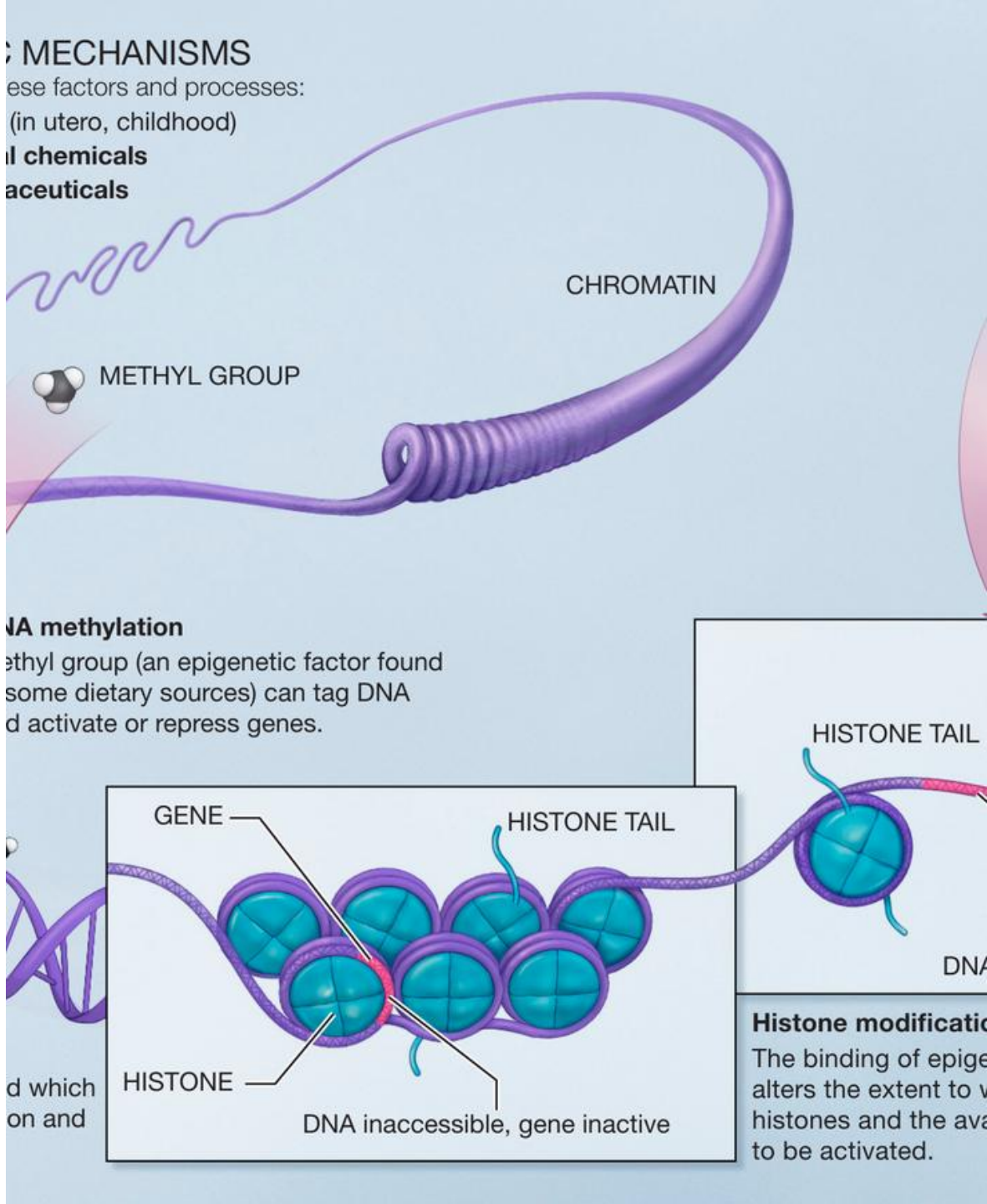
DP Biology – D2.2 (HL only)

Gene expression and epigenetics

- How can a cell change which genes it expresses?
- How are patterns of gene expression passed on?

HL statements D2.2.1–11. Textbook pp. 670–680.
Image: epigenetic mechanisms. National Institutes of Health, public domain.

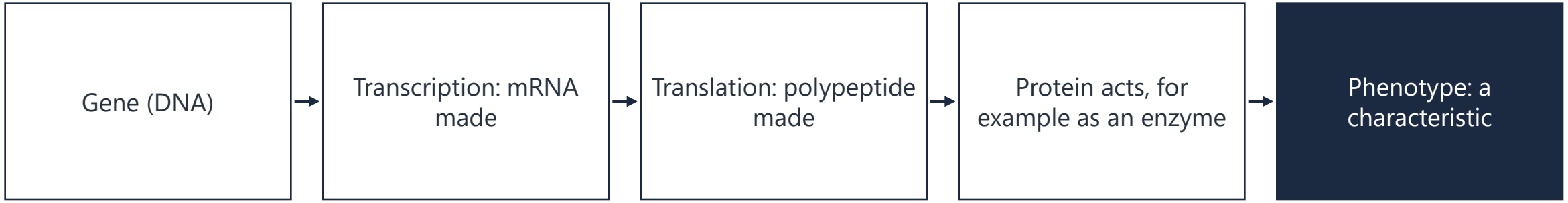


Objectives for each class

Class	Statements	By the end of the class, you can...
1	D2.2.1–3	Explain how genes affect the phenotype, and how transcription factors and mRNA breakdown control expression
2	D2.2.4–5	Explain epigenesis and compare genome, transcriptome and proteome
3	D2.2.6	Explain how methylation of DNA and histones acts as an epigenetic tag
4	D2.2.7–8	Explain epigenetic inheritance and give examples of the environment affecting gene expression
5	D2.2.9–10	Explain why most epigenetic tags are removed from gametes, using ligers and tigons, and evaluate twin studies
6	D2.2.11	Explain how a hormone and a nutrient in bacteria change patterns of gene expression

From gene to phenotype

D2.2.1



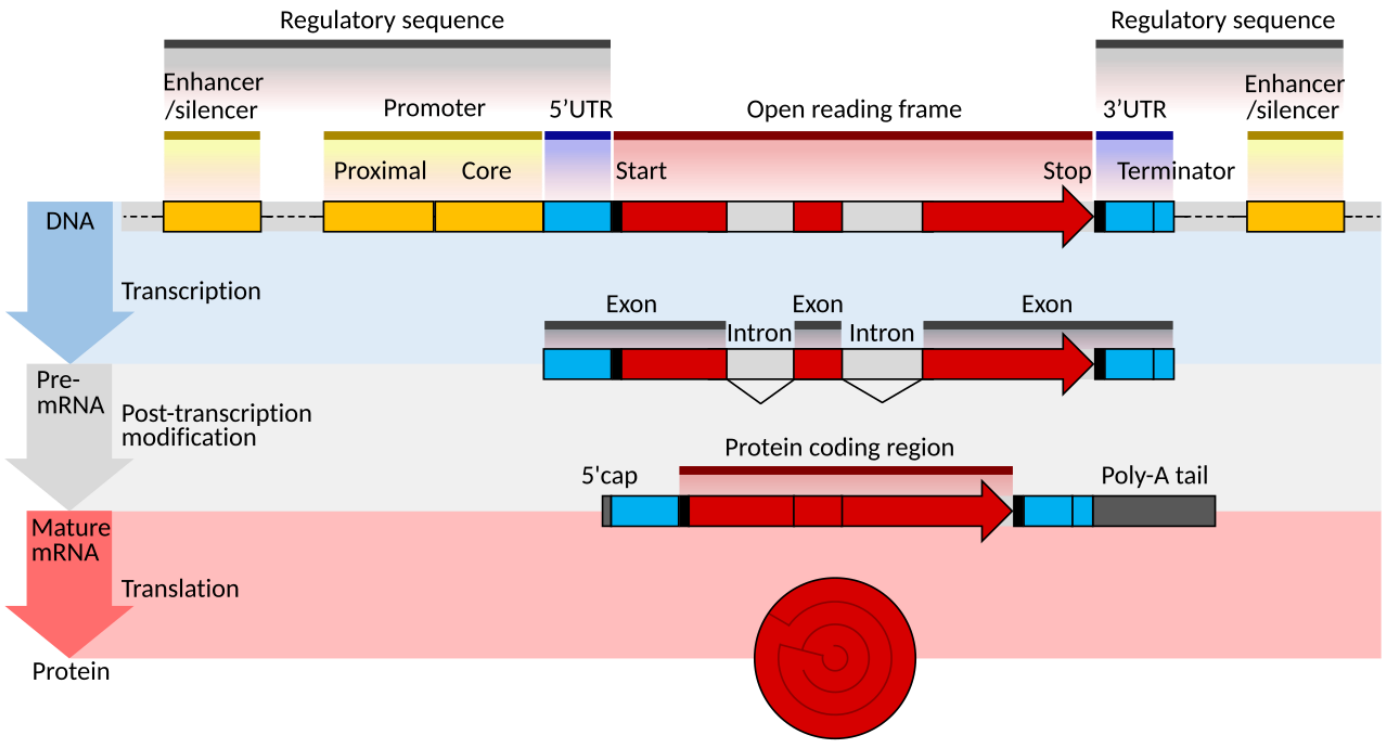
Example

The gene for the enzyme tyrosinase is transcribed and translated in skin cells. The enzyme catalyses the first step in making the pigment melanin. A non-functional allele gives albinism. Each stage, from DNA to enzyme activity, is a point where expression can be controlled.

Key idea

Gene expression is the process by which the information in a gene has an effect on the phenotype. Most genes are expressed only in some cells, at some times.

Controlling transcription



A eukaryotic gene with its regulatory sequences. Thomas Shafee, CC BY 4.0.

- **Promoter**: where RNA polymerase and general transcription factors bind, just before the gene
- **Enhancers**: sequences, sometimes thousands of bases away, that bind activator proteins and raise the rate
- **Silencers** bind repressors and lower it
- **Transcription factors** are proteins that bind specific base sequences

How distance works

DNA can loop, so an activator bound to a distant enhancer contacts the proteins at the promoter. Different cells contain different transcription factors, so they transcribe different genes.

Controlling mRNA breakdown

- After transcription, mRNA gains a 5′ cap and a poly-A tail at the 3′ end
- The tail is slowly shortened in the cytoplasm; when short enough, nucleases break the mRNA down
- In human cells mRNA lasts from minutes to days
- The longer an mRNA lasts, the more protein is made from it

Why break it down?

If mRNA lasted for ever, a cell could never stop making a protein. Short-lived mRNAs suit proteins needed briefly, such as signals; long-lived ones suit proteins needed in large amounts, such as haemoglobin in developing red blood cells.

Epigenesis: building a body

D2.2.4

- **Epigenesis**: as a many-celled organism develops, its cells come to differ from one another
- Starting from one zygote, cells become different by switching genes on and off
- The DNA base sequence does not change, so the **genotype** is the same in all cells
- What changes is gene expression, and so the **phenotype** of each cell

Common mistake

Epigenetic changes are not mutations. A mutation changes the base sequence; an epigenetic change alters which genes are read.

Genome, transcriptome, proteome

D2.2.5

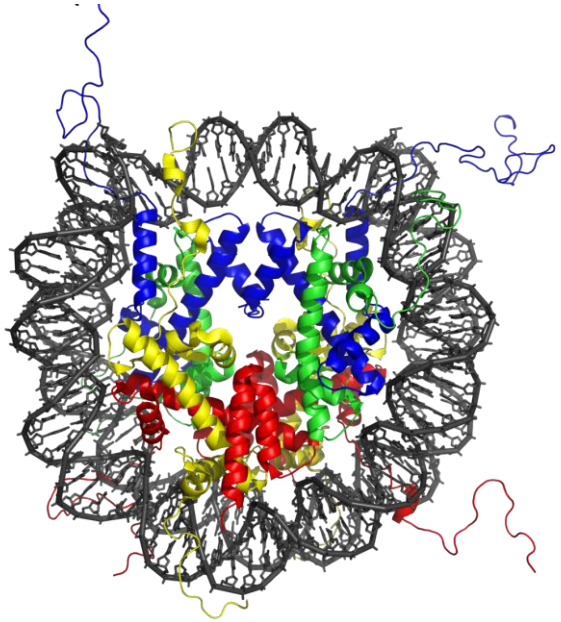
	What it is	Varies?
Genome	All the genetic information of an organism	The same in every cell of an individual
Transcriptome	All the mRNA made in a cell at a given time	Differs between cell types and changes with time and conditions
Proteome	All the proteins made in a cell at a given time	Differs between cells; depends on the transcriptome

Key idea

No cell expresses all of its genes. The pattern of genes expressed decides how the cell differentiates.

Epigenetic tags: methylation

D2.2.6



Nucleosome. Zephyris, CC BY-SA 3.0.

	DNA methylation	Histone methylation
Where	Cytosine in the promoter	Amino acids in histone tails
Effect	Represses transcription of the gene downstream	Can repress or activate transcription
How	Blocks transcription factors; DNA packs tightly	Changes how tightly DNA is packed and which proteins bind

Other tags

Acetylation of histones loosens packing and usually activates genes. Tags are added and removed by enzymes, so they can change during life. You do not need the details of how each tag works.

Passing on gene expression

D2.2.7

- When a cell divides by mitosis, methylation patterns are copied to the new DNA
- So daughter cells keep the same pattern: a liver cell gives rise to liver cells
- If tags survive meiosis and fertilization, a parent's changed expression can pass to offspring
- This is **epigenetic inheritance**: phenotype changes inherited without any change in base sequence

Dutch Hunger Winter

People whose mothers were pregnant during the famine of 1944–45 showed differences in methylation of some genes six decades later, and higher rates of some diseases. Discuss how strong this evidence is.

The environment changes gene expression



Agouti mice. R. Jirtle and D. Dolinoy, CC BY 3.0.

- **Air pollution**: particulate matter, ozone and nitrogen oxides are linked to changes in DNA methylation, for example in genes for immune responses, with links to asthma
- **Diet**: in agouti mice, a mother's diet rich in methyl donors increases methylation of the agouti gene, giving brown, lean offspring
- **Stress, smoking, temperature** can also change tags

Evaluate

Many studies show correlation between exposure and methylation, not cause. Suggest what further evidence would show that a pollutant causes a change in methylation, and that the change causes disease.

Resetting tags in eggs and sperm

- Most tags are removed in the cells that become eggs and sperm, and again in the early embryo
- This resets the genome, so the zygote can develop into every cell type
- But some tags survive: in **imprinted** genes, the copy from one parent is silenced
- So whether an allele is expressed can depend on which parent it came from



A liger. Dinkun Chen, CC BY-SA 4.0.

Ligers and tigons

Liger: lion father, tiger mother; far larger than either. Tigon: tiger father, lion mother; similar size or smaller.

Why ligers are so big

D2.2.9

	Lion	Tiger
Mating	Females mate with several males	Females usually mate with one male
Imprinting in father	Growth-promoting genes active	Little growth promotion
Imprinting in mother	Growth-limiting genes active, to balance the father's	Little growth limitation needed

Put together

A liger gets growth-promoting tags from its lion father, but no matching growth-limiting tags from its tiger mother, so it grows very large. A tigon gets neither strong signal. The genes involved are not yet known: this is a hypothesis that fits the evidence.

Monozygotic twin studies

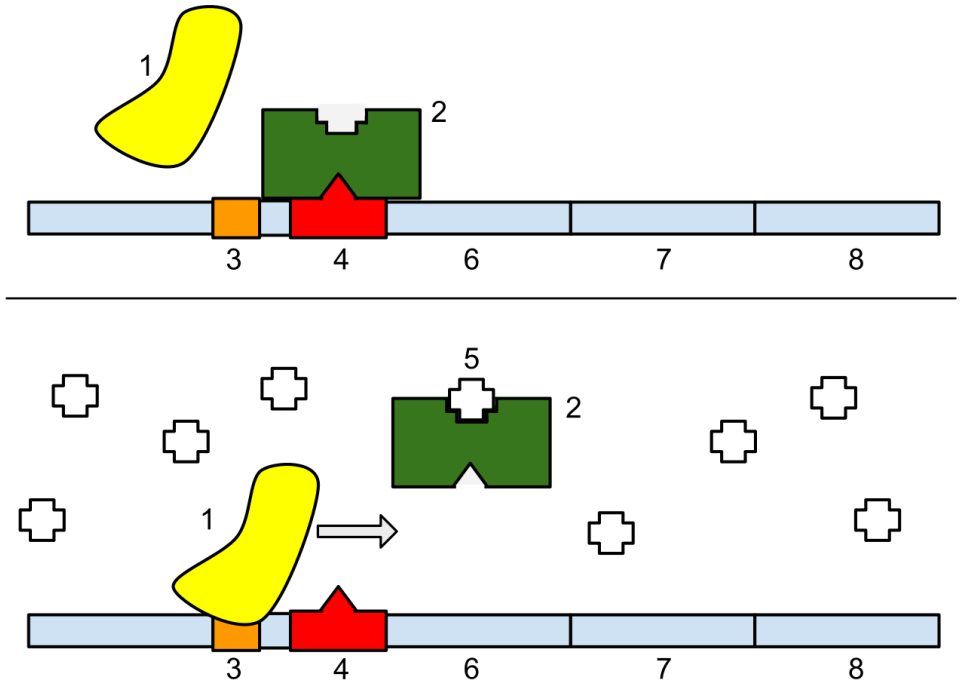
- Monozygotic (identical) twins come from one zygote, so they have the same genome
- Differences between them must come from the environment, including epigenetic changes
- Young twins have very similar methylation patterns; older twins differ more
- The more different their lifestyles, the more their patterns differ

Evaluate

Twins share a womb and often a home, so their environments overlap. Twins raised apart help separate the effects. Small samples and self-reported lifestyles are limitations.

Signals that switch genes

D2.2.11



Lac operon: lactose (white) removes the repressor (green). CC BY-SA 3.0.

Signal	Effect
Lactose in E. coli	Binds the repressor, which leaves the DNA, so genes for lactose uptake and breakdown are transcribed
Oestradiol (a hormone)	Enters target cells, binds a receptor, and the complex acts as a transcription factor, for example switching on the progesterone receptor gene

Why it makes sense

E. coli makes lactose-digesting enzymes only when lactose is present, saving energy and amino acids. A hormone lets one signal change gene expression in many target cells at once.

Check that you can explain

1. How genes affect the phenotype
2. How promoters, enhancers and transcription factors control transcription
3. How mRNA breakdown controls translation
4. Epigenesis, and genome versus transcriptome versus proteome
5. How DNA and histone methylation act as tags
6. Epigenetic inheritance and environmental effects
7. Why tags are reset in gametes, and ligers versus tigons
8. What twin studies show, and how lactose and hormones switch genes

Exit activity: 5 minutes

On your own and without notes. Hand this in as you leave.

1. Distinguish between the genome and the proteome of a cell.
2. Explain how methylation of a promoter affects a gene.
3. Suggest why a liger grows larger than a tigon.

Image credits

Epigenetic mechanisms.png – National Institutes of Health – Public domain
Gene structure eukaryote 2 annotated.svg – Thomas Shafee – CC BY 4.0
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Liger – Shenzhen Safari Park 2023-02-03 01.jpg – Dinkun Chen – CC BY-SA 4.0
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