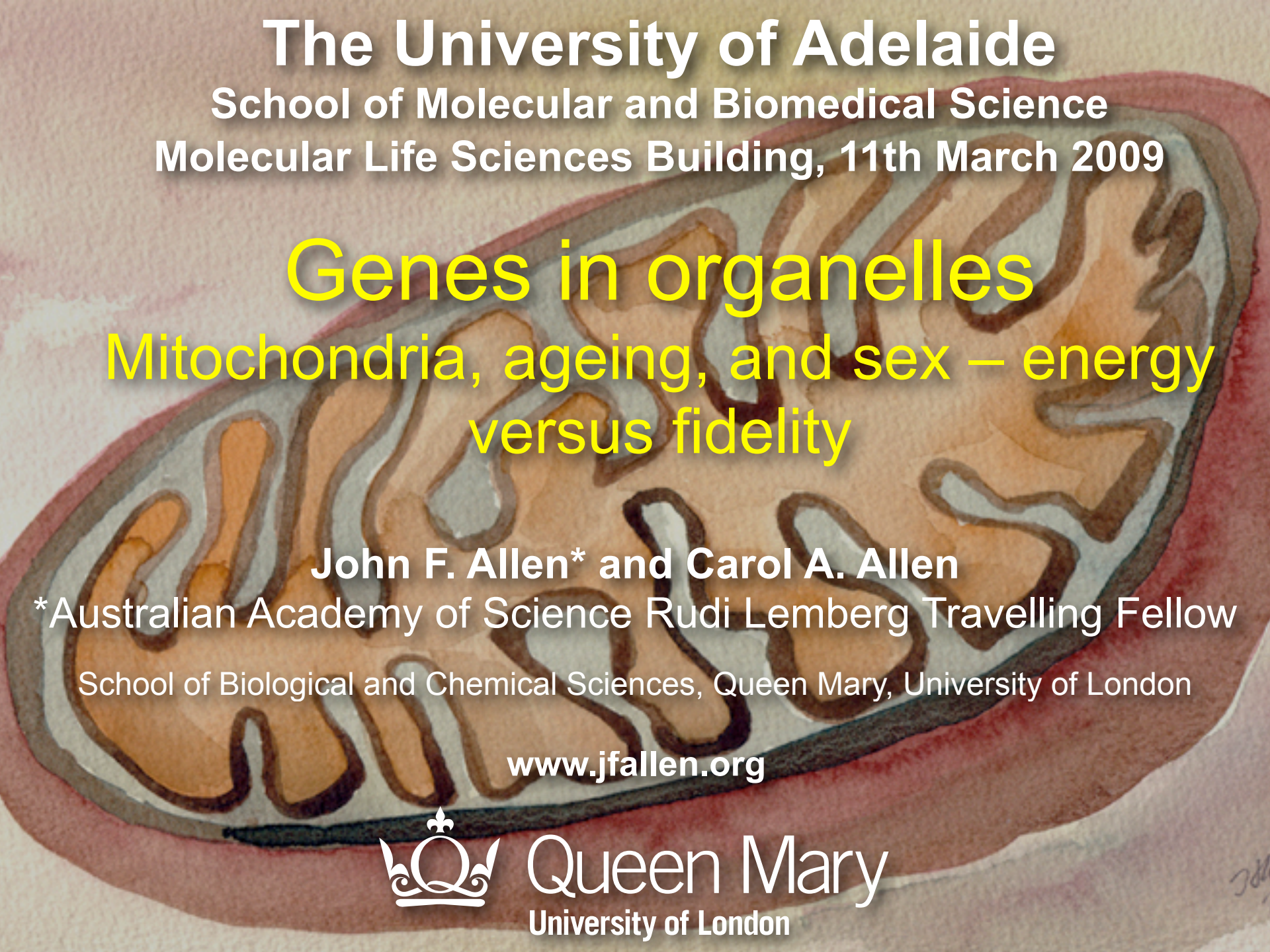

The University of Adelaide

School of Molecular and Biomedical Science

Molecular Life Sciences Building, 11th March 2009

Genes in organelles

Mitochondria, ageing, and sex – energy versus fidelity

John F. Allen* and Carol A. Allen

*Australian Academy of Science Rudi Lemberg Travelling Fellow

School of Biological and Chemical Sciences, Queen Mary, University of London

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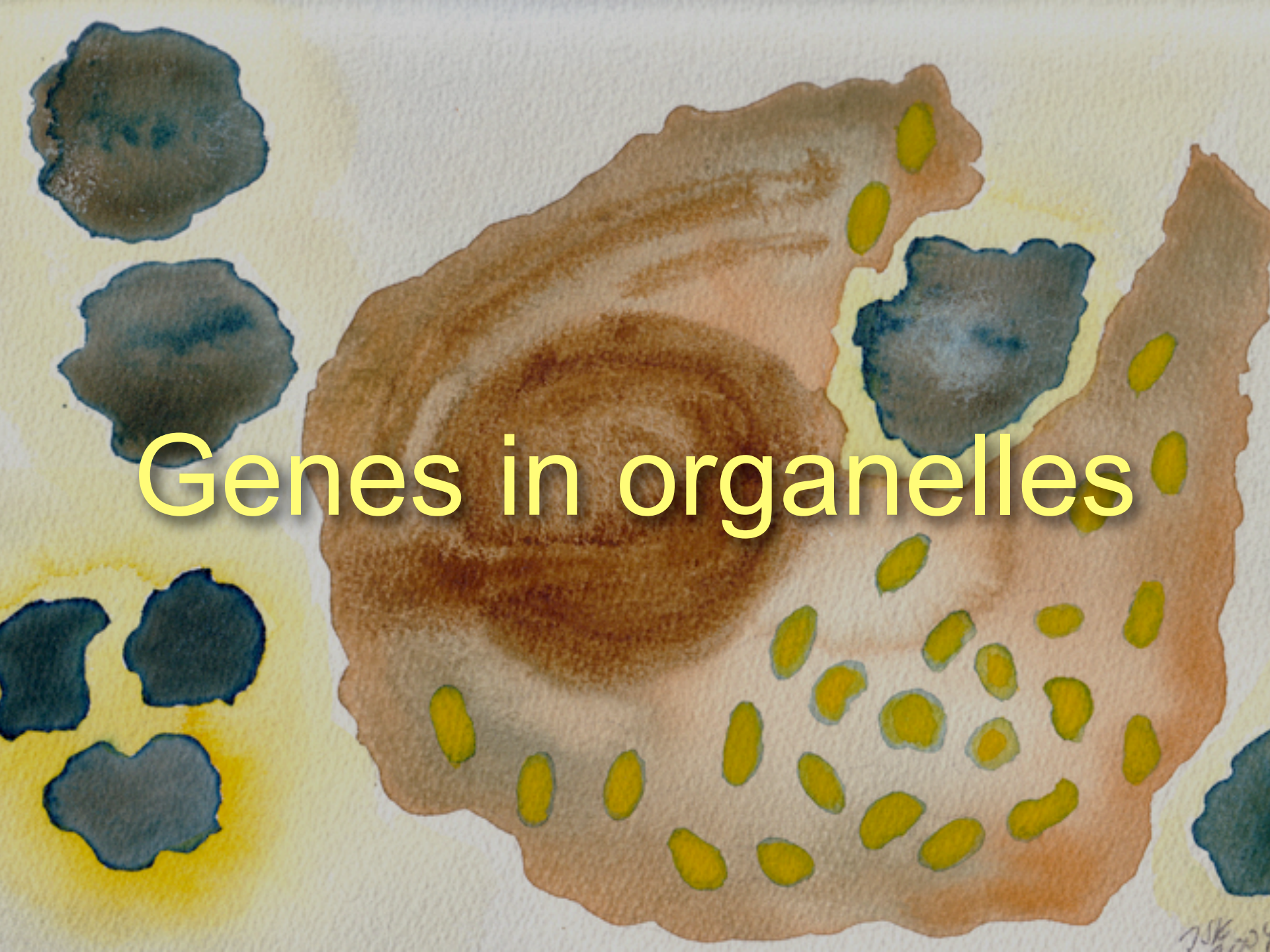
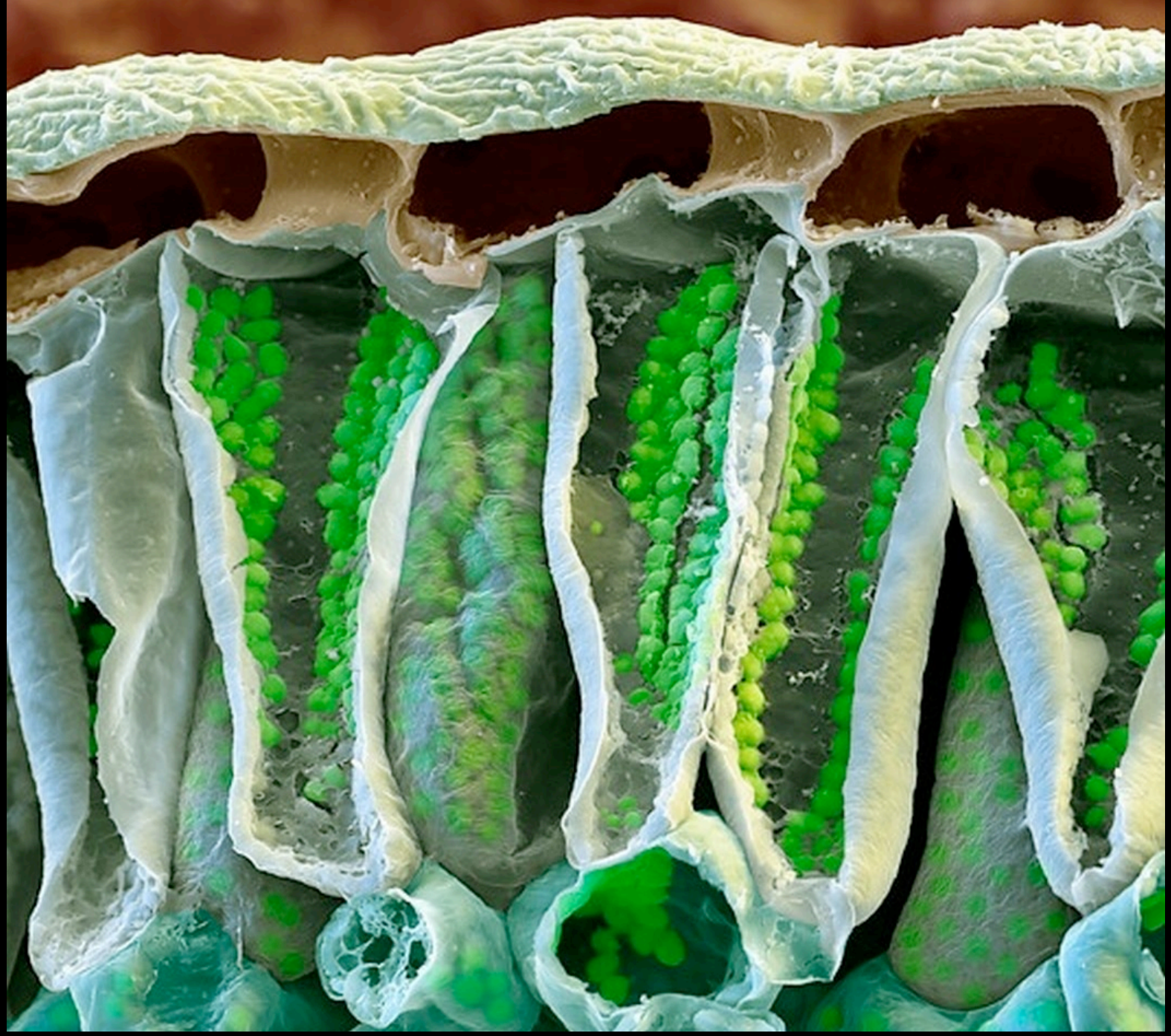
Queen Mary
University of London

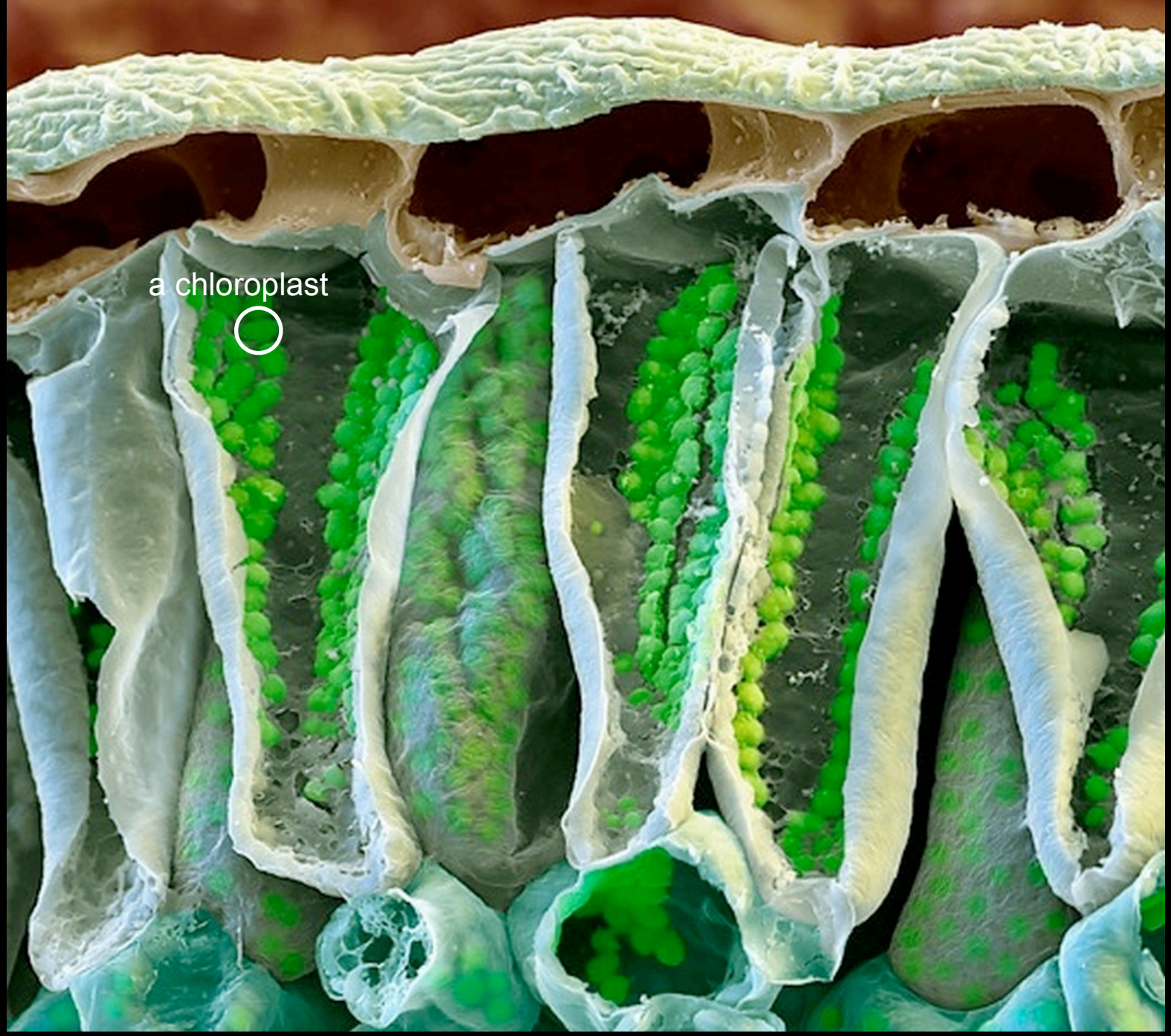
Max Rudolph Lemberg

1896-1975


Genes in organelles



‘Christmas-Rose’ leaf SEM cross-section; Science Photo Library (SPL)



‘Christmas-Rose’ leaf SEM cross-section; Science Photo Library (SPL)

A mitochondrion—one of many tiny power-houses within cells that control our lives in surprising ways

Mitochondria (singular; mitochondrion).

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– mitochondria power animal and plant cells

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Why?

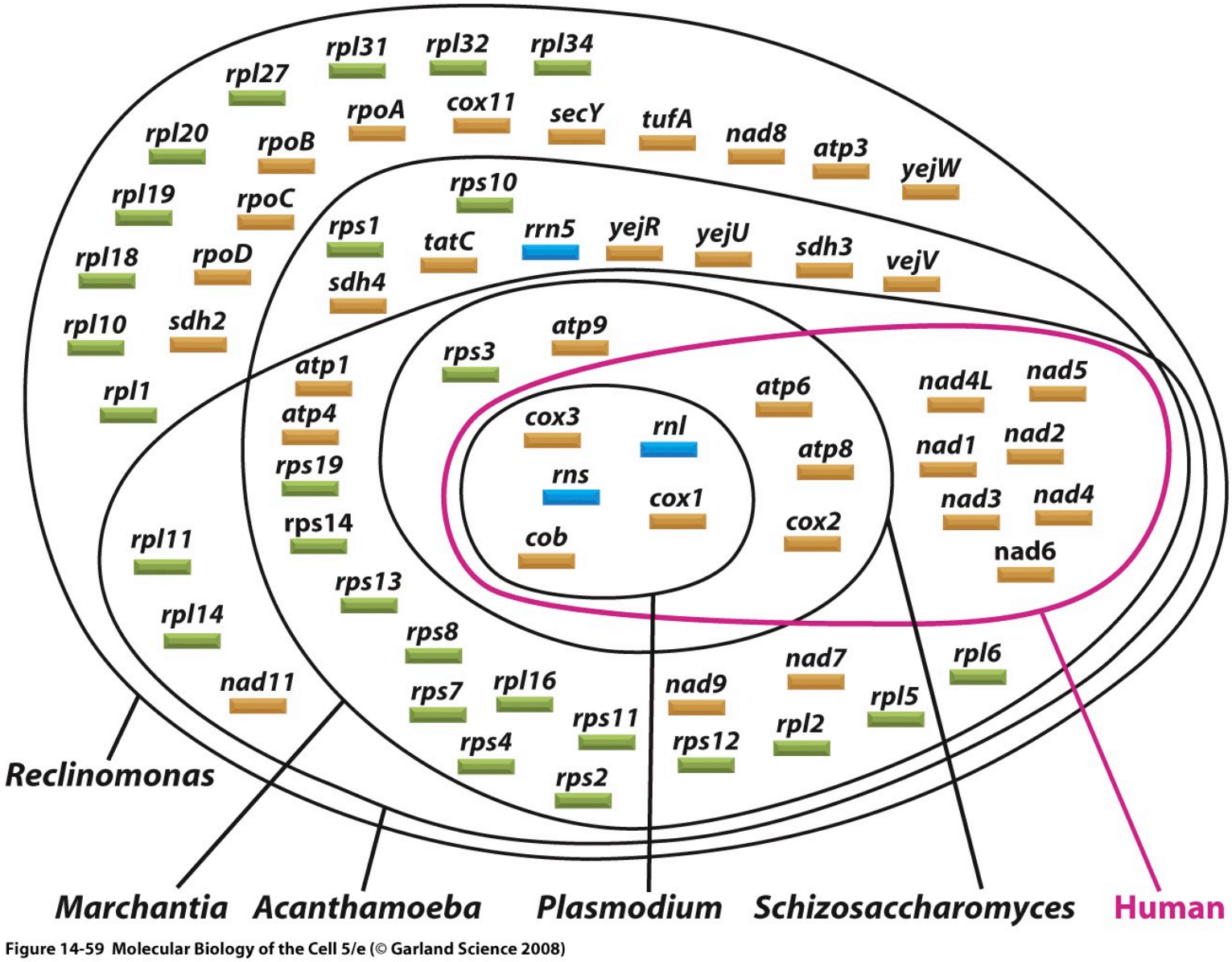
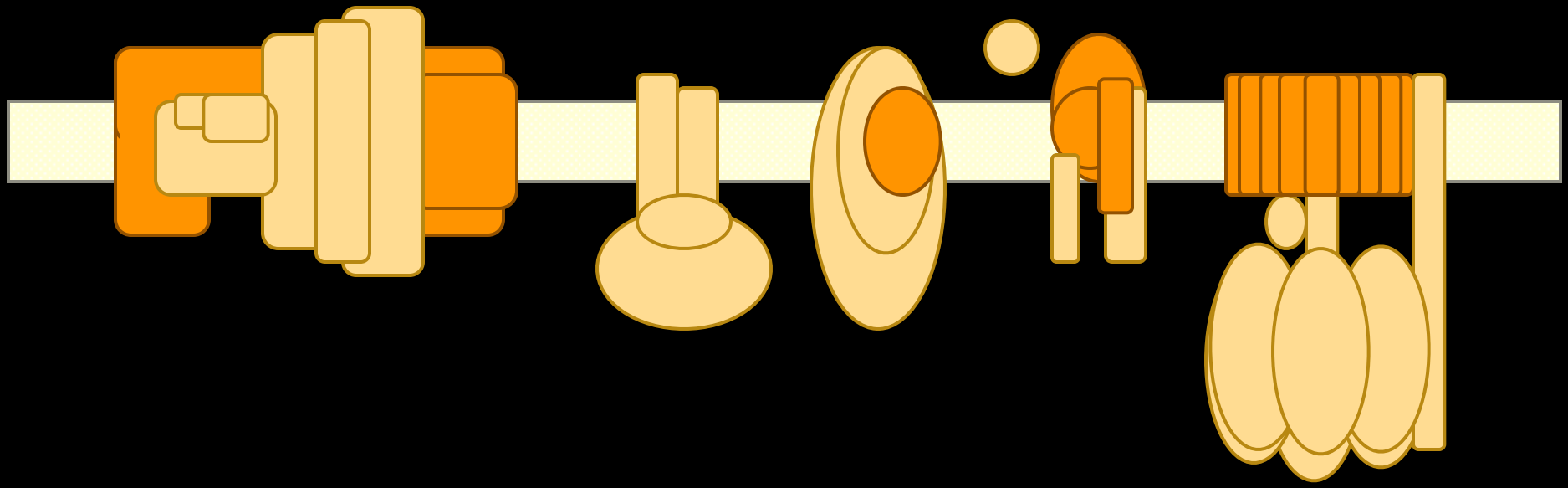
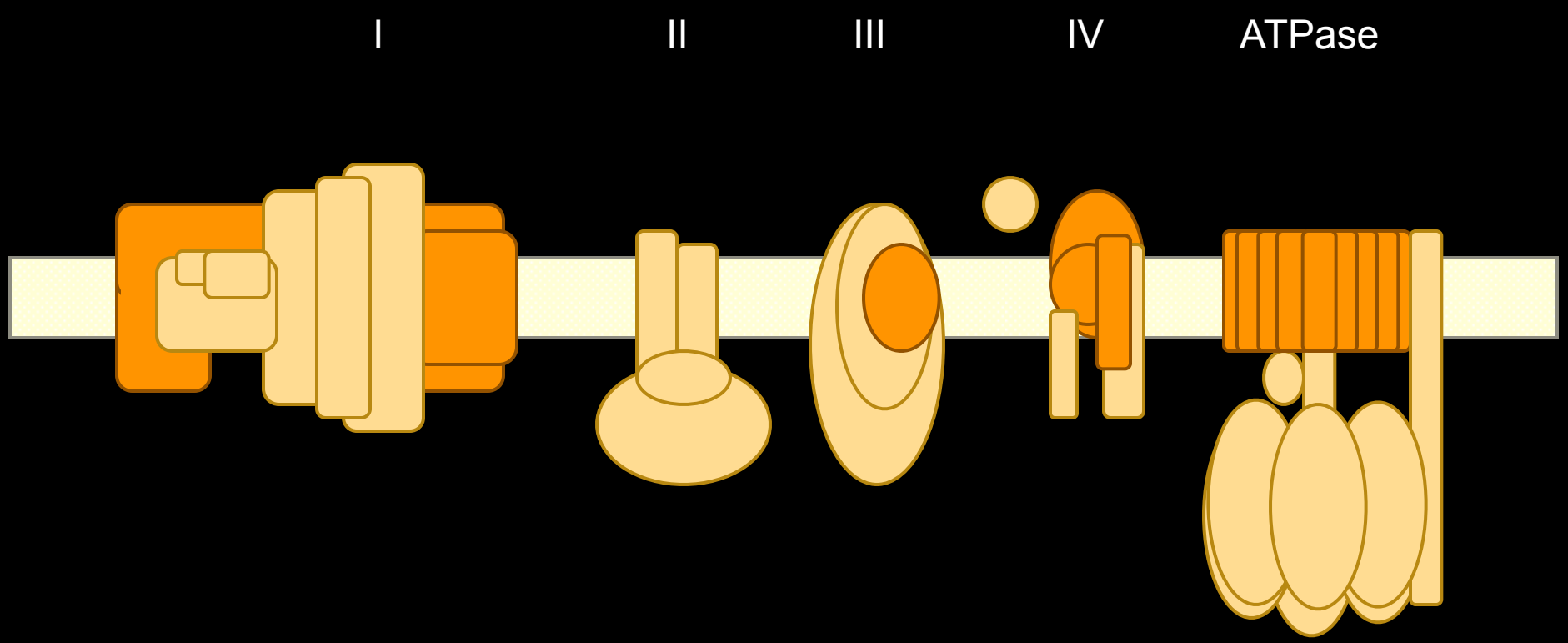


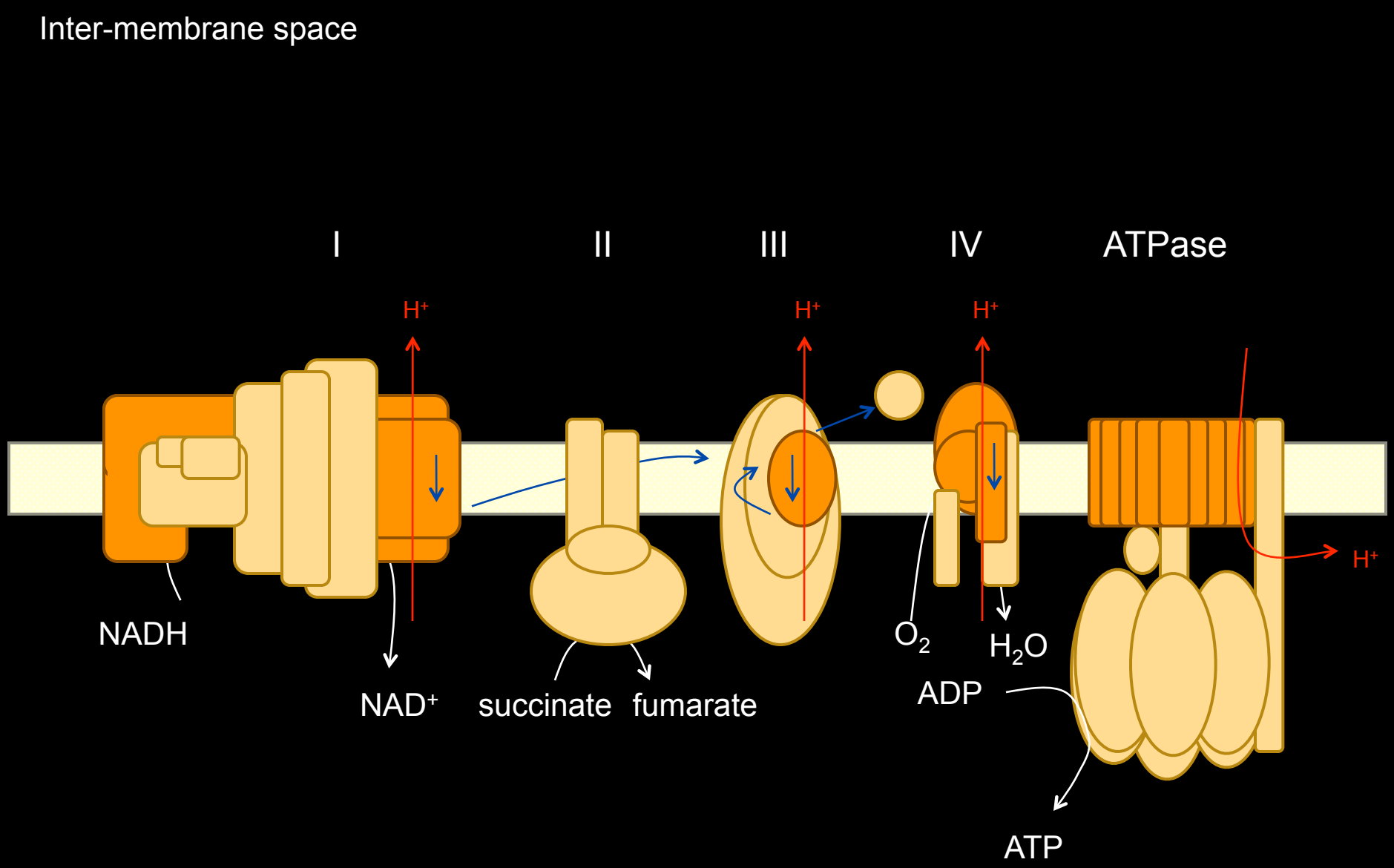
Figure 14-59 Molecular Biology of the Cell 5/e (© Garland Science 2008)

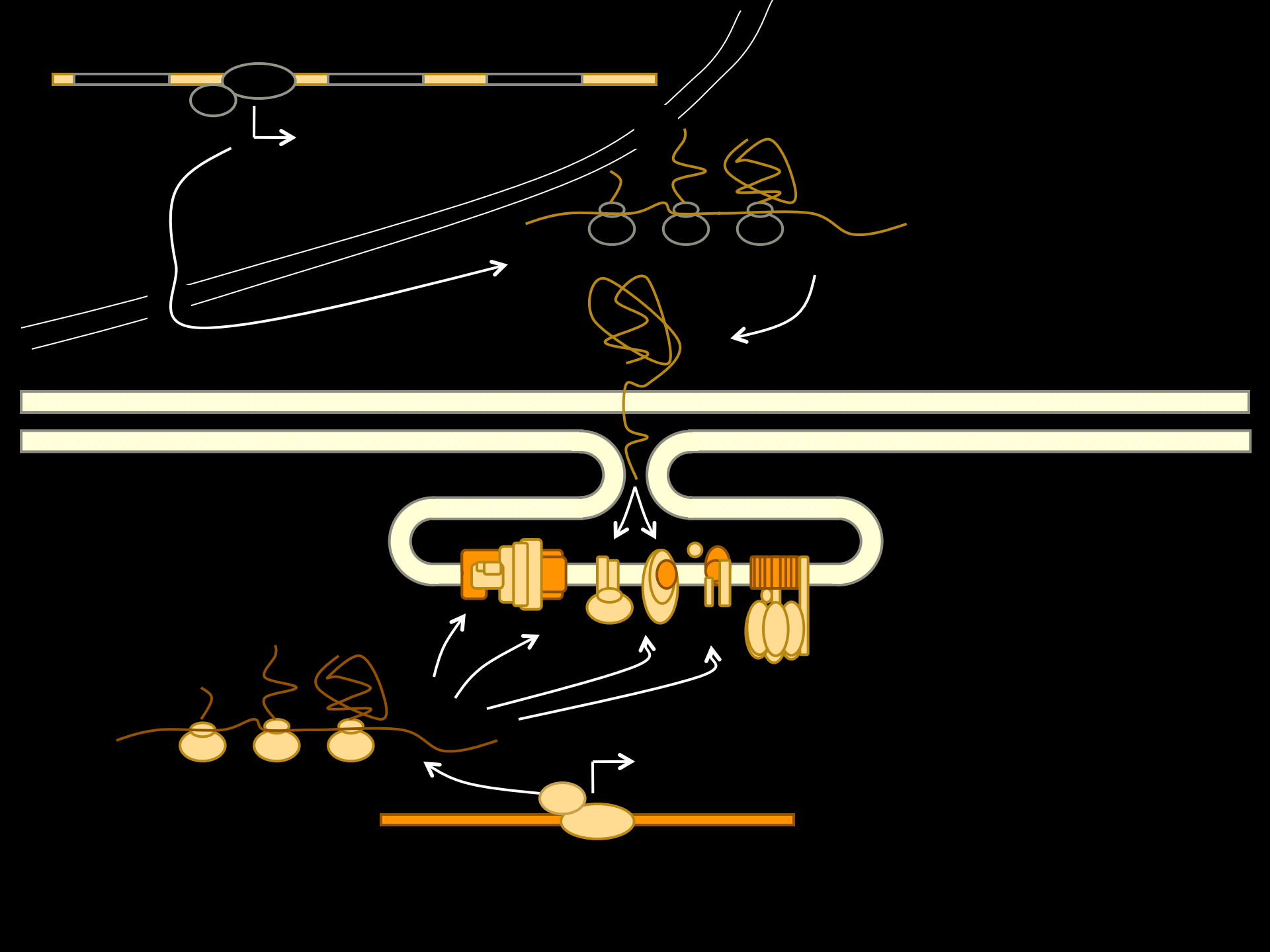
Comparison of mitochondrial genomes

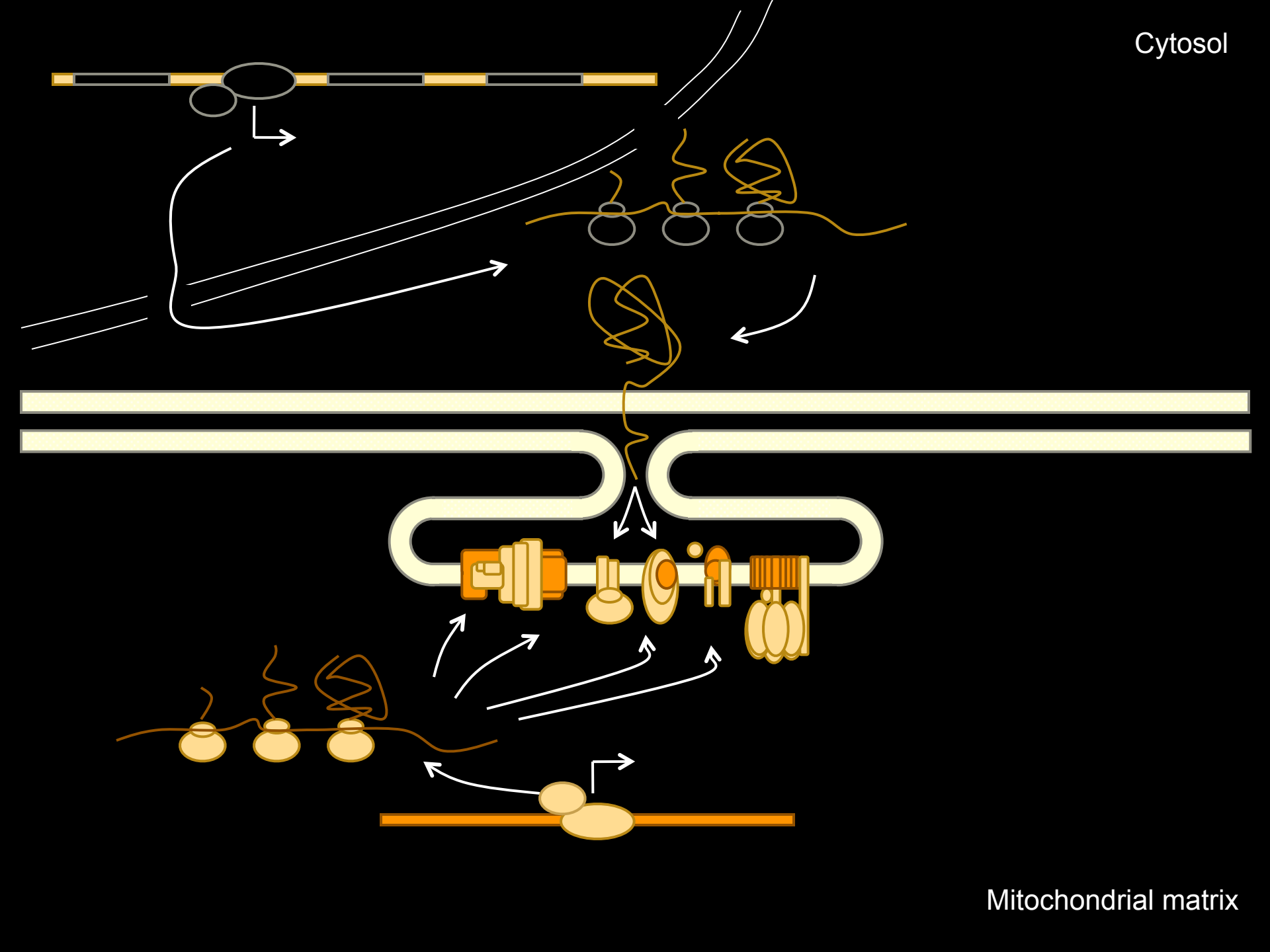
Less complex mitochondrial genomes encode subsets of the proteins and ribosomal RNAs that are encoded by larger mitochondrial genomes. There are only four genes present in all known mitochondrial genomes; these encode ribosomal RNAs *(rns* and *rnl),* cytochrome *b (cob),* and a cytochrome oxidase subunit *(cox1).* Adapted from M.W. Gray et al., *Science* 283:1476-1481, 1999. With permission from AAAS.




Inter-membrane space
I
II
III
IV
ATPase
Mitochondrial matrix


Inter-membrane space
I
II
III
IV
ATPase
H+
H+
H+
H+
NADH
NAD+
succinate
fumarate
O2
H2O
ADP
ATP
Mitochondrial matrix




Cytosol
Mitochondrial matrix

Why Do Mitochondria and Chloroplasts Have Their Own Genetic Systems?

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Mitochondrial DNA is a relic of ancient history. It is a legacy from a single aerobic bacterium that took up residence in the cytoplasm of a primitive cell that ultimately became an ancestor of all eukaryotic cells. Most of the genes of this ancient symbiont were either lost or transferred over the course of evolution to the nucleus of the host cell, leaving only a handful of genes to encode some of the most hydrophobic proteins of the inner mitochondrial membrane.

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Cell and Molecular Biology Concepts and Experiments
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Why do mitochondria and chloroplasts require their own separate genetic systems when other organelles that share the same cytoplasm, such as peroxisomes and lysosomes, do not? …. The reason for such a costly arrangement is not clear, and the hope that the nucleotide sequences of mitochondrial and chloroplast genomes would provide the answer has proved unfounded. We cannot think of compelling reasons why the proteins made in mitochondria and chloroplasts should be made there rather than in the cytosol.

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Molecular Biology of the Cell

Alberts B, Johnson A, Lewis J, Raff M, Roberts K, and Walter P Molecular Biology of the Cell. Fifth Edition. New York and London: Garland Science; 2007

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Hypothesis: The location of these genetic systems has a selective advantage, since energy conversion, in order to be both safe and efficient, requires a set of proteins whose genes reside with them, in the same compartment of the cell.

CoRR - **Co**-Location for **R**edox* **R**egulation.

CoRR applies equally to mitochondria and chloroplasts

*Redox reactions are chemical reaction in which an electron is transferred from one molecule to another - the basis of biological energy conversion.

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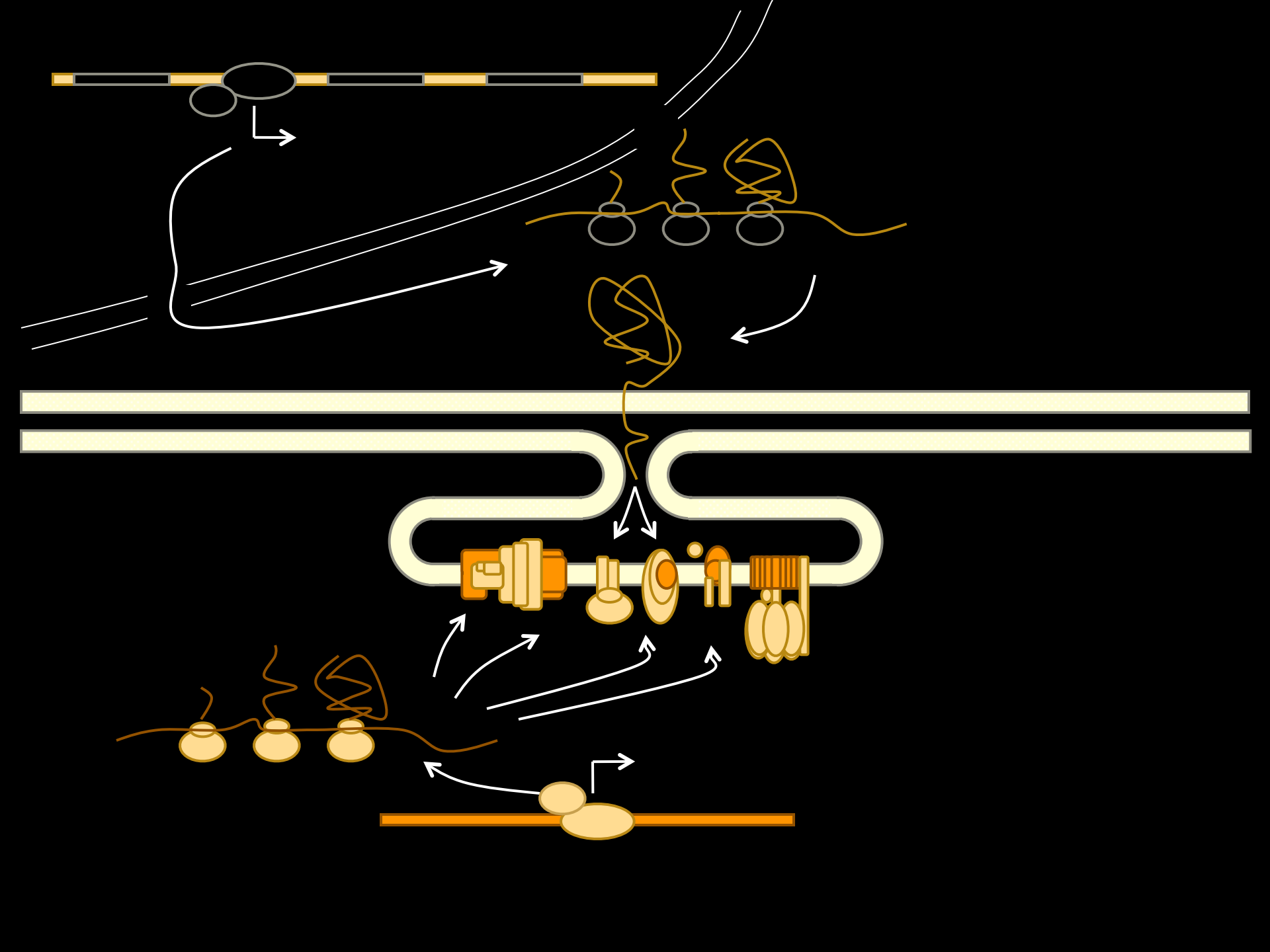
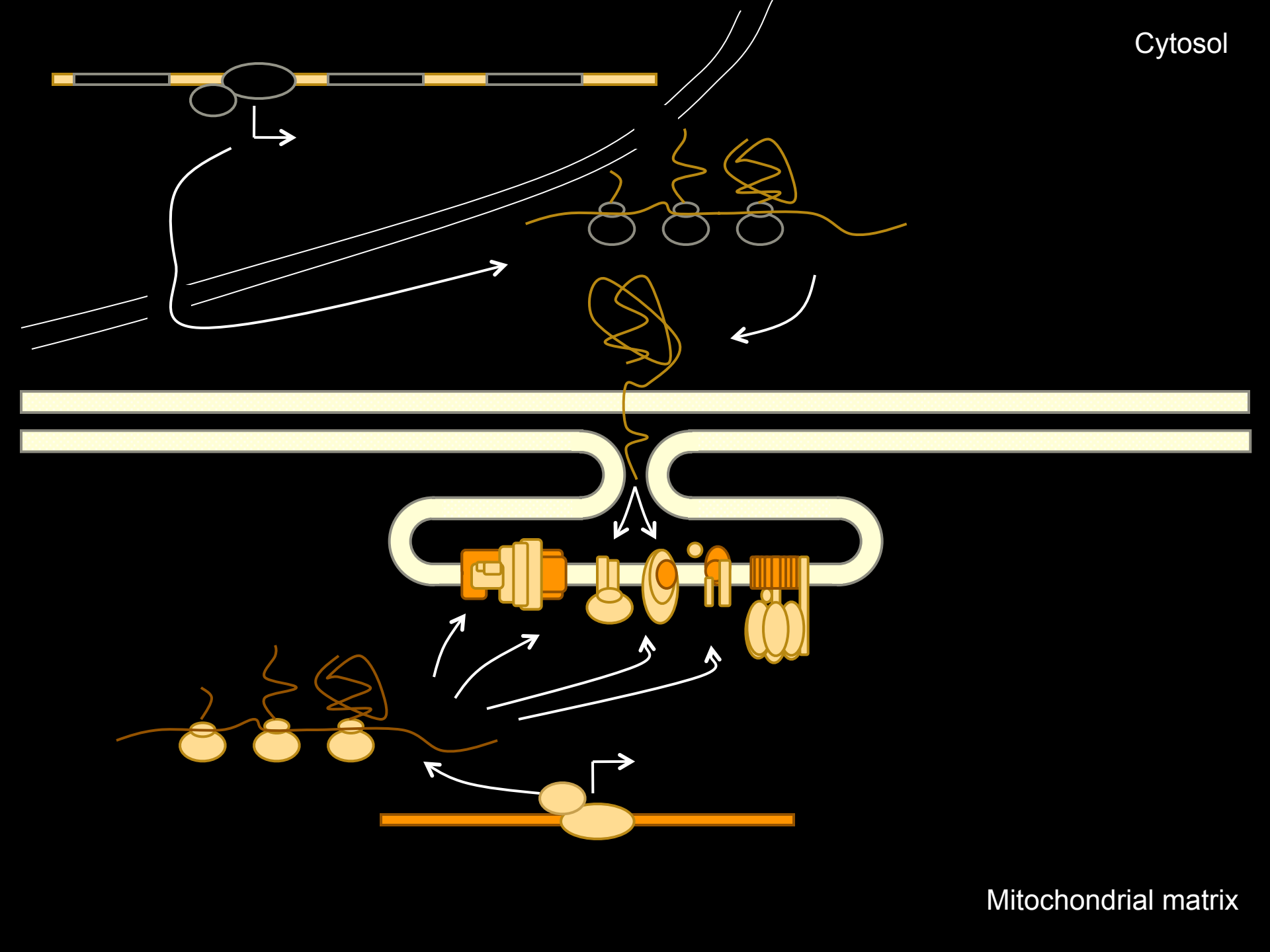
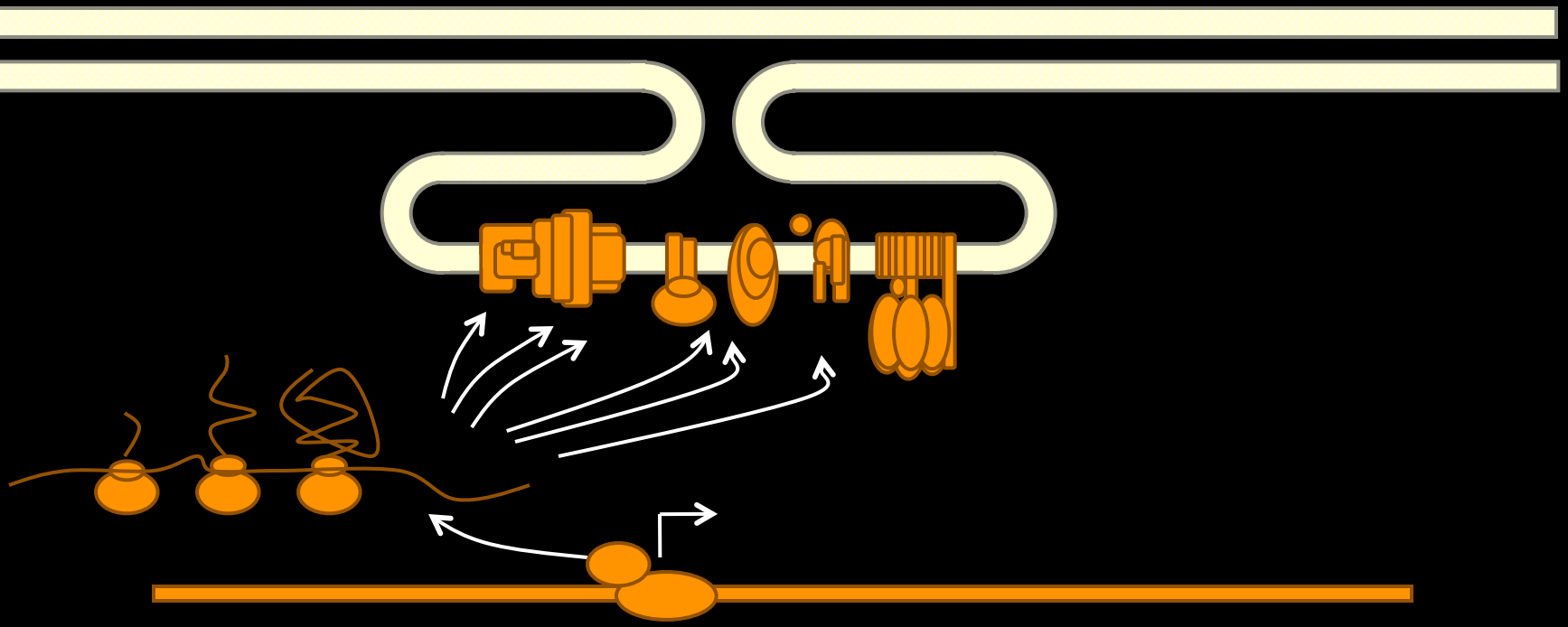
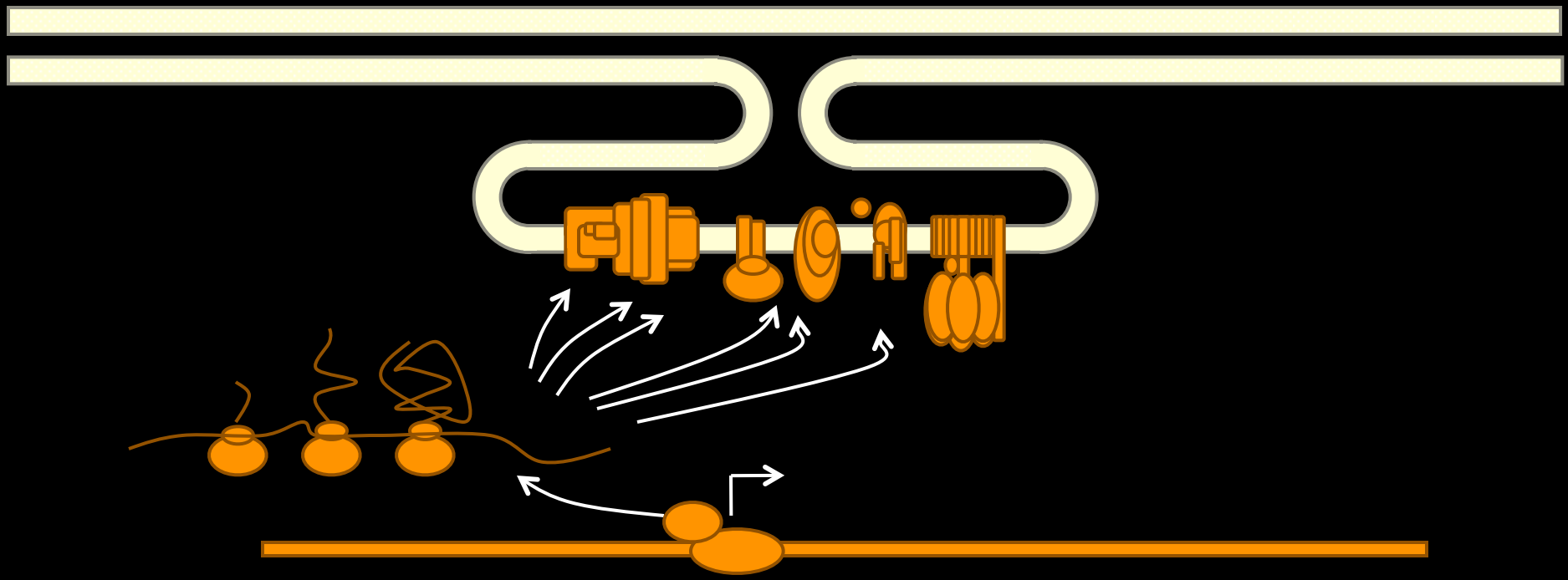
Allen JF (1993) Control of Gene Expression by Redox Potential and the Requirement for Chloroplast and Mitochondrial Genomes. Journal of Theoretical Biology **165**: 609-631

Allen JF (2003) The function of genomes in bioenergetic organelles. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* **358**: 19-37

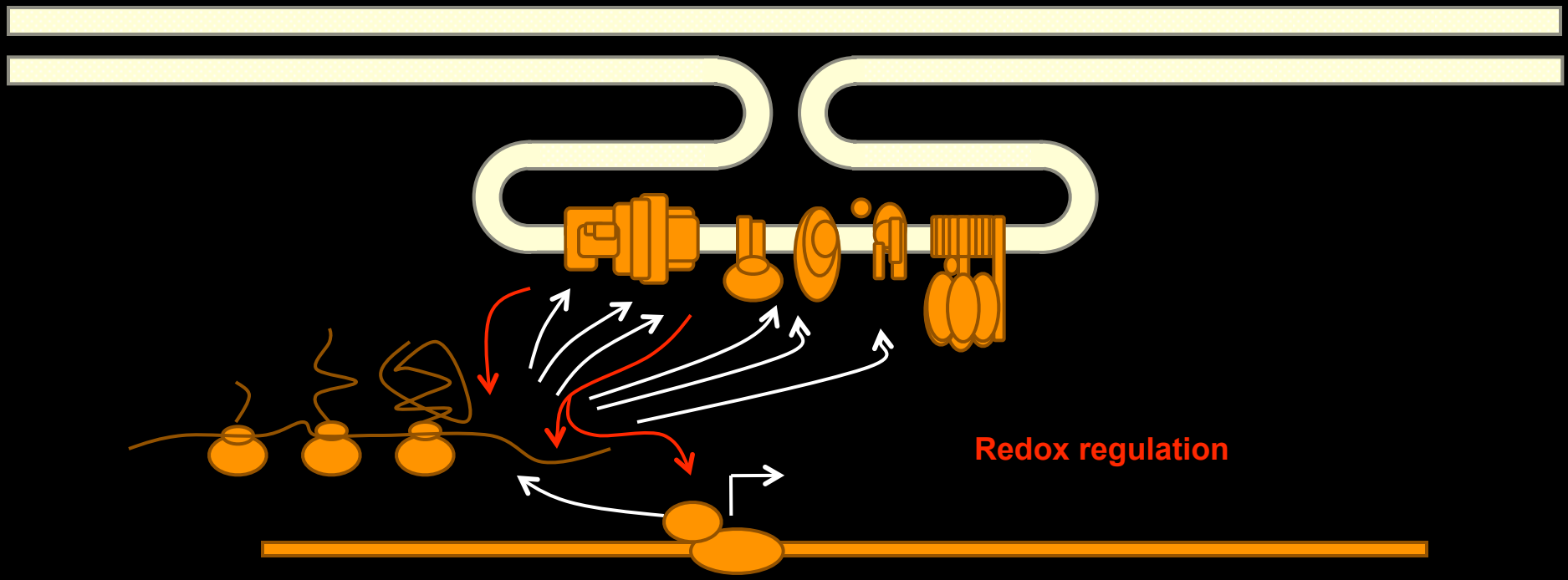



Cytosol
Mitochondrial matrix





Bacterium



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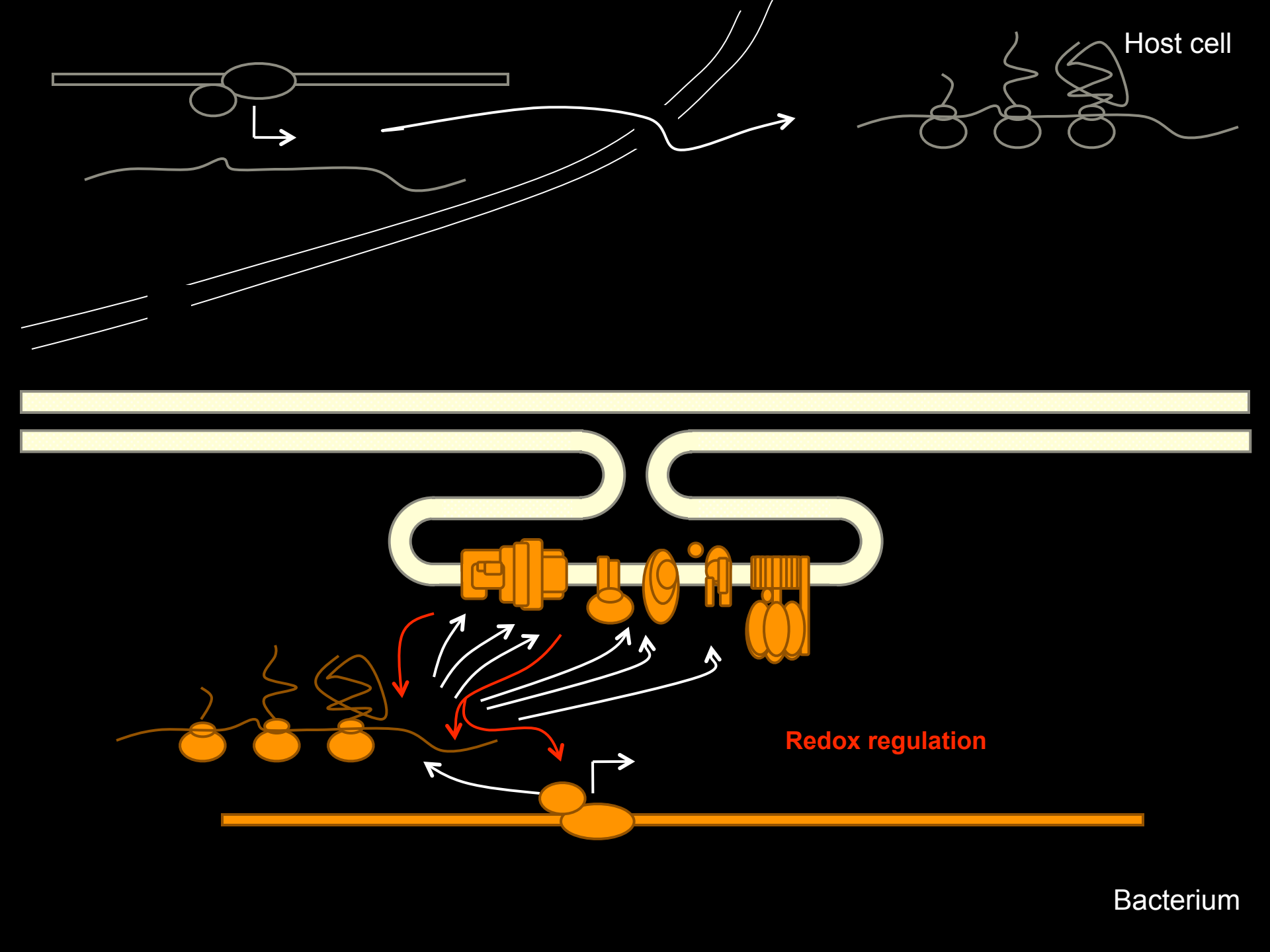
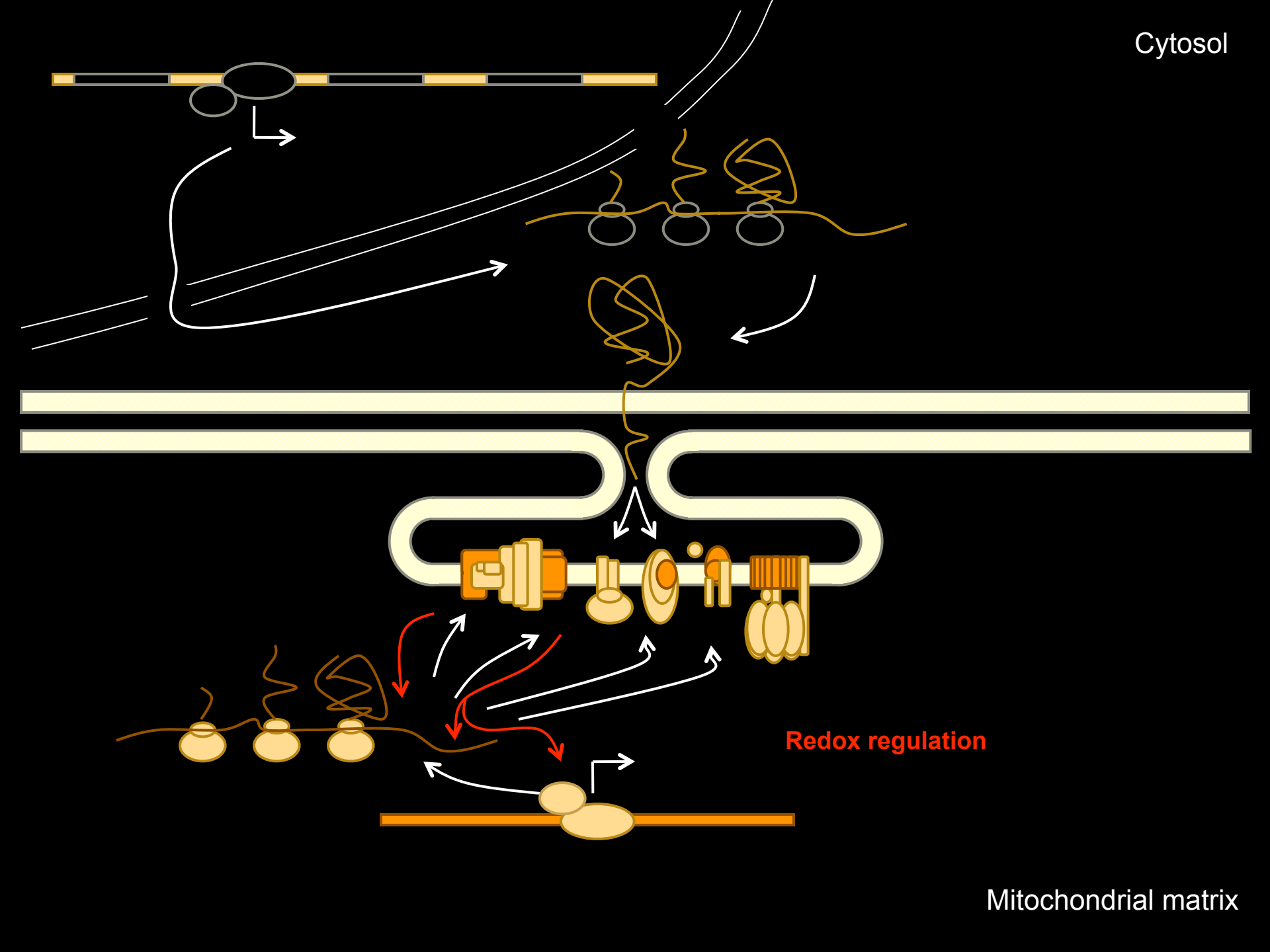

Host cell
Redox regulation
Bacterium


Cytosol
Redox regulation
Mitochondrial matrix

CoRR

Co-Location (of gene and gene product)
for **R**edox **R**egulation

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Predictions of the **CoRR** hypothesis include:

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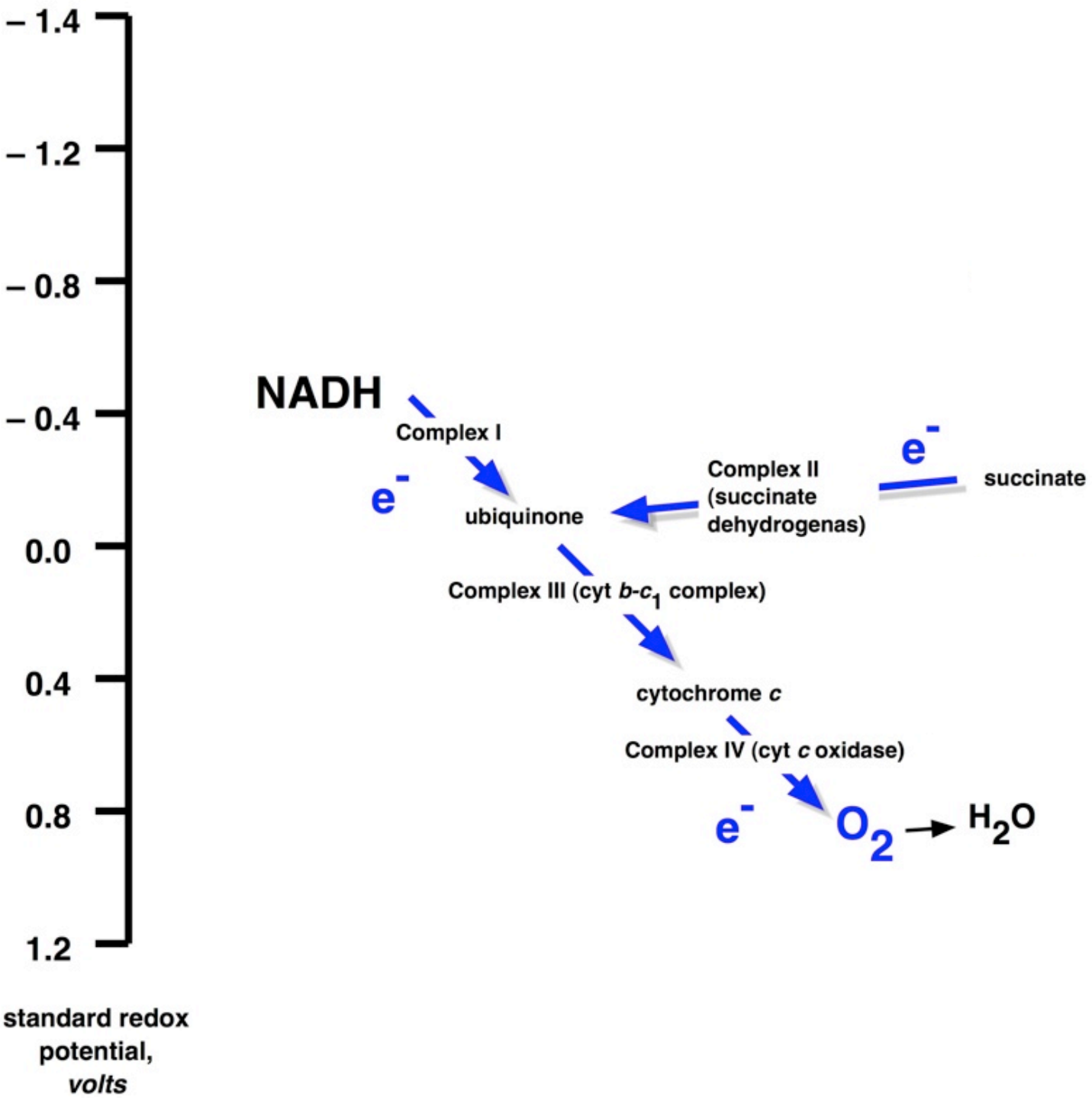
5.....

Co-location for **R**edox **R**egulation - **CoRR**

Prediction

Experimental results

Redox regulatory control of mitochondrial and chloroplast gene expression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– 1.2
– 0.8
– 0.4
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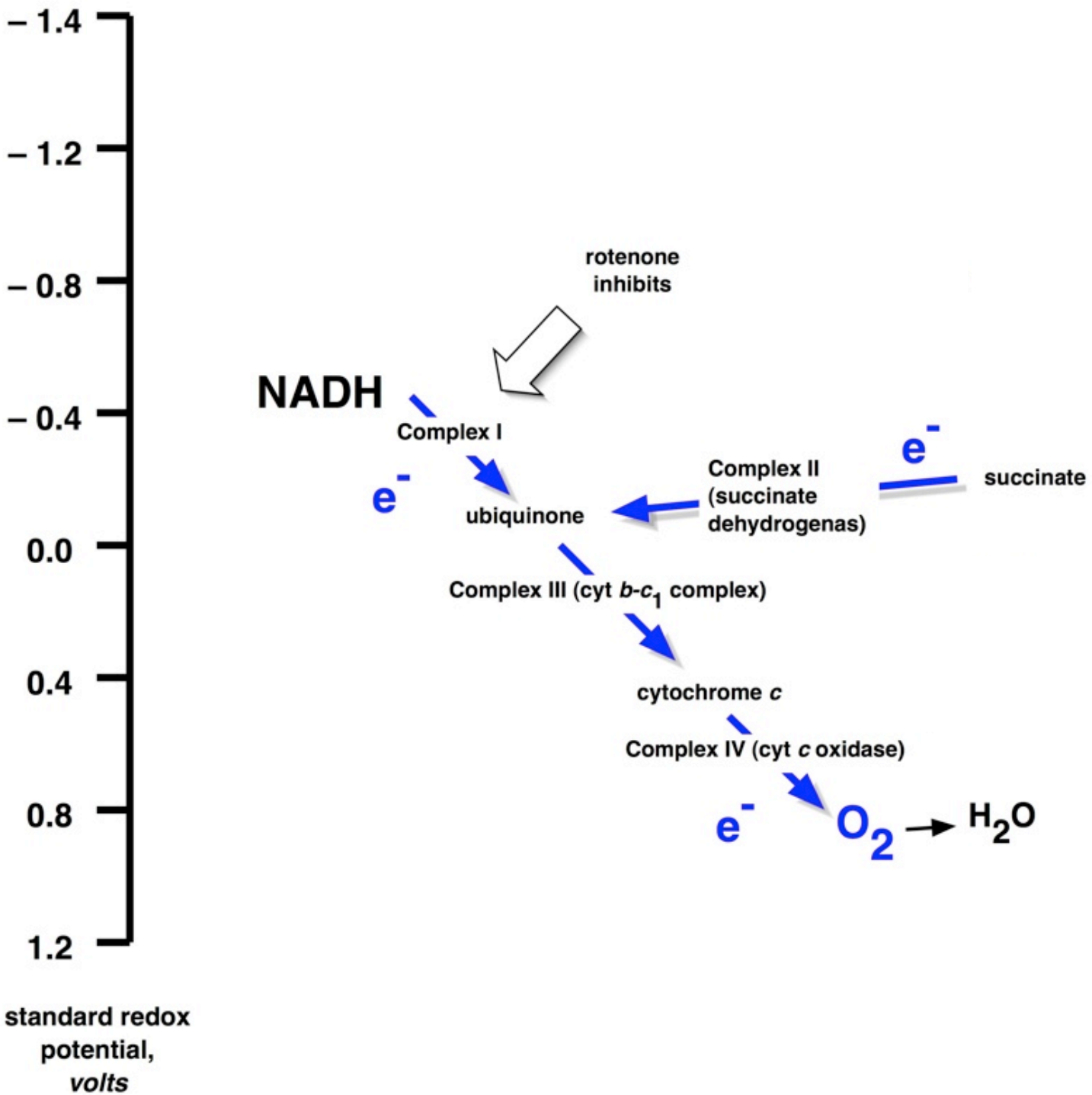
1.2
standard redox potential, volts
NADH
Complex I
e-
ubiquinone
Complex II (succinate dehydrogenas)
e-
succinate
Complex III (cyt b-c1 complex)
cytochrome c
Complex IV (cyt c oxidase)
e-
O2
H2O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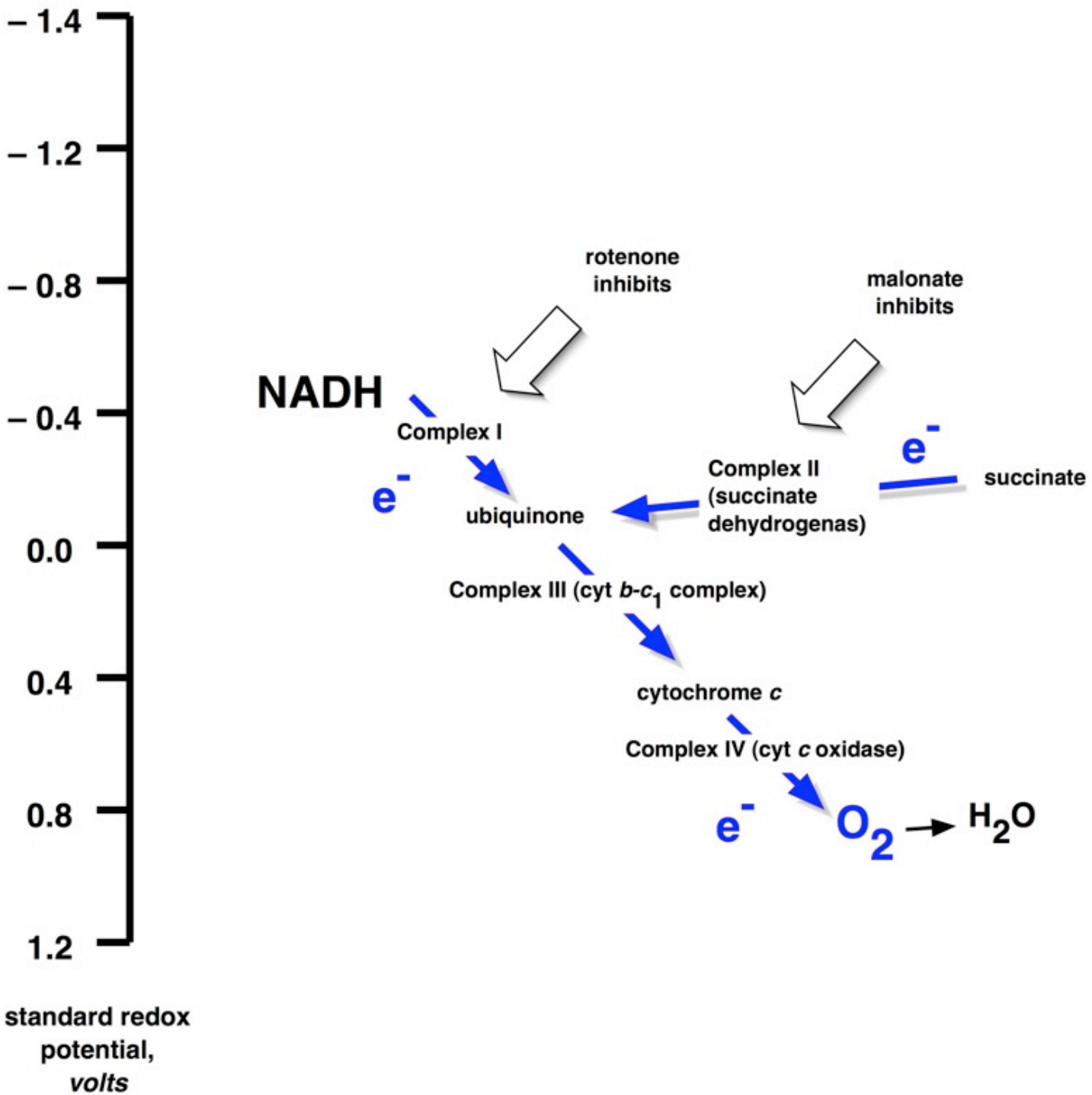
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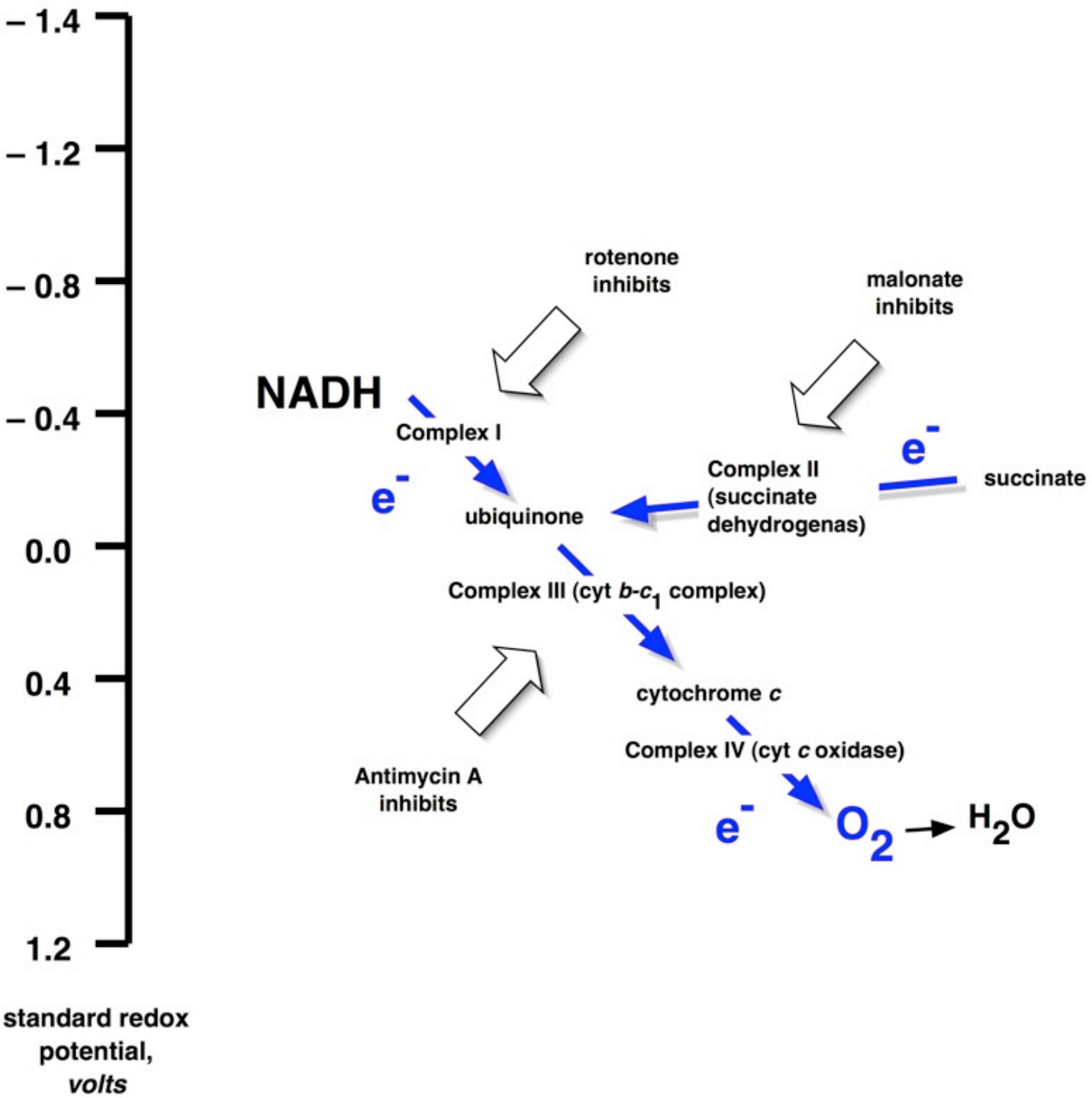
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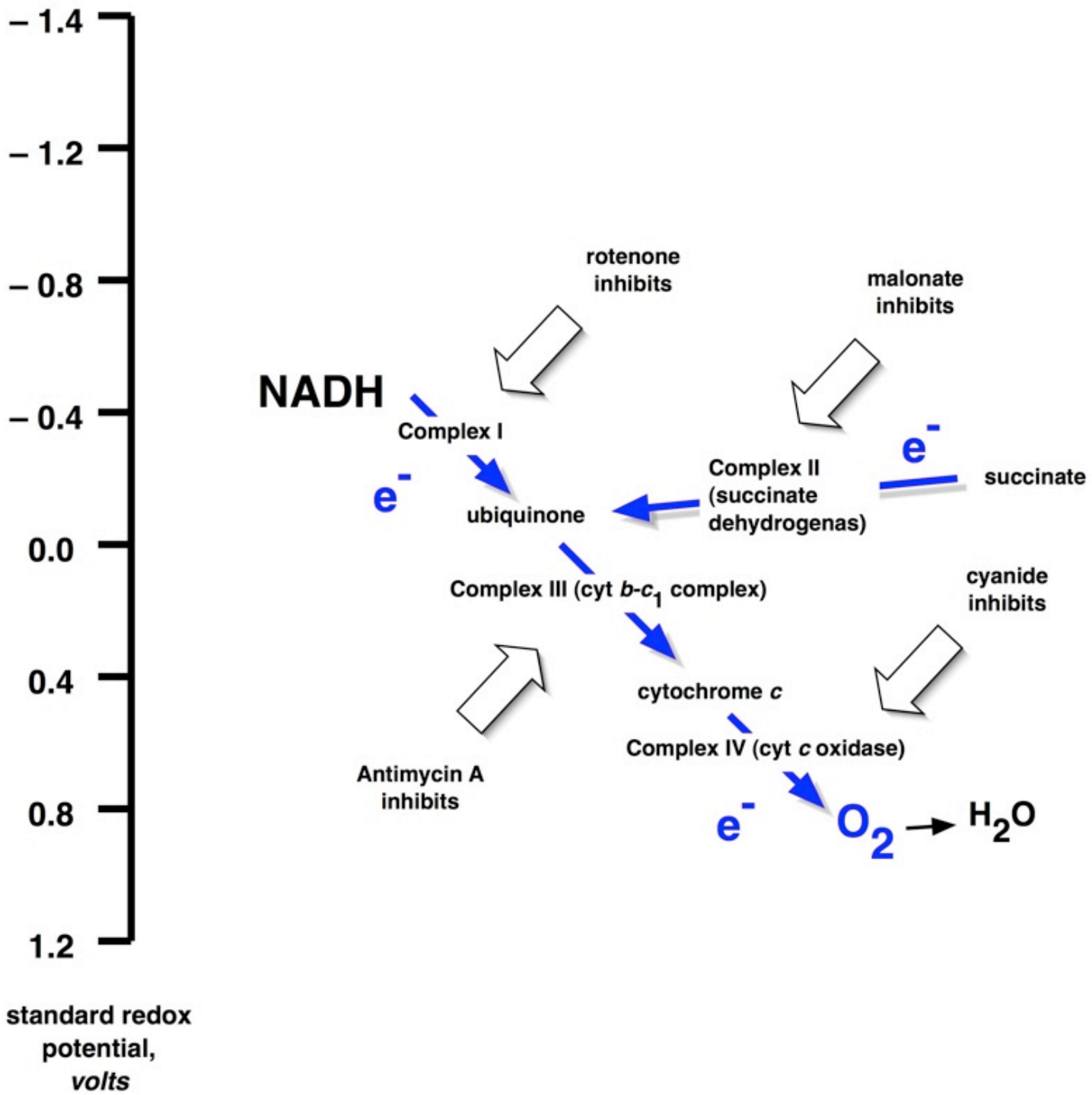
cytochrome c
Complex IV (cyt c oxidase)
Antimycin A inhibits
e-
O2
H2O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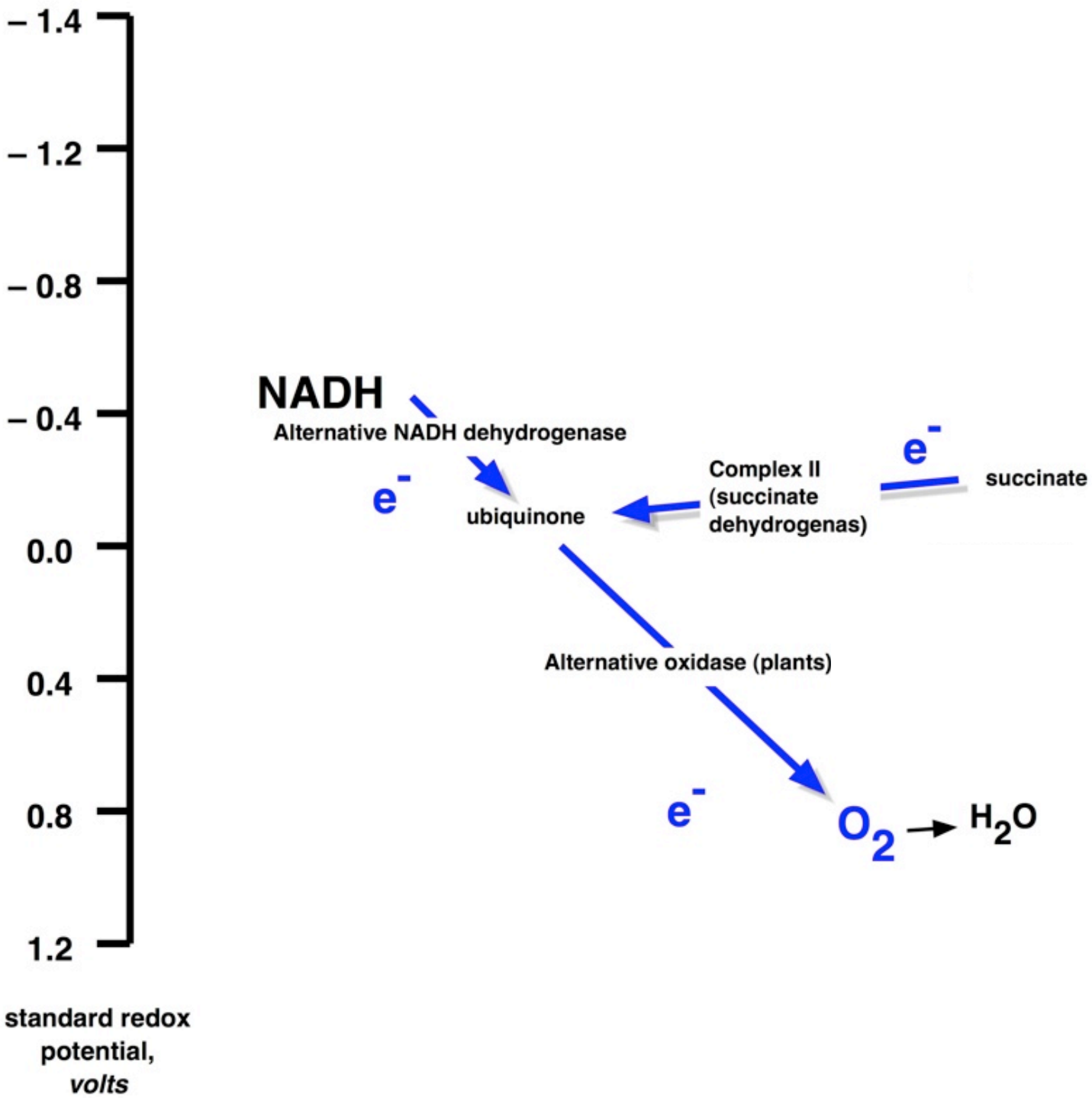
cytochrome c
Antimycin A inhibits
Complex IV (cyt c oxidase)
e-
O2
H2O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standard redox potential, volts
NADH
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e-
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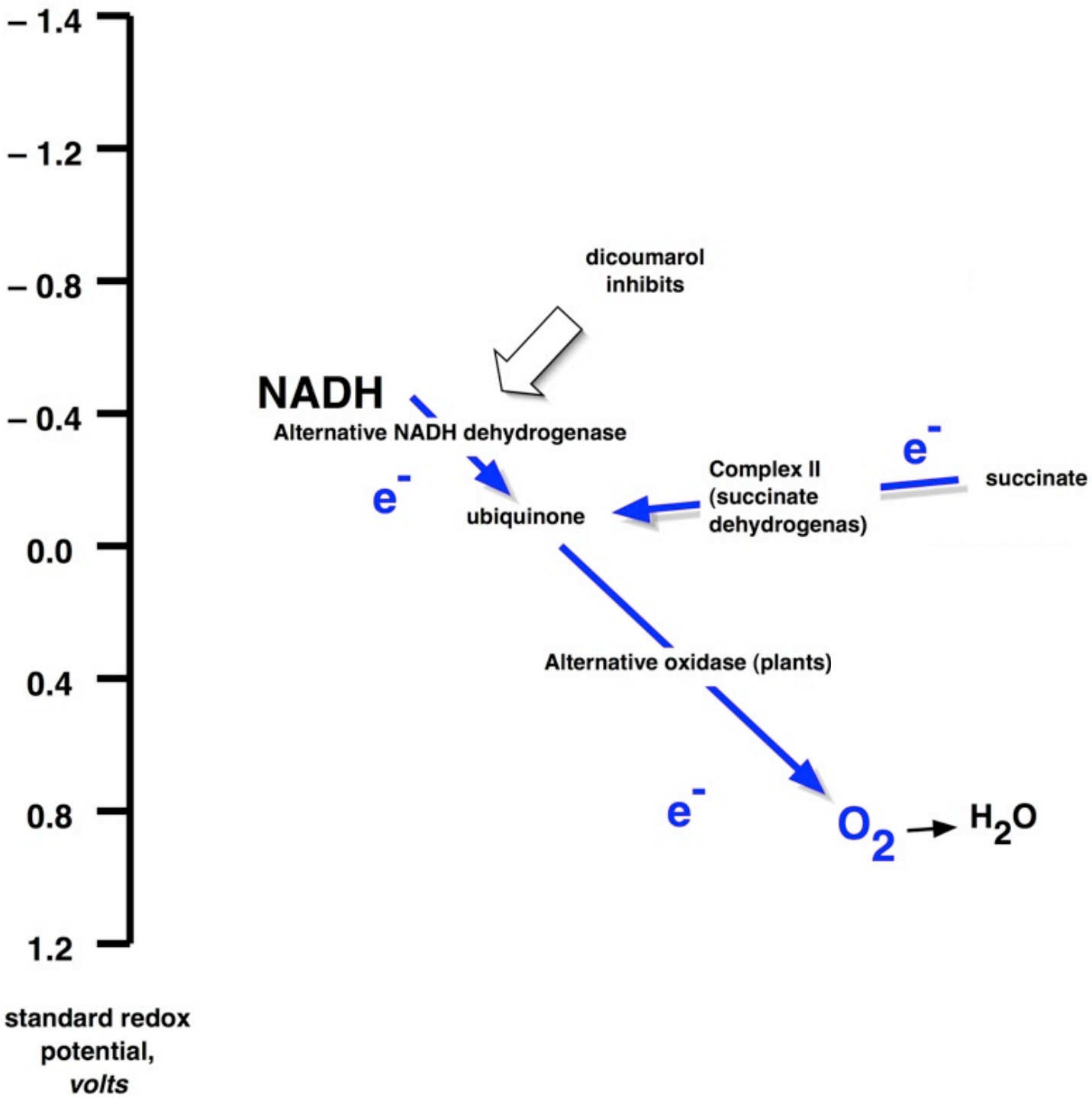
e-
succinate
Alternative oxidase (plants)
e-
O2
H2O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0.4
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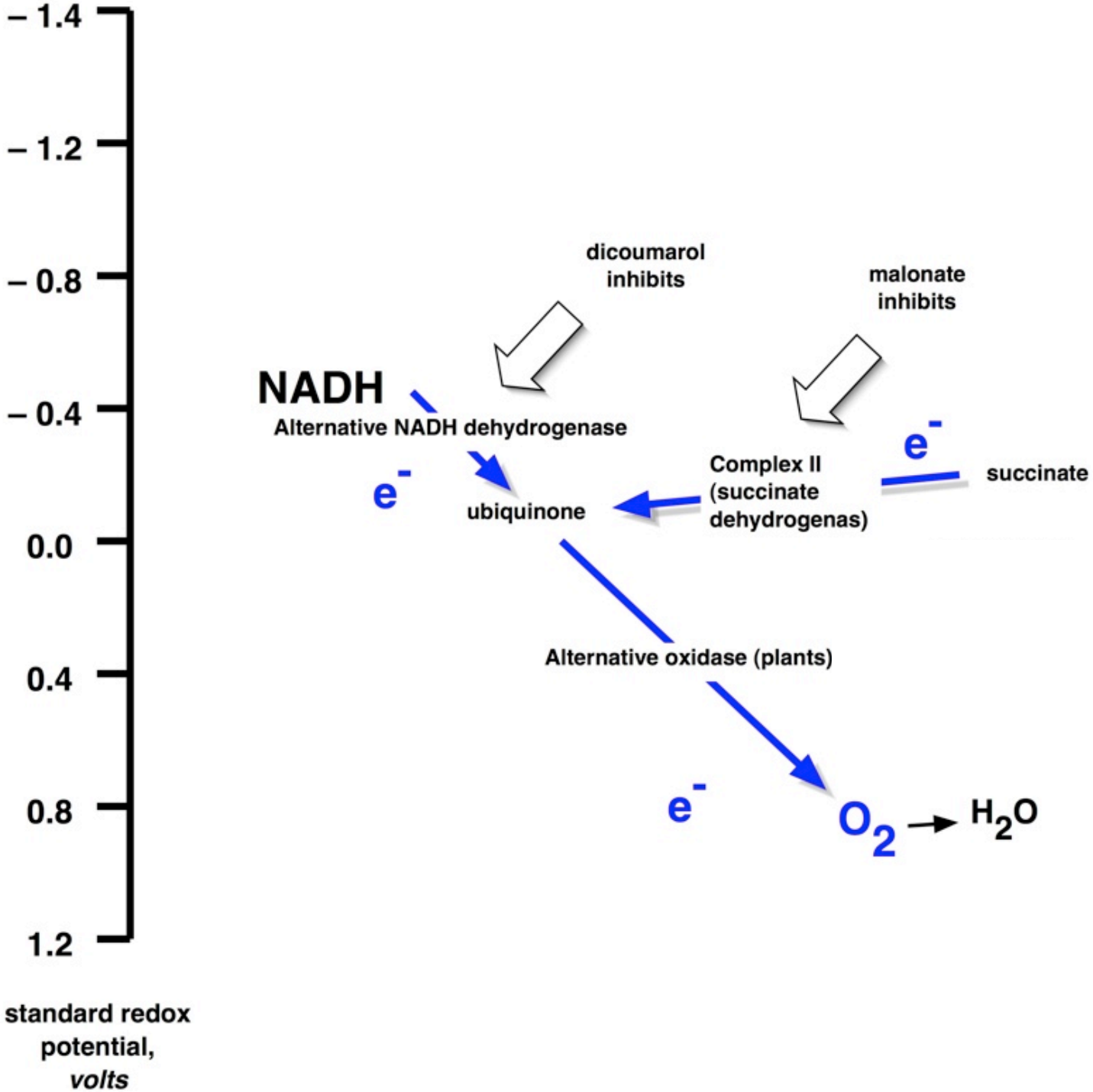
1.2
standard redox potential, volts
dicoumarol inhibits
NADH
Alternative NADH dehydrogenase
e-
ubiquinone
Complex II (succinate dehydrogenas)
e-
succinate
Alternative oxidase (plants)
e-
O2
H2O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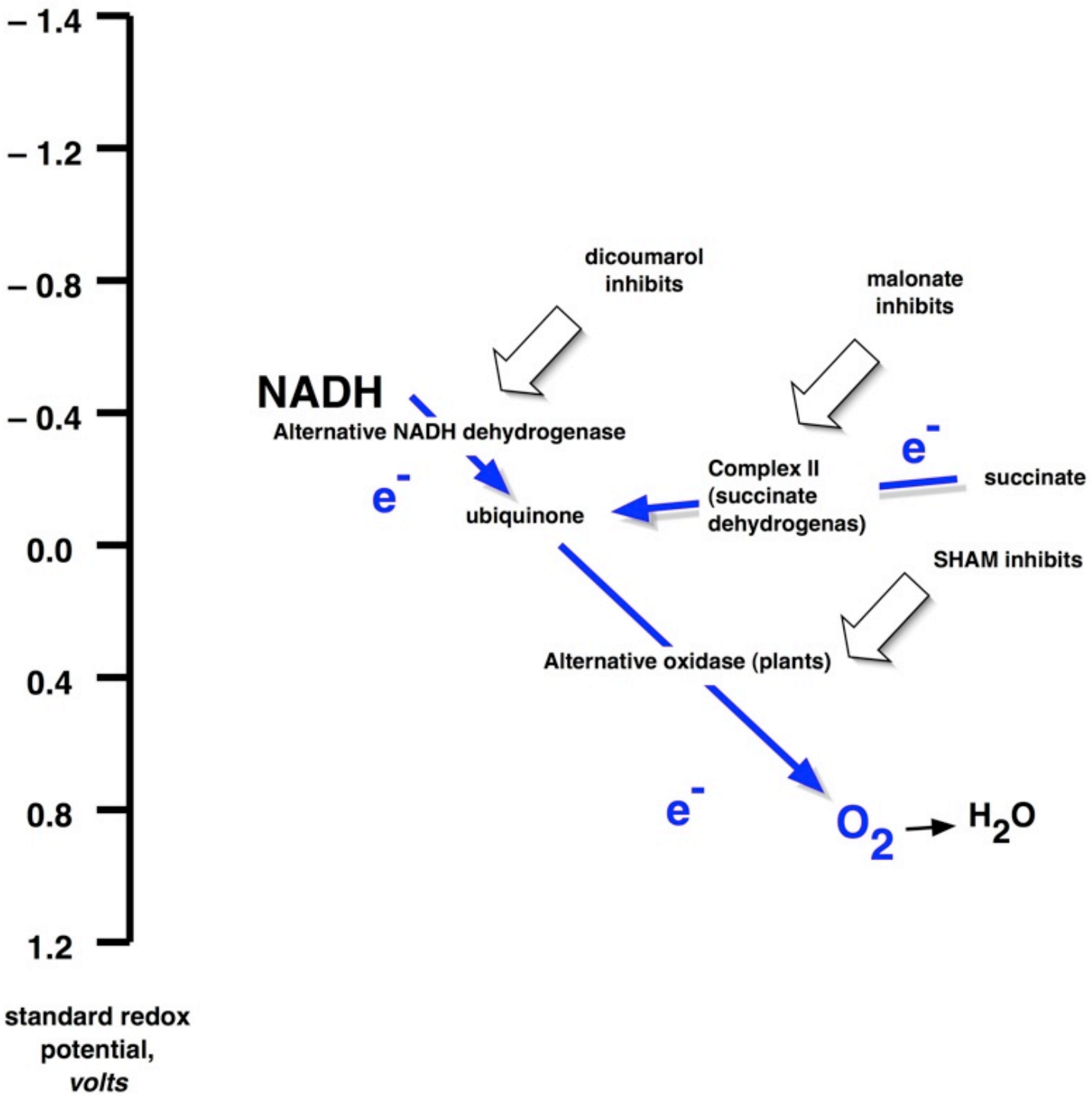
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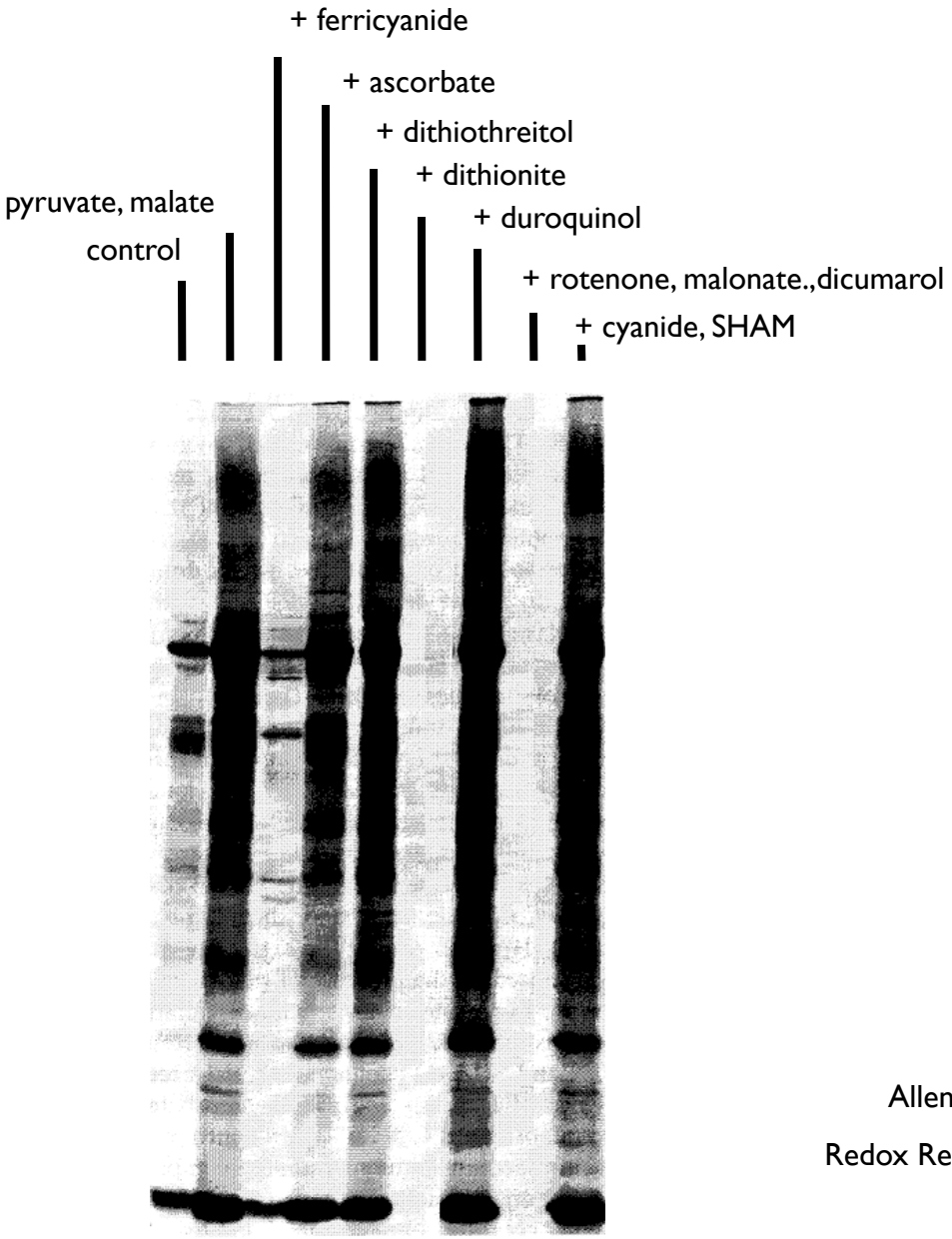

Allen, C.A. et al

Redox Report 1, 119-123

^{35}S-methionine labelling of newly synthesised proteins in pea leaf mitochondria

Co-location for **R**edox **R**egulation - **CoRR**

Advertisement.....

Photosynthesis explains cytoplasmic inheritance.
CoRR!

The University of Adelaide

Mawson Lecture Theatre, Medical School North

Friday 13th March 2009

2.00 p.m.

Coffee & Cake 3.00 – 3.30 in the first floor breakout space, Molecular Life Sciences Building


Mitochondria,
ageing, and sex –
energy versus fidelity


Costs of DNA in mitochondria

Why Do We Still Have a Maternally Inherited Mitochondrial DNA? Insights from Evolutionary Medicine

Douglas C. Wallace

Center for Molecular and Mitochondrial Medicine and Genetics, Departments of Biological Chemistry, Ecology and Evolutionary Biology, and Pediatrics, University of California, Irvine, California 92697-3940; email: dwallace@uci.edu

Annu. Rev. Biochem. 2007. 76:781–821

The *Annual Review of Biochemistry* is online at biochem.annualreviews.org

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10.1146/annurev.biochem.76.081205.150955

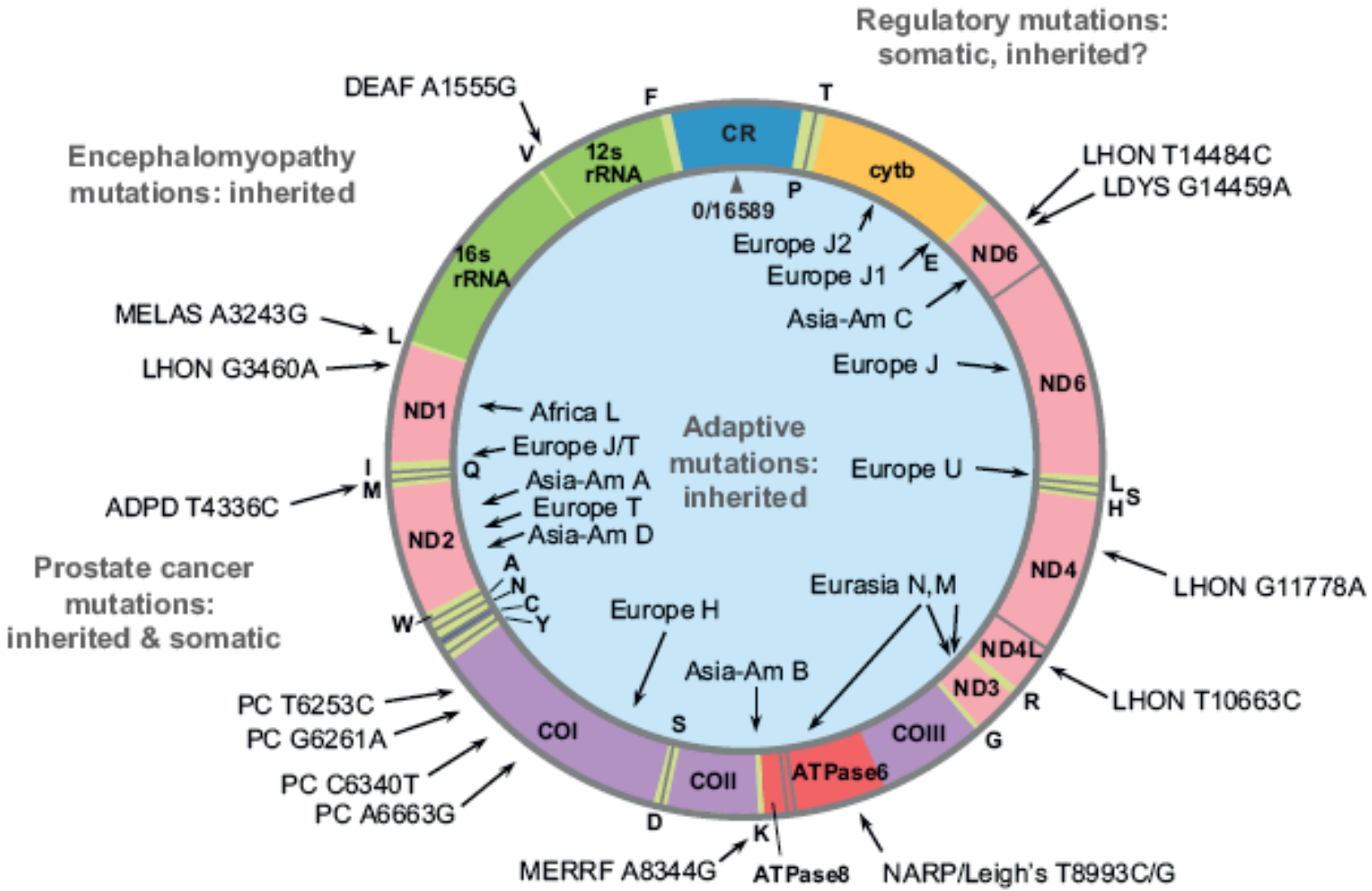
0066-4154/07/0707-0781$20.00

Key Words

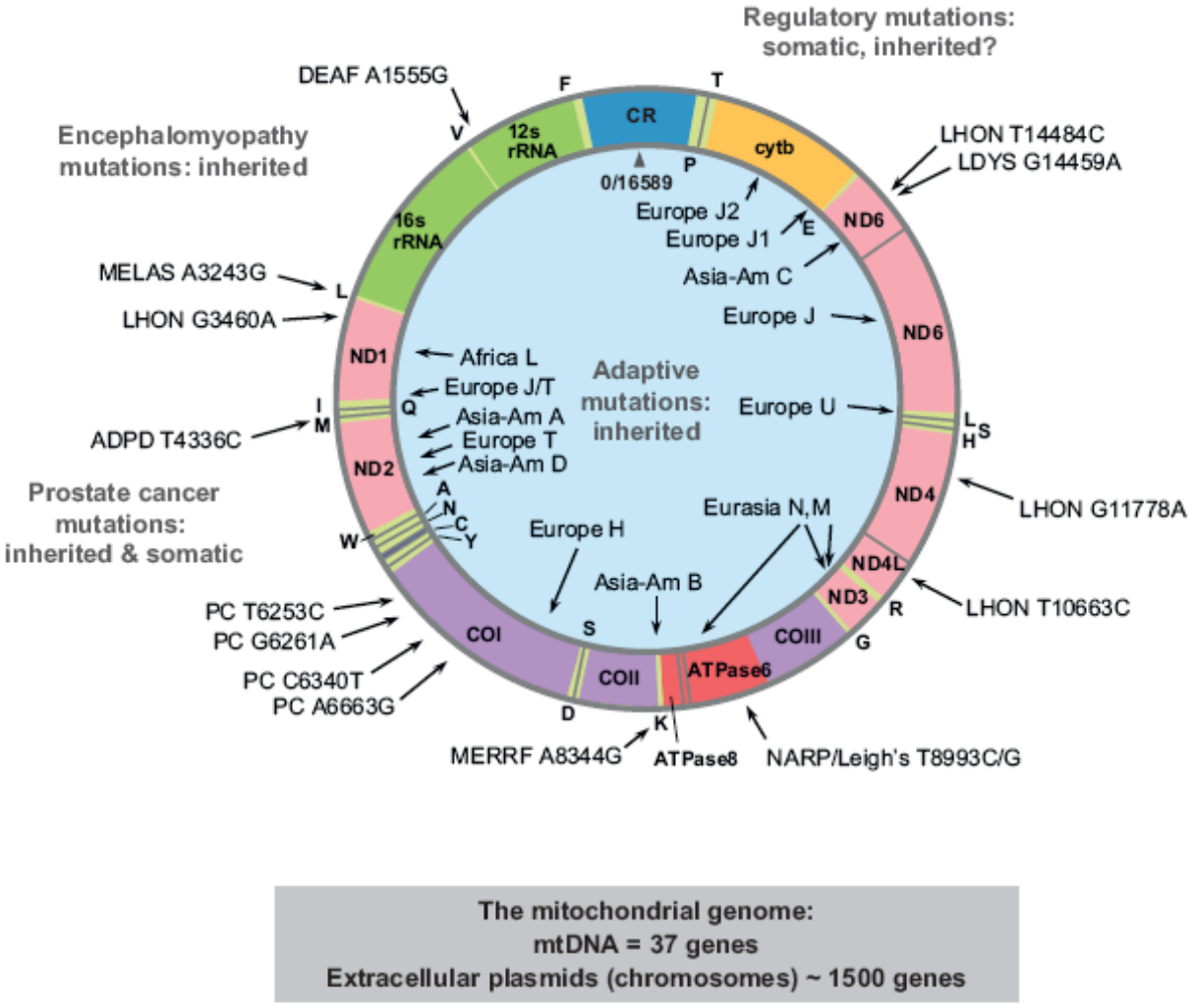
adaptation, genomic evolution, mitochondrial disease, mtDNA, oxidative phosphorylation, proton-translocating OXPHOS complexes

Abstract

The human cell is a symbiosis of two life forms, the nucleus-cytosol and the mitochondrion. The nucleus-cytosol emphasizes structure and its genes are Mendelian, whereas the mitochondrion specializes in energy and its mitochondrial DNA (mtDNA) genes are maternal. Mitochondria oxidize calories via oxidative phosphorylation (OXPHOS) to generate a mitochondrial inner membrane proton gradient (ΔP). ΔP then acts as a source of potential energy to produce ATP, generate heat, regulate reactive oxygen species (ROS), and control apoptosis, etc. Interspecific comparisons of mtDNAs have revealed that the mtDNA retains a core set of electron and proton carrier genes for the proton-translocating OXPHOS complexes I, III, IV, and V. Human mtDNA analysis has revealed these genes frequently contain region-specific adaptive polymorphisms. Therefore, the mtDNA with its energy controlling genes may have been retained to permit rapid adaptation to new environments.



The mitochondrial genome:
mtDNA = 37 genes
Extracellular plasmids (chromosomes) ~ 1500 genes



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Extracellular plasmids (chromosomes) ~ 1500 genes

Figure 2

The human mtDNA map. The human mtDNA encompasses three classes of clinically relevant mutations: recent maternally inherited disease-causing mutations, examples of which are shown on the outside of the circular map; ancient geographically correlated and frequently adaptive polymorphic variants, examples presented inside the circle; and somatic mutations that accumulate with age in postmitotic tissues and provide the aging clock. Letters around the outside perimeter indicate cognate amino acids of the tRNA genes. Letters within the ring represent the proteins encoded by the gene sector, all of which are integral membrane components of the proton-translocating complexes of OXPHOS. The polypeptides, corresponding gene, and complexes are ND1-4, -4L, -5, and -6 (*nad1-4, -4l, -5*, and *-6* gene) of complex I; cytb or cytochrome *b* (*cob* gene) of complex III; COI-III (*cox1–3* genes) of complex IV; and ATP6 and ATP8 (*atp6* and *atp8* genes) of complex V.


The mitochondrial
theory of ageing

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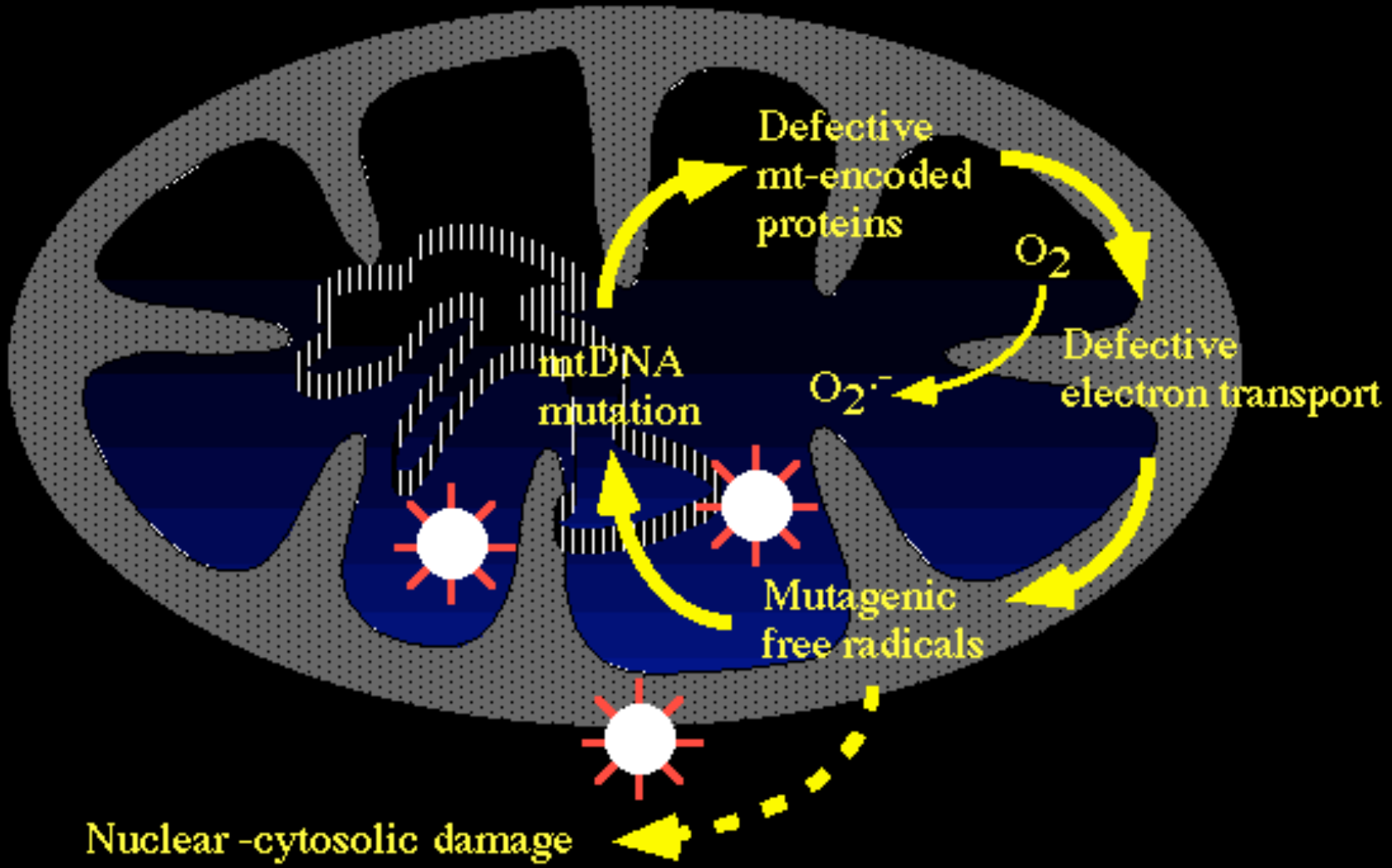
The products of these reactions damage mitochondrial genes, which then produce defective proteins, which then make more "errors" in electron transfer....damaging more genes, making more defective proteins....and so on.


Defective
mt-encoded
proteins
O_2
Defective
electron transport
mtDNA
mutation
$O_2^{\cdot -}$
Mutagenic
free radicals
Nuclear -cytosolic damage


Separate sexes as mitochondrial division of labour

Why there are two sexes

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Problem: Mitochondrial Ageing predicts that offspring should inherit their mothers' acquired state of accumulated damage, but they evidently do not. Babies are not born at the physical age of their mothers.

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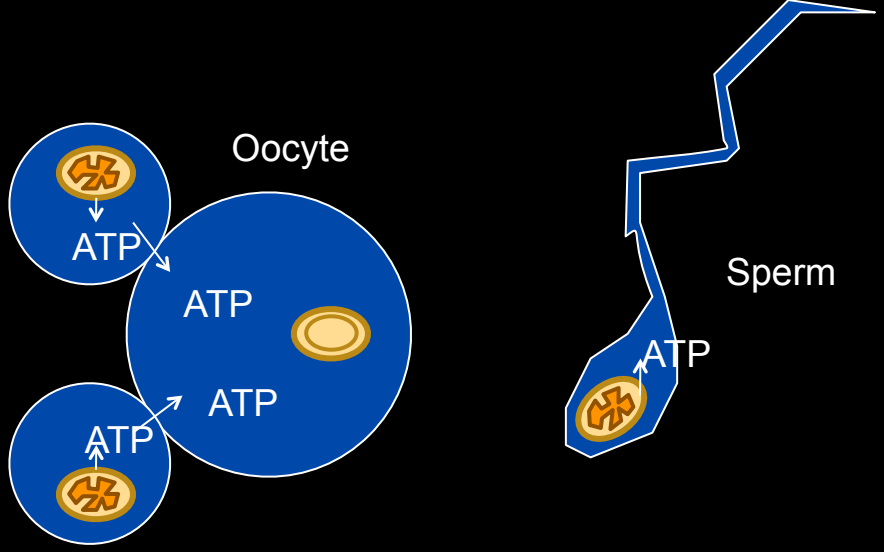
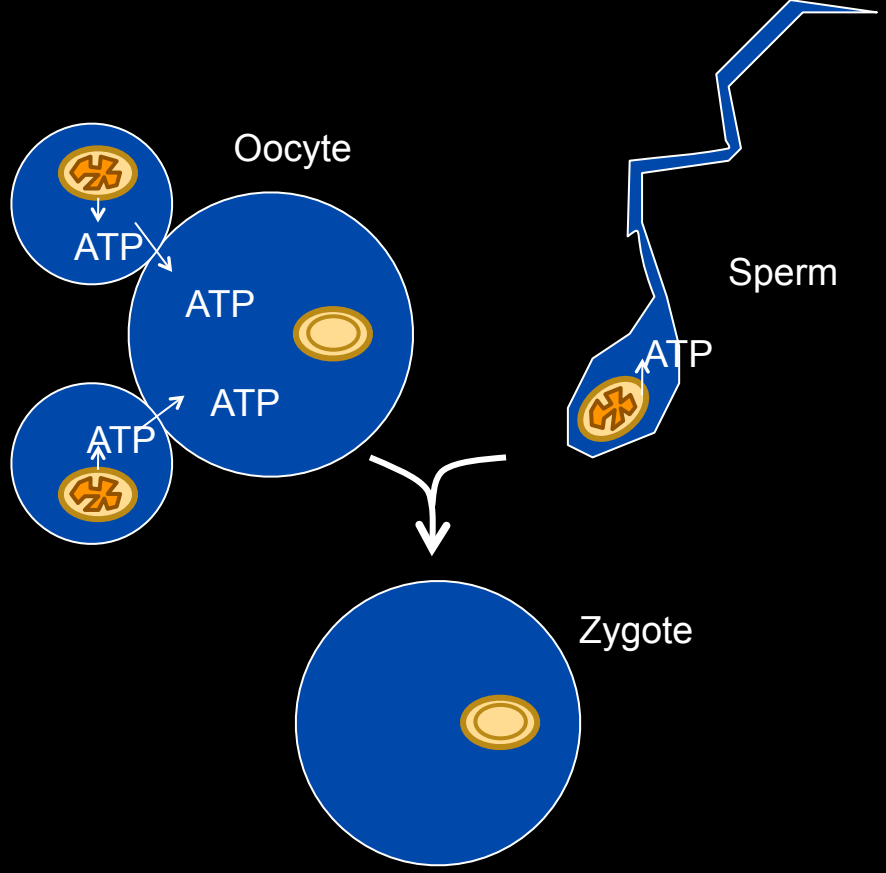
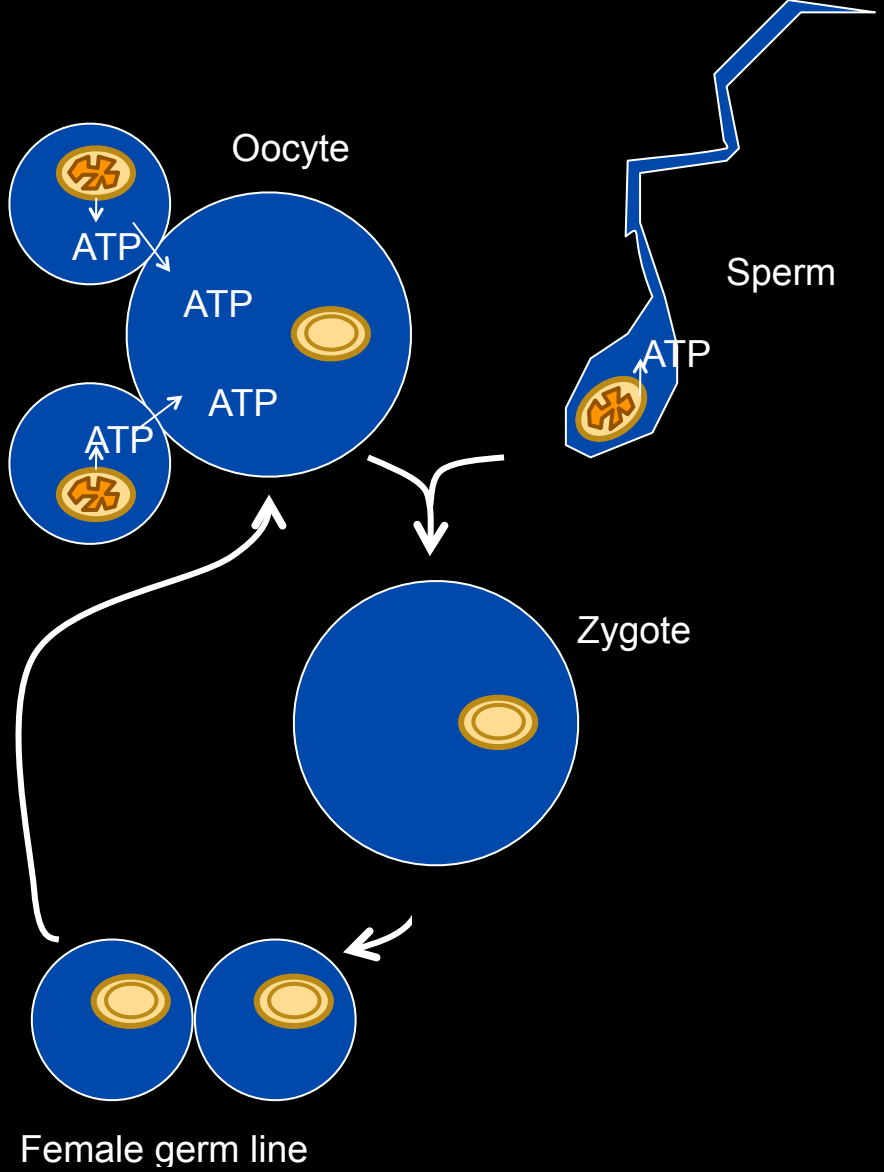
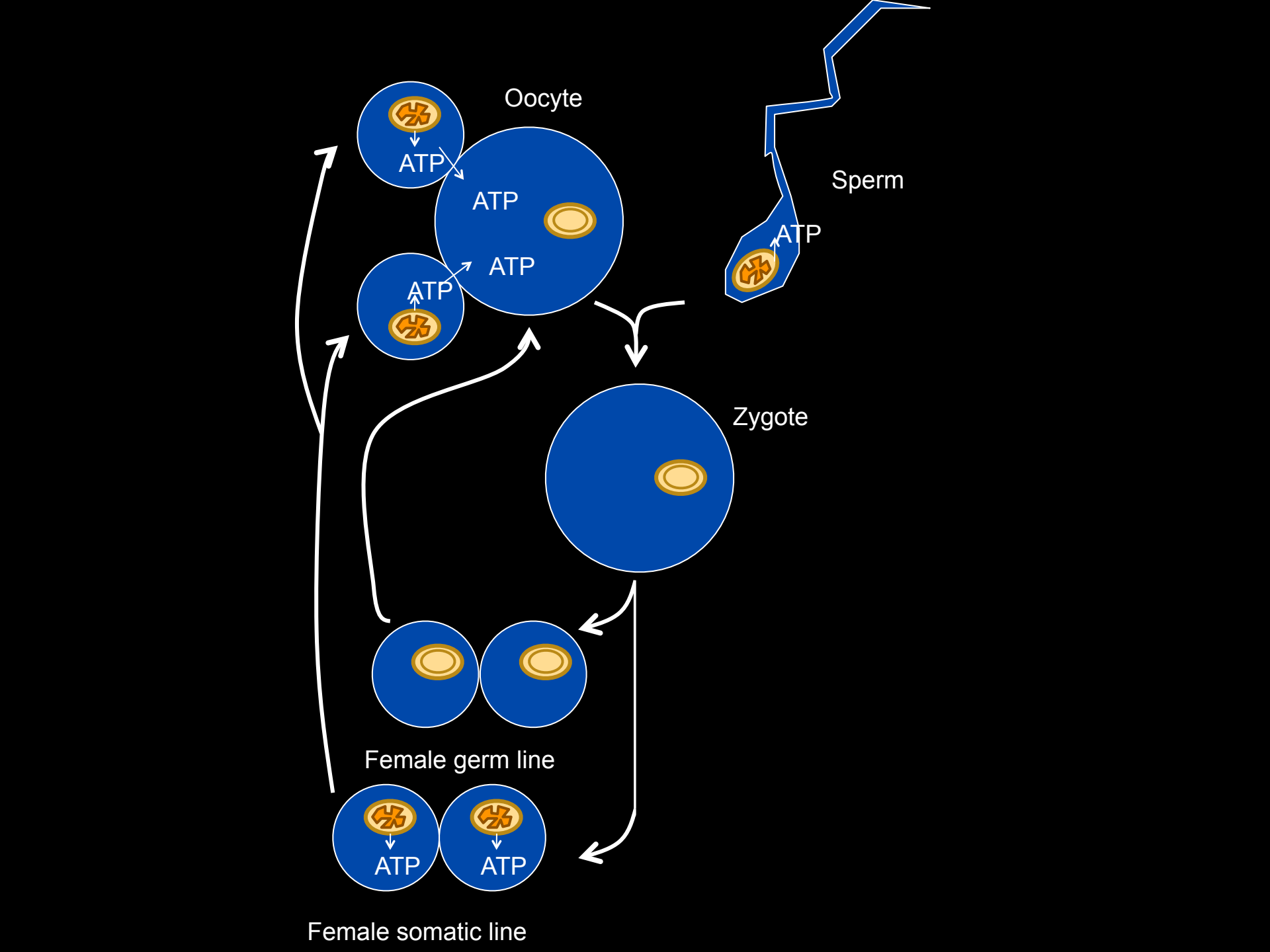
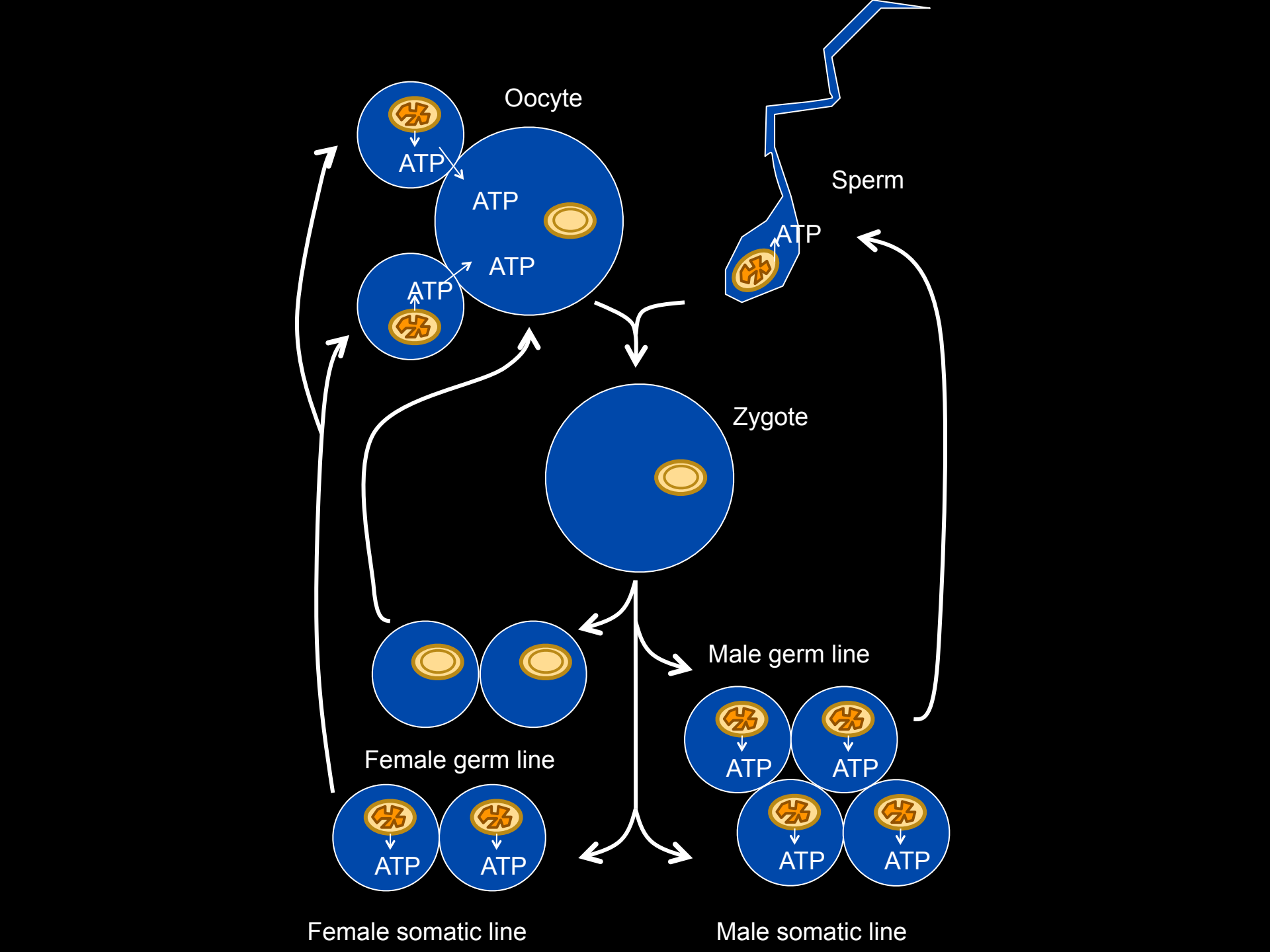
And they can never be both.

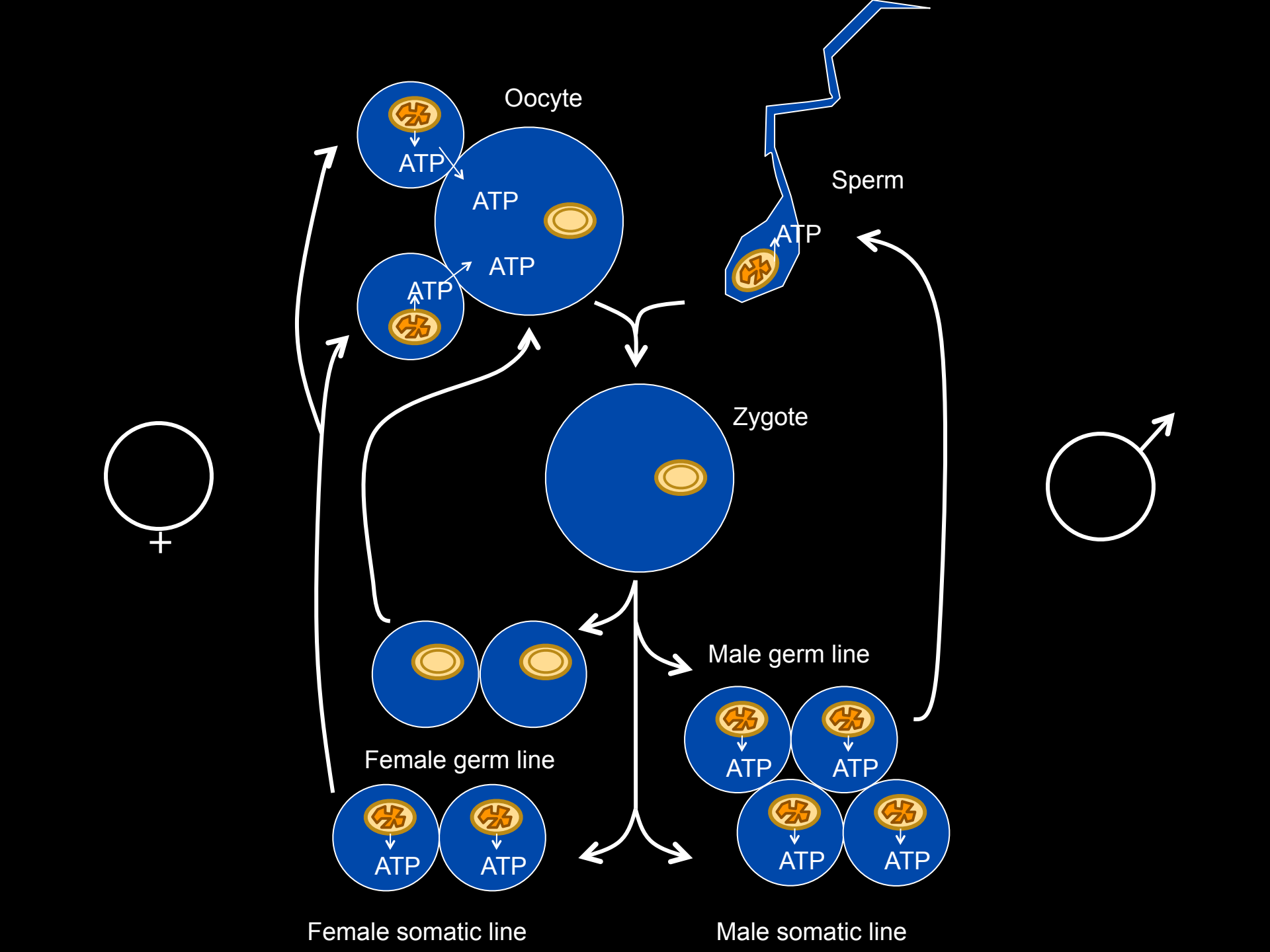

Oocyte
ATP
ATP
ATP
ATP
Sperm
ATP


Oocyte
ATP
ATP
ATP
ATP
Sperm
ATP
Zygote


Oocyte
ATP
ATP
ATP
ATP
Sperm
ATP
Zygote
Female germ line


Oocyte
ATP
ATP
ATP
ATP
Sperm
ATP
Zygote
Female germ line
ATP
ATP
Female somatic line


Oocyte
ATP
ATP
ATP
ATP
Sperm
ATP
Zygote
Male germ line
ATP
ATP
ATP
ATP
Female germ line
ATP
ATP
Female somatic line
Male somatic line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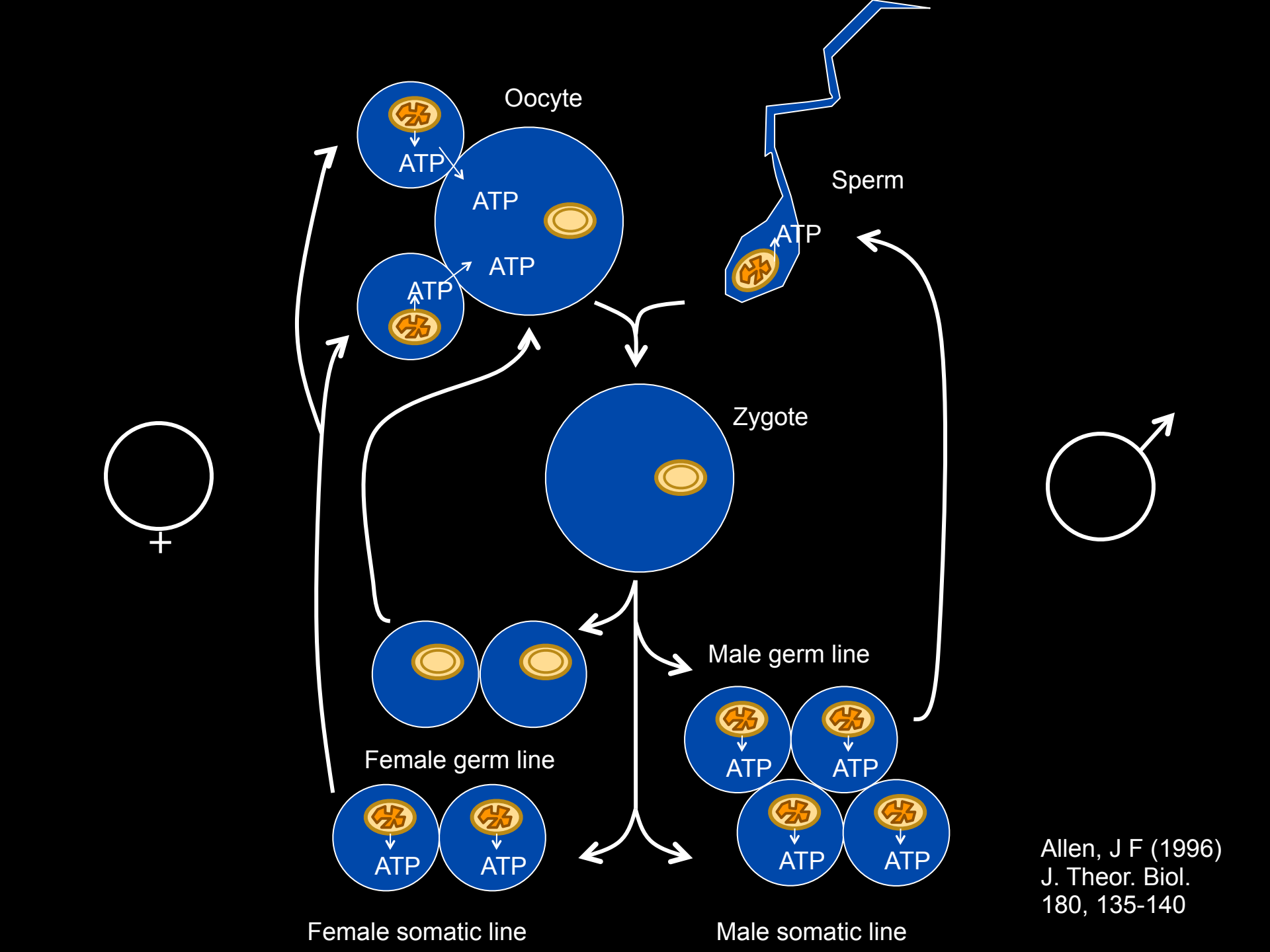
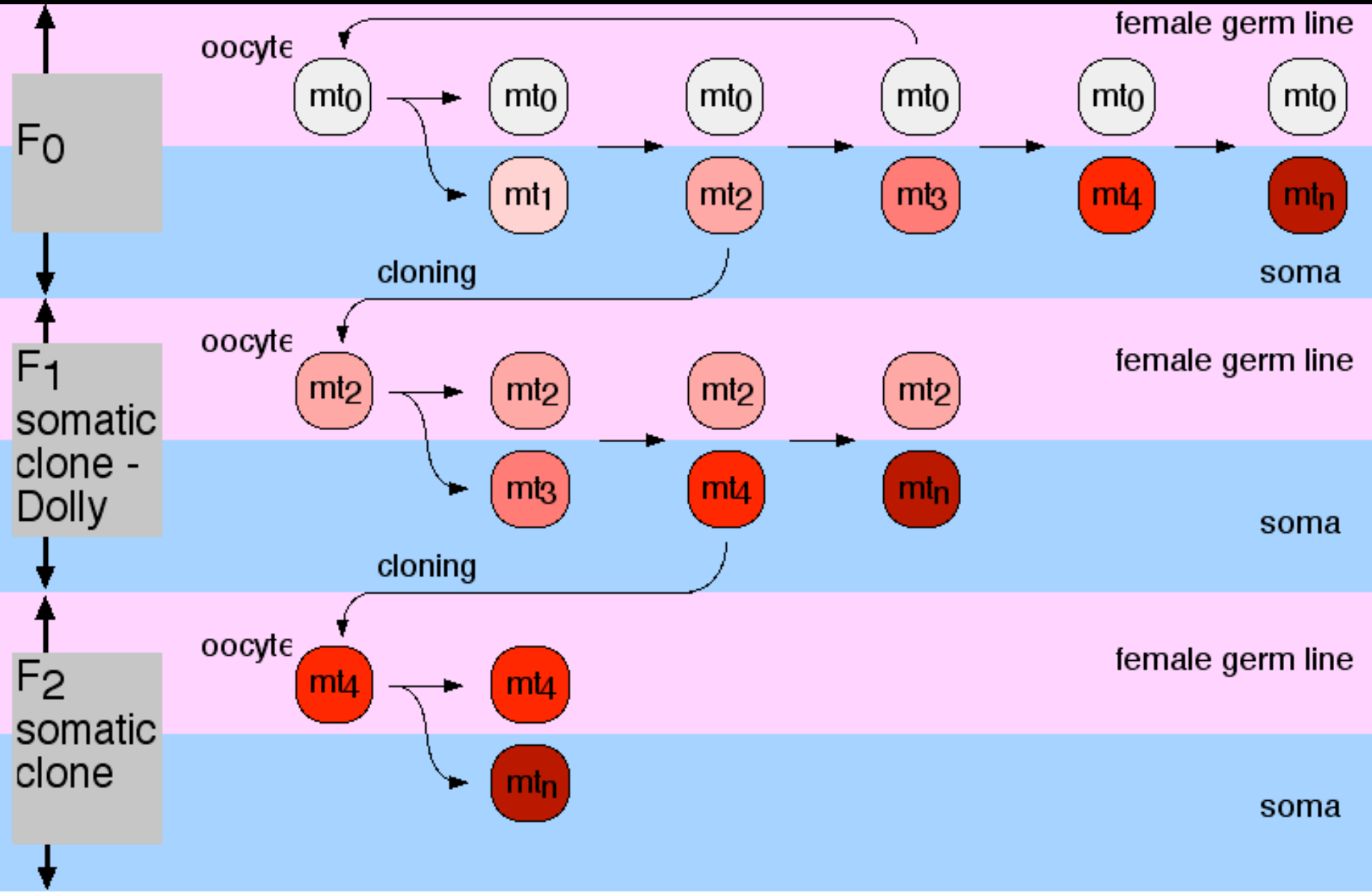


Allen, J F (1996)
J. Theor. Biol.
180, 135-140



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Dolly, the Finn Dorset ewe, the first mammal to be cloned from an adult cell. Finn Dorset sheep normally live to 11 or 12 years. Dolly had been suffering from lung cancer and died of a drug overdose on 14th February 2003, aged 5. Dolly is survived by three or four of her six lambs.

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Obituary: Dolly the Sheep
http://www.nature.com/nsu/030210/030210-15.html

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– An immortal line of genetic template mitochondria in the female germ line; … from egg back to egg

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– but might exist also in female germ lines as protected genetic templates, incapable of energy conversion, and from which all other mitochondria and chloroplasts derive

Coda. Two views of mitochondria
View 1

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John Burn (Newcastle Institute of Clinical Genetics). Quoted in *The Times*, 9th September 2005

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"My belief is that what we are doing is changing a battery that doesn't work for one that does….Changing the mitochondria won't affect the important DNA."

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View 2

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Nick Lane. *Power, Sex, Suicide. Mitochondria and the Meaning of Life.* Oxford University Press. 2005.

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Mitochondria:

– *"…give striking new insights into why we are here at all, whether we are alone in the universe, why we have our sense of individuality, why we should make love, where we trace our ancestral roots, why we must age and die—in short, into the meaning of life."*

A mitochondrion—one of many tiny power-houses within cells that control our lives in surprising ways


Stanmore
Canons Park
Queensbury
Kingsbury
Edgware
Burnt Oak
Colindale
Hendon Central
Brent Cross
Golders Green
Hampstead
Neasden
Dollis Hill
Willesden Green
Kilburn
West Hampstead
200m
Finchley Road & Frognal
Finchley Road
Swiss Cottage
St. John's Wood
Brondesbury Park
Brondesbury
Mill Hill East
Totteridge & Whetstone
Woodside Park
West Finchley
Finchley Central
East Finchley
Highgate
Archway
Tufnell Park
Hampstead Heath
Gospel Oak
Belsize Park
Kentish Town West
Kentish Town
Chalk Farm
Camden Town
Camden Road
Mornington Crescent
Oakwood
Southgate
Arnos Grove
Bounds Green
Wood Green
Turnpike Lane
Manor House
Arsenal
Holloway Road
Caledonian Road
Caledonian Road & Barnsbury
Finsbury Park
Seven Sisters
Tottenham Hale
Blackhorse Road
Walthamstow Central
Canonbury
Highbury & Islington
Hackney Central
Hackney Wick
Dalston Kingsland
Homerton
King's Cross St. Pancras
Great Portland Street
Euston
Angel
Farringdon
Barbican
Old Street
Liverpool Street
Moorgate
Paddington
Edgware Road
Baker Street
Warren Street
Regent's Park
Euston Square
Euston 200m
Goodge Street
Russell Square
Holborn
Tottenham Court Road
Oxford Circus
Bond Street
Lancaster Gate
Queensway
Bayswater
Marylebone
Notting Hill Gate
Marble Arch
Chancery Lane
St. Paul's
Bank
Monument
Tower Hill
Fenchurch Street 150m
Tower Gateway
Aldgate
Aldgate East
Shoreditch
Whitechapel
Stepney Green
Bethnal Green
Mile End
Bow Road
Bow Church
200m
Bromley-by-Bow
Pudding Mill Lane
Devons Road
All Saints
Poplar
Blackwall
East India
Canning Town
Bus to London City Airport
West Ham
Plaistow
Upton Park
East Ham
Barking
Upney
Becontree
Dagenham East
Dagenham Heathway
Stratford
Leyton
Leytonstone
Wanstead
Gants Hill
Redbridge
Snaresbrook
South Woodford
Woodford
Buckhurst Hill
Loughton
Roding Valley
Chigwell
Grange Hill
Hainault
Fairlop
Barkingside
Newbury Park
Theydon Bois
Debden
Upm
Holland Park
High Street Kensington
Hyde Park Corner
Green Park
Piccadilly Circus
Leicester Square
Covent Garden
Charing Cross
Mansion House
Cannon Street
Blackfriars
Temple
Embankment
Charing Cross 100m
Knightsbridge
Gloucester Road
Sloane Square
St. James's Park
South Kensington
Victoria
Westminster
Earl's Court
Waterloo
Pimlico
Vauxhall
Southwark
Waterloo East
Borough
Lambeth North
Elephant & Castle
100m
River Thames
London Bridge
Rotherhithe
Bermondsey
Canada Water
Canary Wharf
Heron Quays
South Quay
Crossharbour & London Arena
Mudchute
Island Gardens
Surrey Quays
New Cross Gate
New Cross
Greenwich
Cutty Sark
for Maritime Greenwich
Deptford Bridge
North Greenwich
Limehouse
Westferry
Shadwell
Wapping
West India Quay
Royal Victoria
Custom House
for ExCeL
Prince Regent
Royal Alb
Becke
West Silvertown
Under construction
Pontoon Dock
London City Airport
Silvertown
North Woolwich
Under construction

Queen Mary
University of London

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Thomas Buckland
Sujith Puthiyaveetil


Ebikabowei Bozimo
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Thomas Buckland
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The end. Thank you for listening.