

Gene Expression and Regulation

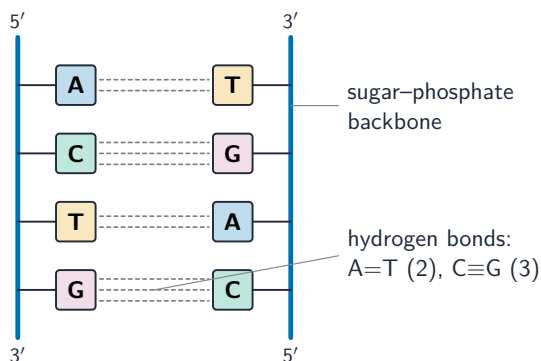
AP Biology

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.



the two strands run in opposite directions (antiparallel)

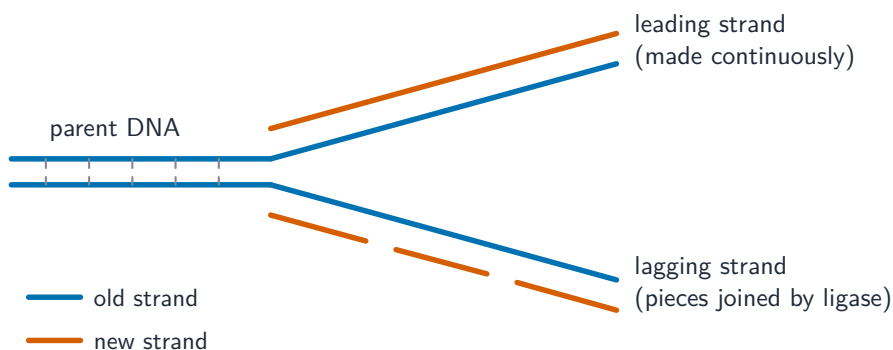
DNA: two antiparallel strands held by complementary base pairs

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.

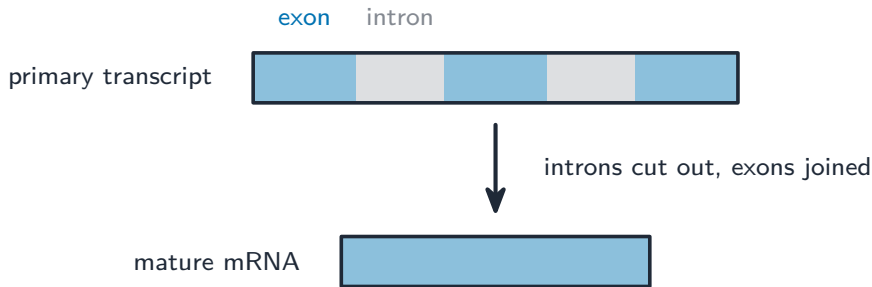


each new molecule = one old strand + one new strand (semi-conservative)

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.

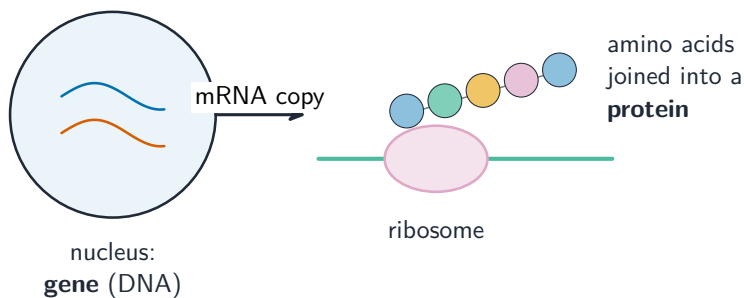


Introns are removed and exons joined to make mature mRNA

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.



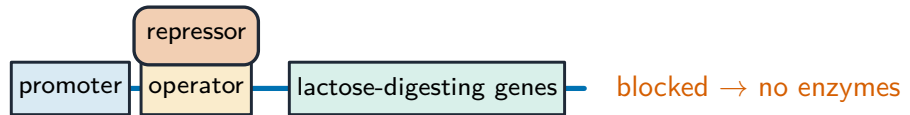
mRNA is read by a ribosome to build a protein from amino acids

Regulation of Gene Expression

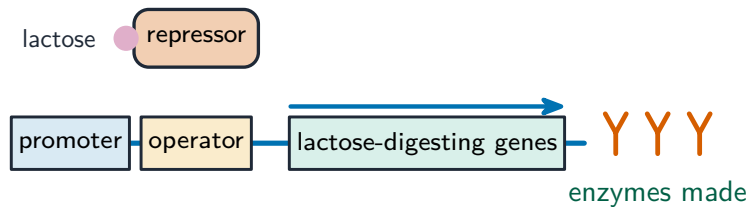
Cells control **which** genes are expressed and **when**. In prokaryotes, **operons** 操纵子 switch groups of genes on or off. In eukaryotes, regulation happens at many levels – which genes are transcribed (transcription factors, promoters, enhancers), RNA

processing, and after translation. This lets a cell respond to its environment without changing its DNA.

no lactose



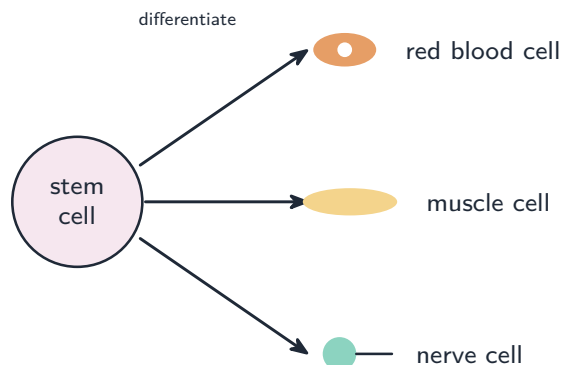
lactose present



The lac operon switches genes on only when lactose is present

Gene Expression and Cell Specialization

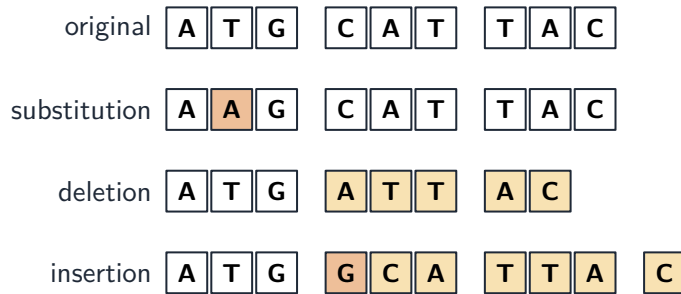
Every cell in a body has the **same** DNA, yet cells differ because they express **different** genes – **differential gene expression** 差异表达. This is how one fertilized egg produces many specialized cell types (muscle, nerve, skin); signals during development turn specific genes on and off.



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.



red = changed base; shaded = shifted by a frameshift (deletion or insertion)

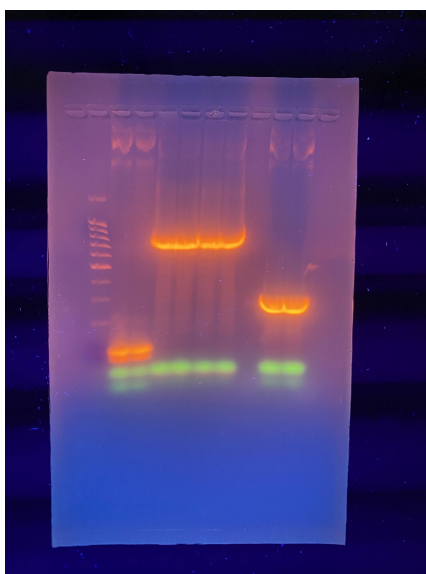
Substitution, deletion, and insertion mutations

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

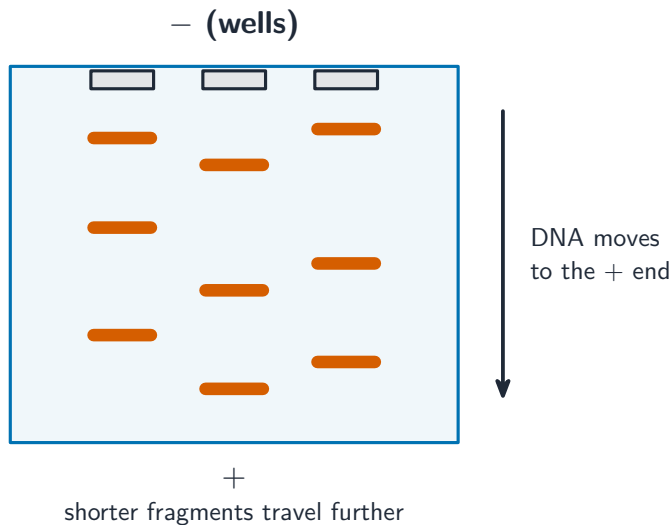


A thermal cycler repeatedly heats and cools samples to amplify DNA (PCR)

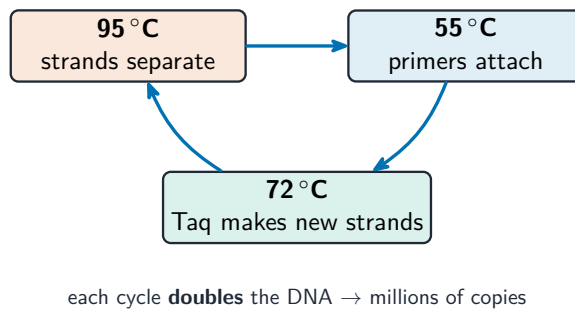


Agarose gel under UV light: DNA fragments separate by size as bright bands

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.