8. Why mitochondria make complexity possible

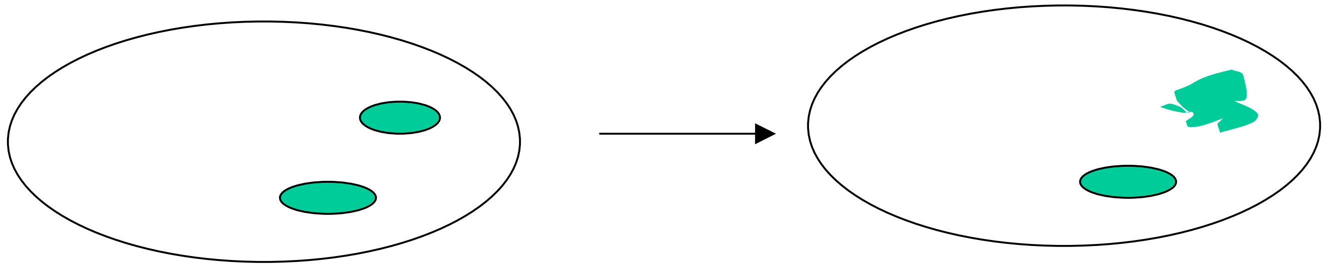
Bacteria: small size

- fast growing is important
- small genome size & fast replication
- large surface area to volume ratio: energetic efficiency
- some complex internal membrane but never approach eukaryotic complexity

Eukaryotic cells: large size (complexity)

- internal energy generation
- mitochondrial genome: mutual control?

Mitochondrial gene transfer to nucleus



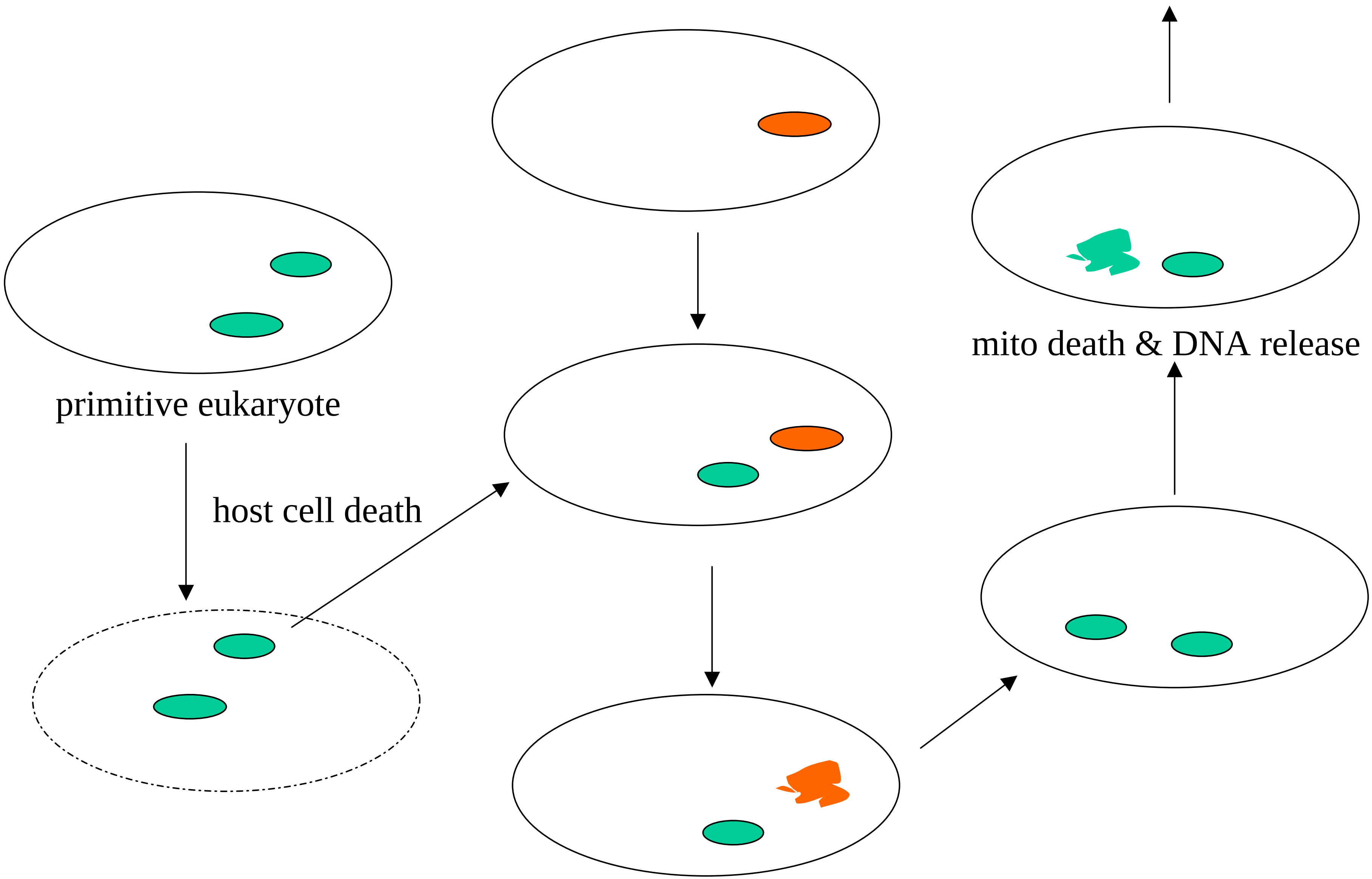
primitive eukaryote   mito death & DNA release

Jeremy Timmis: Nature 2003
    chloroplast gene transfer to nucleus: ~1/16000 seeds in tobacco plant
    a single plant produces as many as a million seeds

Nuclear-mitochondrial sequences (numts)
    the same gene in both the mito and nucleus
    duplication of chloroplast and mito genes in the nuclear genomes of many species
    at least 354 separate independent transfers in humans

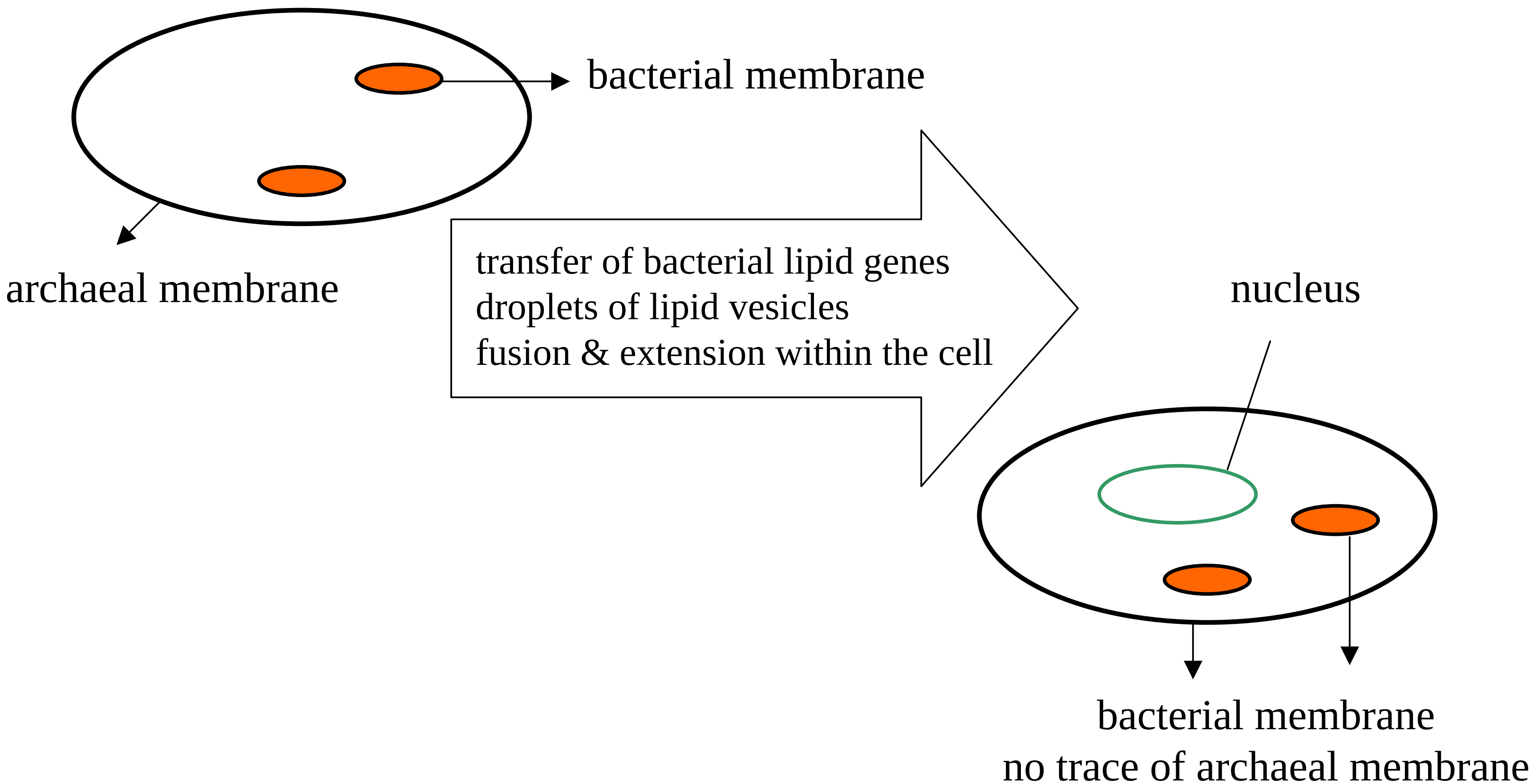
Clesson Turner, 2003: demonstration of gene transfer continuing today
    a rare genetic disease Pallister-Hall syndrome
    a spontaneous transfer of mito DNA to the nucleus

One way gene transfer from mito to nucleus



The origin of the nucleus

What happens to the genes that are transferred?

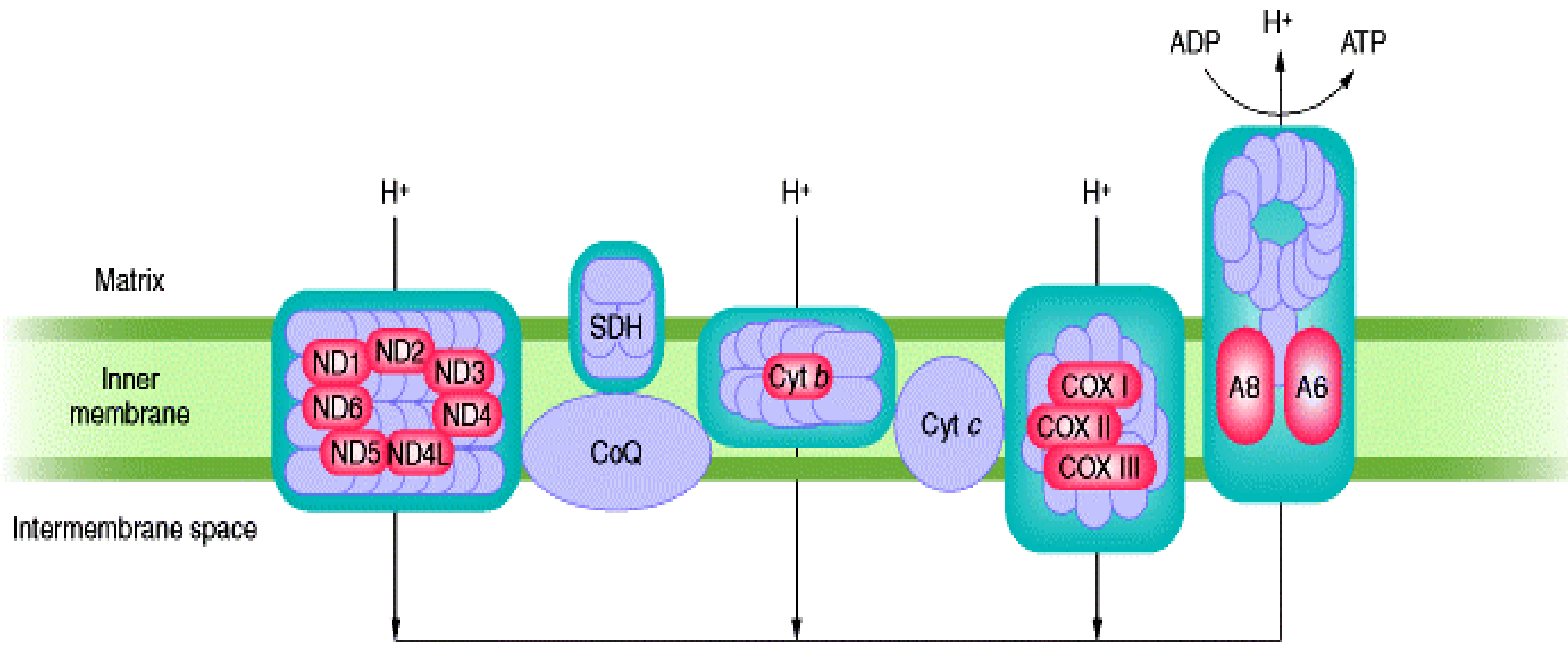


A probable evidence: fresh nuclear membrane in cell division
The replacement of membrane: natural selection for bacterial membrane
Terpenoids: the syntheses of isoprene units are vestiges of archaeal membrane

Why did mito retain any genes at all?

Big disadvantages

1. Thousands of copies in a cell: a costly process
2. Competition between different mito genomes within the same cell
3. Vulnerability to damage by free radicals



Subunits	Complex I	Complex II	Complex III	Complex IV	Complex V
nDNA-encoded	35	4	10	10	12
mtDNA-encoded	7	0	1	3	2

37 genes: 22 tRNA genes, 2 ribosomal RNA genes, 13 polypeptide-encoding gene

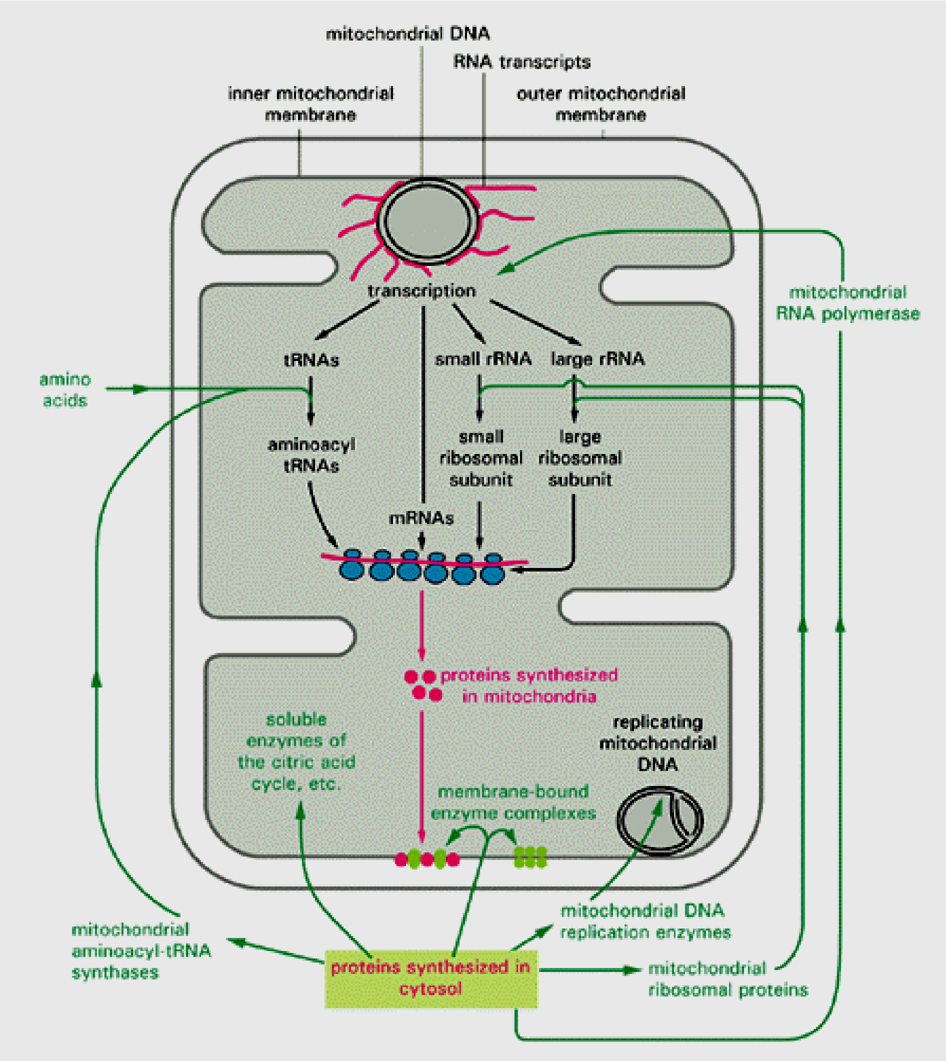
Assignment: a table of mito genes from different species

Retaining a handful of mito genes is a costly process

Tagged proteins, but not all, to be transferred to mito

Still on going process? One day no mito genes will be left?

Different species different numbers of genes: random nature?



The nucleus is not enough

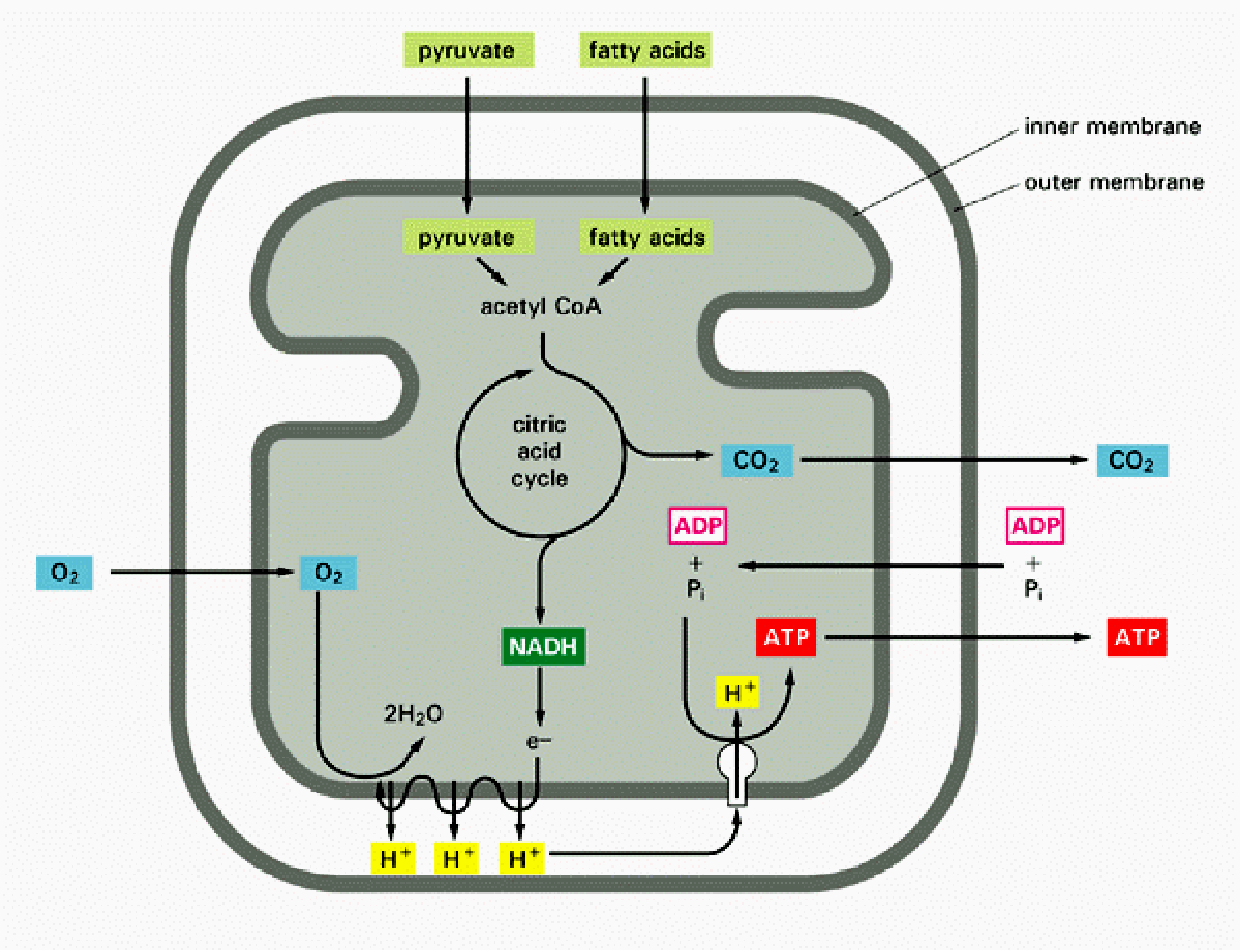
No species has lost them all: 95~99.9%, but not all
Gene loss has occurred in parallel
But kept essentially the same handful

Probable reasons:

- physical nature to be targeted to mito: disproved
- different genetic code in mito: many species have universal code
- **genetic outpost on site where respiration occur: 1993 John Allen**

The problem of poise

Speed & demand: respiration speed depends on demand
Balanced by the availability of glucose, ADP, Pi, oxygen



Two choices of ETC components: reduced or oxidized, never both

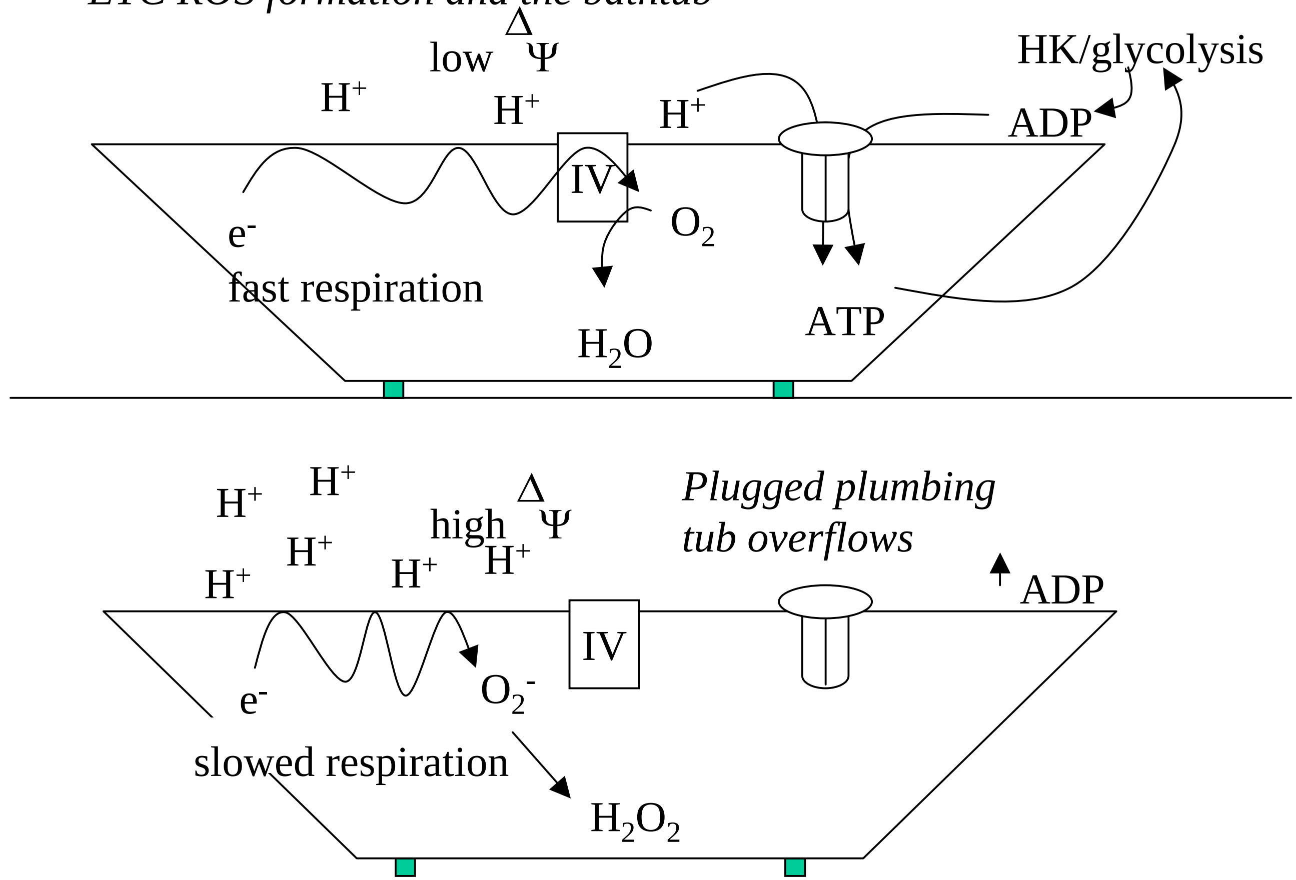
The dynamic equilibrium between ox and red determines the overall speed

To sustain poise

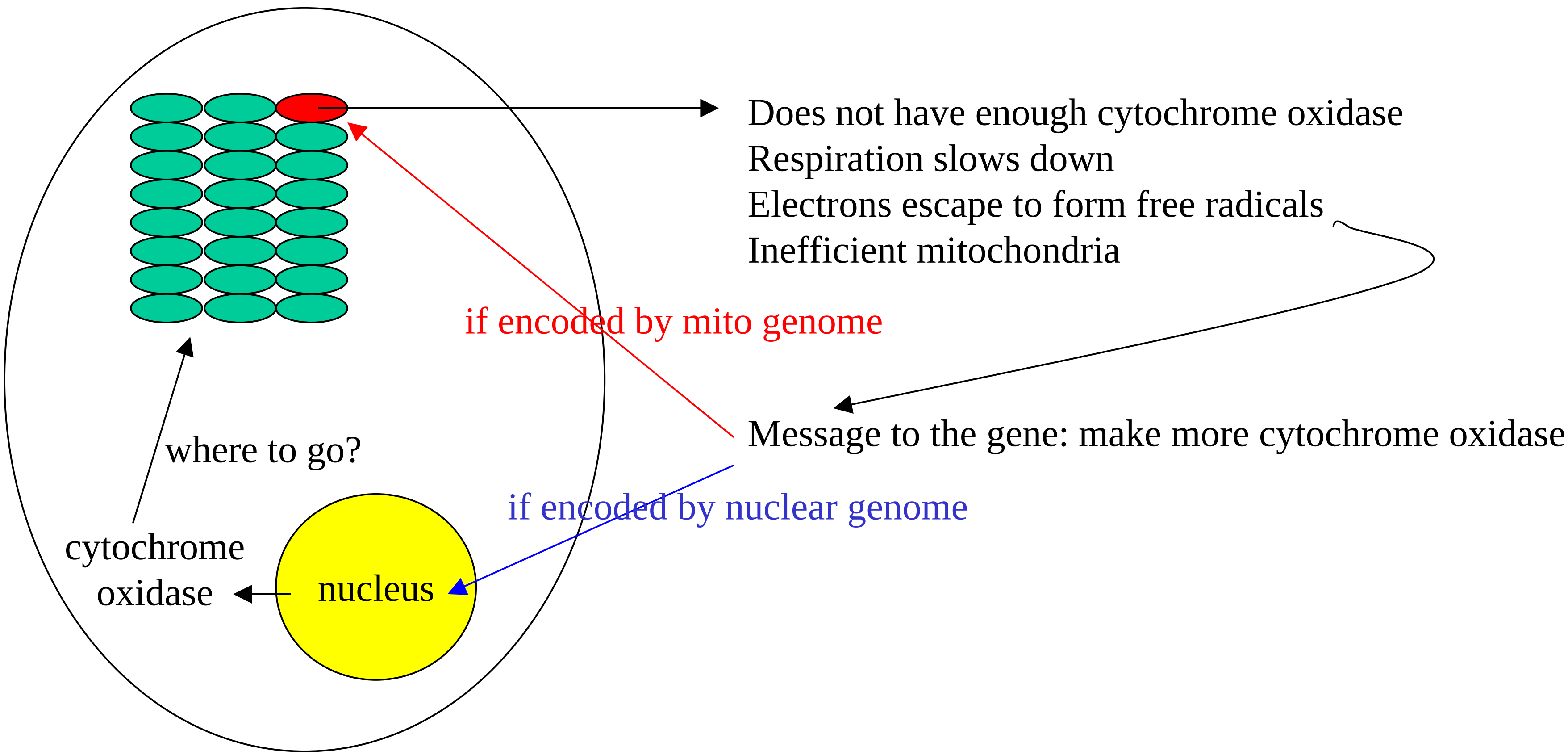
- Keep respiration as fast as possible
- Restrict the leak of reactive free radicals

Correct balance of electrons entering the ETC and the number of carriers

ETC ROS formation and the bathtub



Why mitochondria need genes (not proteins)



How could a few mito genes dominate?

A few core subunits (encoded by mito genes)
act as a flag, around which nuclear subunits assemble
The overall number of flags in the cell as a whole,
at any one time, might remain fairly constant
the rate of respiration in all the mitochondria in a cell at once
is tightly controlled

Both the mito and chloroplast genes of all species always encode
the critical electron-transport proteins

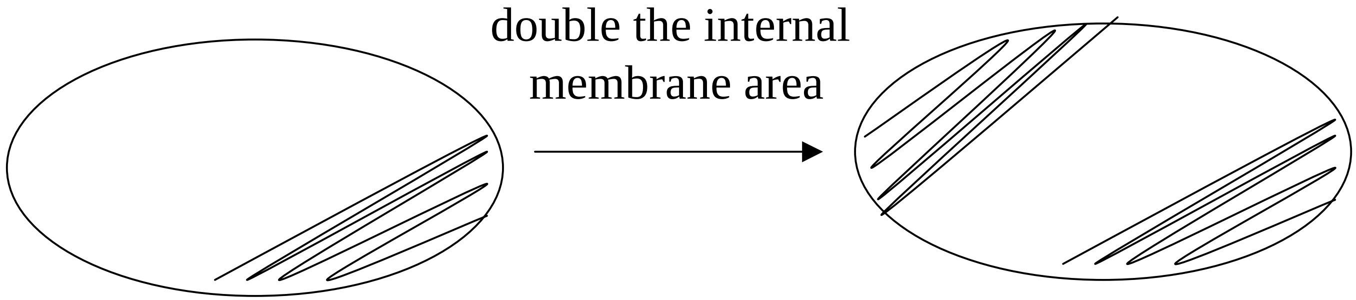
Plasmodium mitochondria
encode 3 proteins: cytochromes

Any organelles that do not need to conduct electrons will lose their genome
ex. hydrogenosomes

Barrier to complexity in bacteria

If mito need a core of genes to control the speed of respiration
bacteria can’t evolve into eukaryotes by natural selection alone

Nitrosomonas and *Nitrosococcus*



Control of respiration?

PART 4 Power Laws
Size and the ramp of ascending complexity

Size & complexity: larger size requires greater genetic and anatomical complexity
Large size: more mito, more power, greater metabolic efficiency

Complexity was programmed: evolution to greater complexity by God

<u>If not programmed,</u>
Complexity by chance?
- simply because there was nowhere to go
- pioneering theory: evolutionary success was more likely to be found
  - in the exploitation of new niches

Complexity was inevitable outcome of the workings of natural selection?
- complexity was possible by an immediate payback for an immediate advantage
- but nature seems to favor simplicity (ex. Bacteria)

1. Evolutionary Drift to complexity

Simply a response to the possibilities offered by the environment

2. Any inherent tendency to complexity?

Sex: suggested by Mark Ridley

Energy rather than sex

- the efficiency of energy metabolism
- greater size favored by a lower living cost (the economy of scale)
- Cope's rule: evolutionary trend towards greater size
  - but evolution also favors to smaller as much as larger

Larger size = greater complexity?

- On being the right size (JBS Haldane)
- 10 fold increase in each dimension means
  - surface area: 100-fold increase
  - mass: 1000-fold increase
- if retaining the same metabolic rate
  - 1000 times more oxygen, food, and waste
  - it means 10 times more absorption of food and oxygen through skin
    and 10 times more excretion of waste through kidney

The higher animals are not larger than the lower

because they are more complicated

(they are more complicated because they are larger)

There surely is a limit on being larger in size

Beyond which, only by way of specific adaptations

specialized organs

differentiated cells

Focusing on cells

larger cells than larger animals

immediate cost:a need for new genes, better organization, more energy

any immediate payback? Power laws of biological scaling

The power laws of biology

Metabolic rate and Mass

Rat compared to human

7 times as much oxygen and nutrients per min
rat cells must work 7 times harder
rat must eat 7 times as much food relative to its size

The larger the animal gets, the less it needs to eat per gram weight
Why?

Max Rubner, 1883
a log-log plot of metabolic rates of 7 dogs against the weights(3.2~31.2 kgs)
the slope was mass$^{2/3}$
explained by the generation of heat and loss (mass & surface area)
mass & surface area: 1000:100 (3:2 in log-log scale)

Max Kleiber

extended the survey to other species

the slope was ¾ (actually 0.73)

extended even further to plant and single cells

A universal law in biology: quarter-power scaling (Kleiber's law)

Then, why 2/3 or 3/4?

A radical explanation by Geoffrey West, James Brown, Brian Enquist in 1997

based on fractal geometry of branching supply networks (ex. circulatory system)

The fractal tree of life

What is fractal geometry? http://en.wikipedia.org/wiki/Fractal

Application to biology

might the fractal geometry of nature's supply networks account for the universal scaling of metabolic rate with body size?

looks high plausible

because the consumption of food and oxygen arrive at the individual cells by way of the branching supply network (blood vessels)