA → RNA → protein: transcription makes mRNA, translation reads it in three-base **codons** at the ribosome.
- Remember RNA is single-stranded and uses **U** instead of T; replication is **semi-conservative**.
- Every cell has the **same DNA** — cells differ because they express **different genes** (differential gene expression).
- A **mutation** is a change in the DNA sequence and may be harmful, neutral, or beneficial (the raw material for selection).
- Link biotech tools to their jobs: PCR copies DNA; gel electrophoresis separates fragments by size.