DP Biology – C2.1 (HL only)

Chemical signalling

- How can cells tell apart the many signals reaching them?
- What happens inside animal cells when a chemical signal arrives?

HL statements C2.1.1–14. Textbook pp. 450–466.
Image: Hawaiian bobtail squid, home of glowing Vibrio fischeri bacteria. Nick Hobgood, CC BY-SA 3.0.



Objectives for each class

Class	Statements	By the end of the class, you can...
1	C2.1.1–3	Explain what receptors and ligands are, describe quorum sensing, and compare four kinds of signalling chemical
2	C2.1.4–6	Explain the chemical variety of signals, local and distant effects, and the two kinds of receptor
3	C2.1.7–9	Explain signal transduction, the acetylcholine receptor and G protein-coupled receptors
4	C2.1.10–11	Explain how adrenaline and insulin signal through their receptors
5	C2.1.12–14	Explain intracellular receptors, the effects of oestradiol and progesterone, and feedback in signalling

Receptors and ligands

C2.1.1

- A **ligand** is a signalling chemical
- A **receptor** is a protein with a binding site that fits one ligand
- Binding changes the receptor's shape, which starts a response
- Only cells with the right receptor respond, so the same signal can reach many cells but act on few

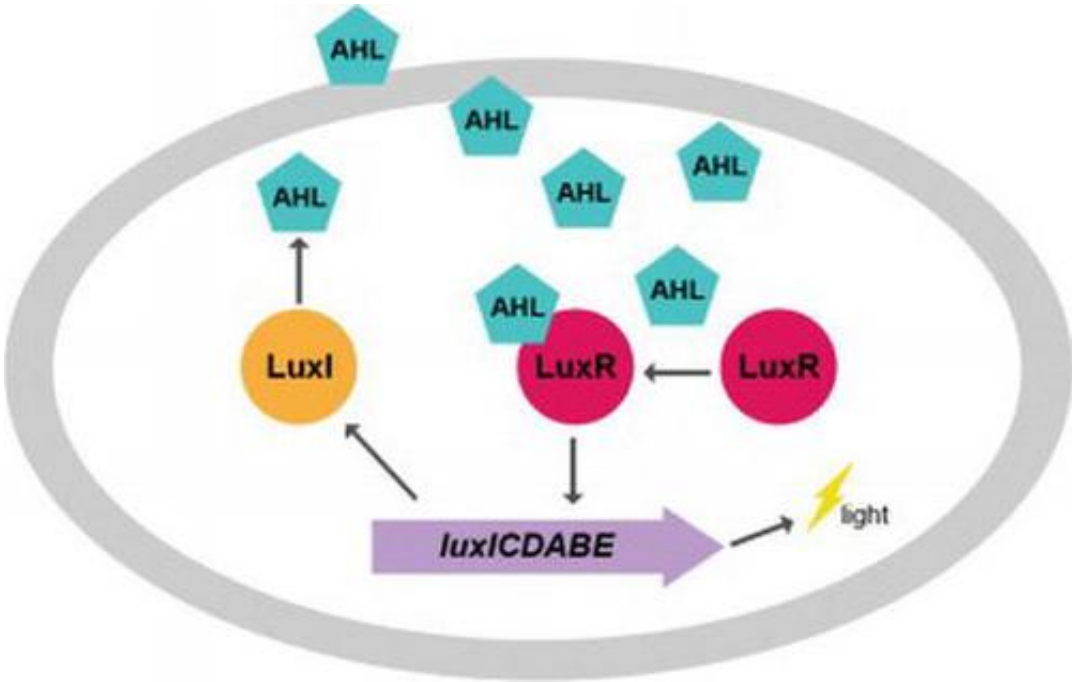
	Compared with an enzyme
Same	Specific binding site; shape change
Different	The ligand is not changed by the receptor

Key idea

Specificity of receptors is how cells tell apart the many signals around them.

Quorum sensing in bacteria

C2.1.2



Quorum sensing in Vibrio fischeri. Wang, Payne and Bentley, CC BY 3.0.

- Each bacterium releases a signal (an **autoinducer**) into its surroundings
- When there are few cells, the signal stays dilute
- When the population is dense, the signal passes a threshold and binds receptors
- This switches on genes in all the cells at once

Vibrio fischeri

In the light organ of the bobtail squid, these bacteria reach high densities and switch on the genes for luciferase, producing light. Light is only worth making when there are enough cells to glow brightly. The squid uses the glow as camouflage against moonlight.

Four kinds of signalling chemical

C2.1.3

Category	Made by and travels	Example
Hormone	Endocrine glands; carried in the blood to distant targets	Insulin, adrenaline, oestradiol
Neurotransmitter	Neurons; crosses a synapse of about 20 nm	Acetylcholine, dopamine
Cytokine	Many cells, often immune cells; acts on nearby cells	Interleukins, interferons
Calcium ions	Released inside cells from stores	Triggers muscle contraction and neurotransmitter release

Activity

Sort the examples into the four categories, then say how far each signal travels.

A huge variety of signals

C2.1.4

Hormones	Examples
Amines	Adrenaline, thyroxine
Proteins and peptides	Insulin, glucagon, ADH
Steroids	Oestradiol, progesterone, testosterone

Neurotransmitters	Examples
Amino acids	Glutamate, GABA
Peptides	Endorphins
Amines	Dopamine, serotonin
Gas	Nitric oxide

Why so many?

Each signal must be recognized by its own receptor, so many different shapes are needed. Different chemistry also suits different jobs: small, lipid-soluble steroids enter cells; proteins stay outside; a gas like nitric oxide diffuses quickly but only acts nearby.

Near and far

C2.1.5

	Neurotransmitters	Hormones
Distance	Across a synapse	Around the body in blood
Speed	Milliseconds	Seconds to hours
Duration	Removed quickly, so effects are brief	Can last hours
Targets	One cell or a few	Every cell with the right receptor

Example

Luteinizing hormone travels from the pituitary to the ovaries or testes; acetylcholine crosses a 20 nm gap to a muscle fibre.

Receptors outside and inside

C2.1.6

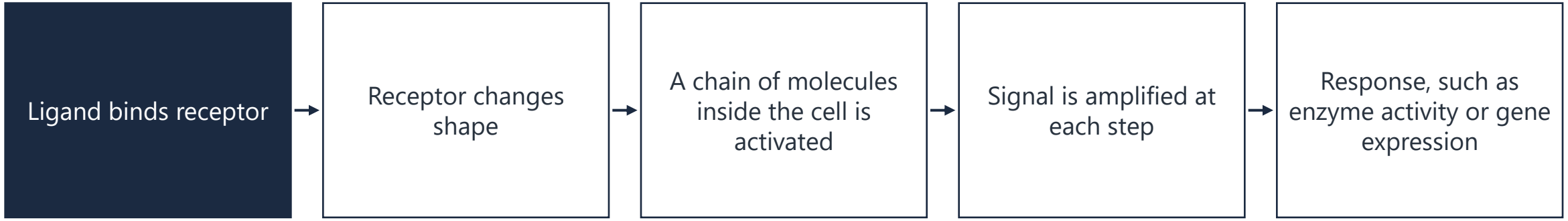
	Transmembrane receptor	Intracellular receptor
Where	In the plasma membrane	In the cytoplasm or nucleus
Ligand	Hydrophilic; cannot cross the membrane	Hydrophobic; diffuses through the membrane
Amino acids	Hydrophobic where it crosses the membrane; hydrophilic outside	Mostly hydrophilic, so it is dissolved in the cytoplasm
Examples	Insulin, adrenaline, acetylcholine receptors	Steroid hormone receptors

Link

This links to where hydrophobic and hydrophilic amino acids sit in proteins (B1.2).

Signal transduction

C2.1.7

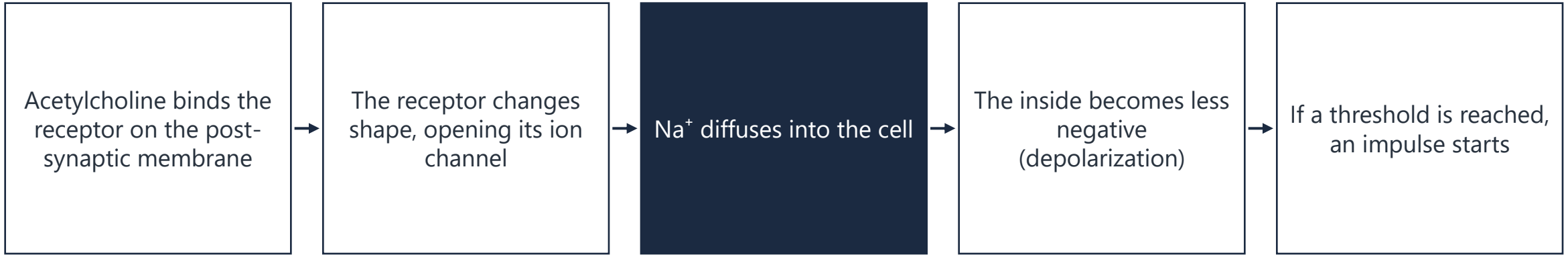


Key idea

A signal transduction pathway is the sequence of events inside the cell after a ligand binds. The ligand usually does not enter the cell: the message is passed on by changes in shape and by second messengers. Because each activated molecule activates many others, one ligand can cause a large response.

The acetylcholine receptor

C2.1.8



The receptor is the channel

In this receptor, the binding site and the ion channel are parts of the same protein, so the response is very fast. Acetylcholinesterase then breaks acetylcholine down, closing the channel. Nicotine also binds this receptor, which is why it is called the nicotinic acetylcholine receptor.

G protein-coupled receptors

C2.1.9

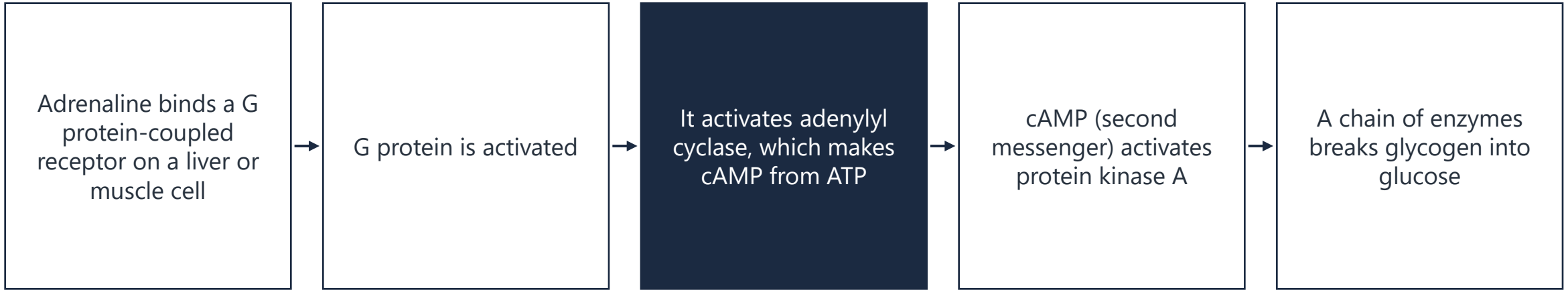


Many receptors, one system

Humans have about 800 G protein-coupled receptors, for hormones, neurotransmitters, smells and tastes, and light in the eye. Each has seven helices that cross the membrane. About a third of all medicines act on these receptors.

How adrenaline works

C2.1.10

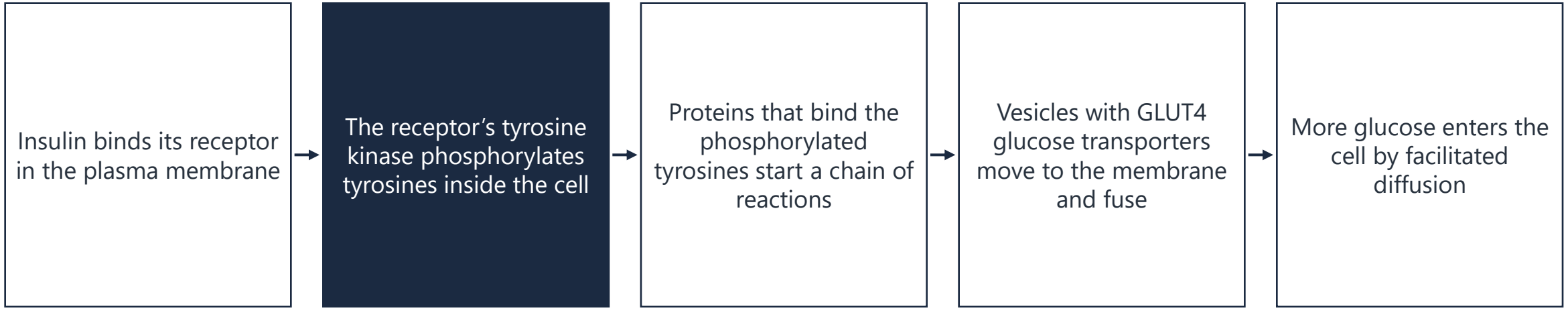


Amplification

One adrenaline molecule activates many G proteins, each enzyme makes many cAMP molecules, and so on. A few molecules of hormone can release millions of glucose molecules within seconds, ready for fight or flight. Adrenaline also raises heart rate and breathing rate.

Insulin and tyrosine kinase receptors

C2.1.11

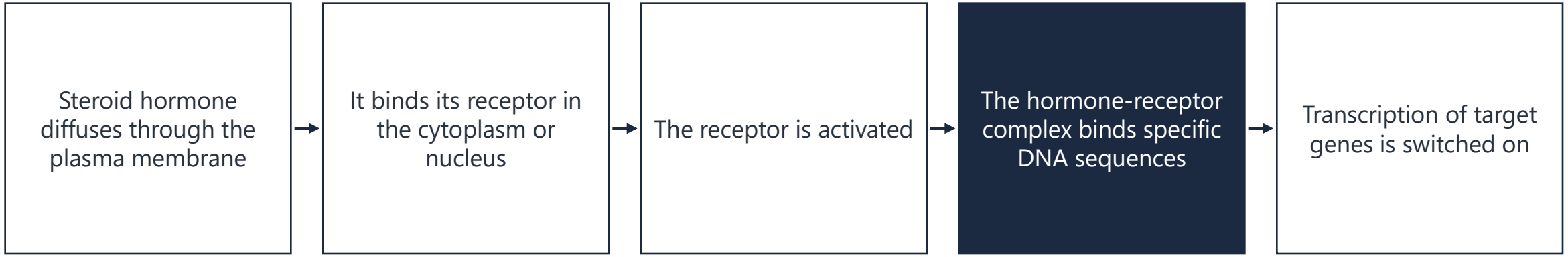


Compare

Adrenaline uses a G protein and cAMP; insulin's receptor is itself an enzyme (a kinase) that adds phosphate to tyrosine. Both start inside the cell without the hormone entering. Muscle and fat cells respond to insulin by taking up glucose, lowering blood glucose.

Steroid hormones and gene expression

C2.1.12



Examples

Oestradiol, progesterone and testosterone all work this way. The response is slower than for a transmembrane receptor, because new proteins must be made, but it can last longer. The activated receptor acts as a transcription factor.

Oestradiol and progesterone

C2.1.13

	Oestradiol	Progesterone
Target cells	Cells in the hypothalamus that secrete GnRH	Cells of the endometrium (uterus lining)
Effect	Changes GnRH secretion, which controls FSH and LH release from the pituitary	Keeps the endometrium thick and supplied with blood, ready for an embryo
How	Binds an intracellular receptor; changes gene expression	Binds an intracellular receptor; changes gene expression

Link

These effects are part of the control of the menstrual cycle (D3.1).

Positive and negative feedback

C2.1.14

	Negative feedback	Positive feedback
Effect	The response reduces the signal	The response increases the signal
Result	Keeps a variable stable	Drives a rapid, one-way change
Example	Insulin lowers blood glucose, so less insulin is secreted	In quorum sensing, the autoinducer switches on its own production; or oxytocin in childbirth

Think about it

Why must positive feedback loops always have an end point? What would happen to a cell if a negative feedback loop failed?

Check that you can explain

1. Ligands, receptors and quorum sensing
2. Four categories of signalling chemical, and their chemical variety
3. Local and distant signals, transmembrane and intracellular receptors
4. Signal transduction, the acetylcholine receptor and G proteins
5. How adrenaline and insulin act on their target cells
6. How steroid hormones change gene expression, with oestradiol and progesterone
7. Positive and negative feedback in signalling

Exit activity: 5 minutes

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

1. Distinguish between a transmembrane receptor and an intracellular receptor.
2. Outline the role of cAMP in the action of adrenaline.
3. Give one example each of positive and negative feedback in signalling.

Image credits

Euprymna scolopes (Bobtail squid).jpg – Nhobgood Nick Hobgood – CC BY-SA 3.0

Quorum sensing in Vibrio fischeri.png – Sally Wang, Gregory F. Payne and William E. Bentley – CC BY 3.0

All from Wikimedia Commons (commons.wikimedia.org, search the file name). Some images are cropped. CC licences: creativecommons.org/licenses