Indian railway network

WHAT IS SHOWN

- Cities and towns of India connected by rail
- **Entities / places**

WHAT IS NOT SHOWN

- Number of trains in each route
- What determines how many trains operate in a route
- **Flux (dynamic movement)**

www.indmaps.com/railway-map

Mumbai city map

WHAT IS SHOWN

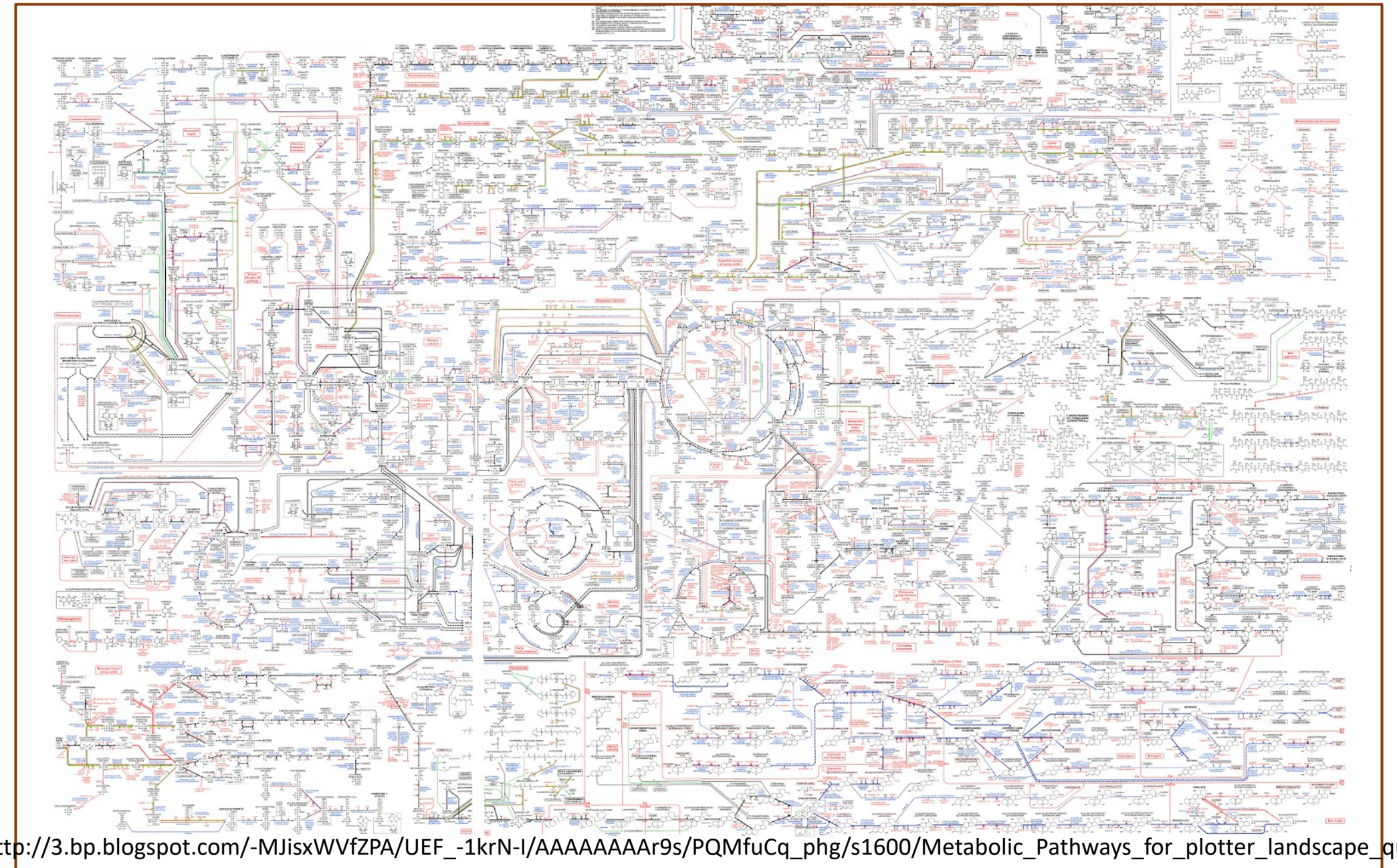
- Various locations connected by road (road network)

WHAT IS NOT SHOWN

- Number of vehicles in each road
- What determines how many vehicles ply on a road
- Temporal variations

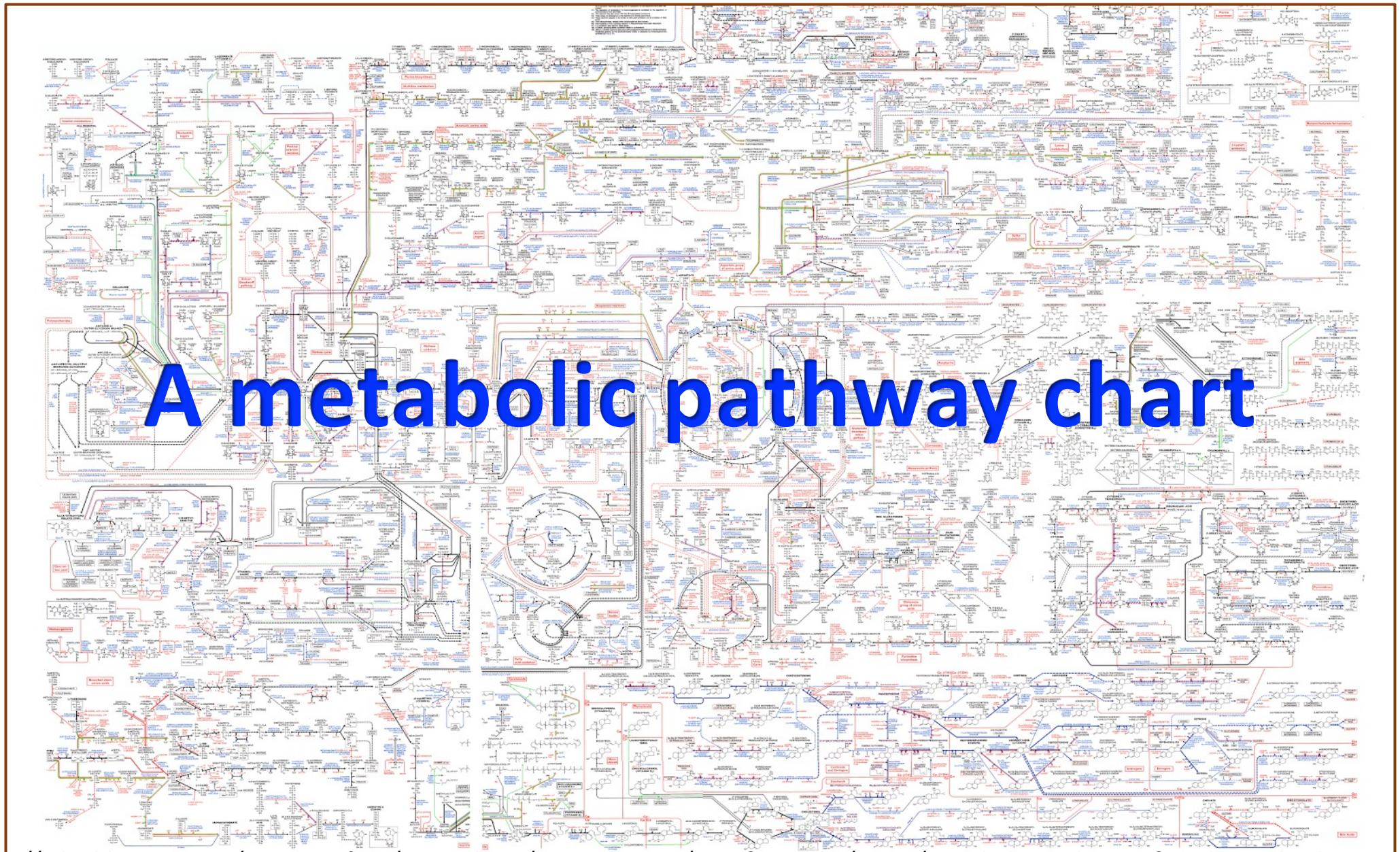
www.mapsofmumbai.com/general-information/maps/mumbai-city-map.html

What can this be?



http://3.bp.blogspot.com/-MJisxWVfZPA/UEF_-1krN-I/AAAAAAAAr9s/PQMfuCq_phg/s1600/Metabolic_Pathways_for_plotter_landscape_quantized.png

What can this be?



http://3.bp.blogspot.com/-MJisxWVfZPA/UEF_-1krN-I/AAAAAAAAr9s/PQMfuCq_phg/s1600/Metabolic_Pathways_for_plotter_landscape_quantized.png

Metabolic pathway chart

- A metabolic pathway chart is like a rail or road map
- A dot represents a metabolite i.e., chemical compound
- A line connects compounds that can be inter-converted

- Metabolism is the totality of an organism's chemical reactions
- Metabolism is an emergent property
  - Emergent properties are those that arise from the **orderly arrangement and/or interactions** of a set of components / parts
  - The parts / components by themselves do not have the "property"

We are discussing the metabolism of… all organisms!

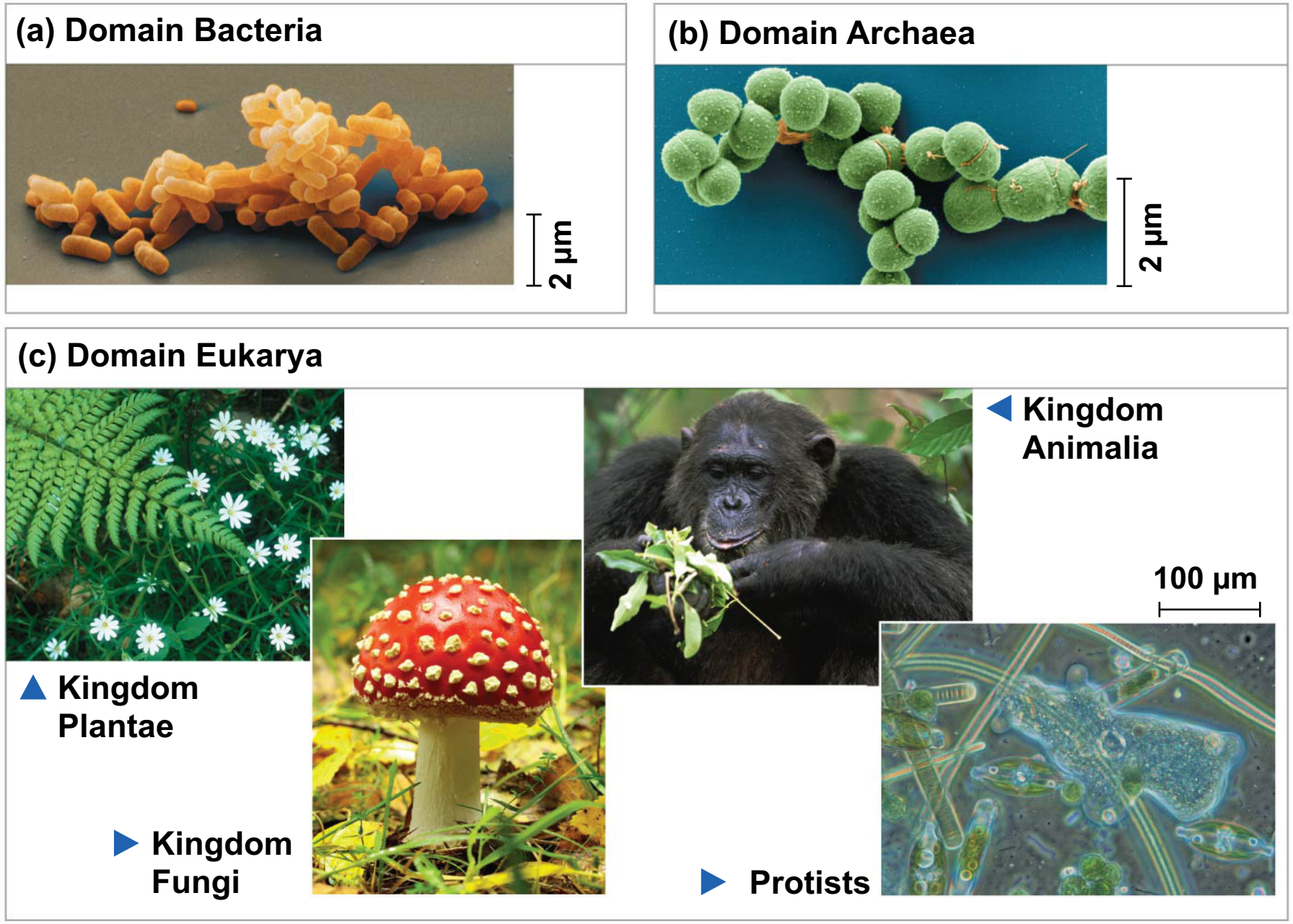


Figure 1.15 of Campbell Biology by Reece and others (10th edition)

Today's topics

- Why does a cell need metabolism?
- Concept of energy currencies
- Standard and cellular conditions
- An overview of respiration

Cell: a thermodynamic “open” system

From the view point of thermodynamics, a cell is an open system

- Cells exchange both heat and matter with the surroundings
- To do this “work”, cells need energy
- Cells uptake nutrients, metabolize them, and excrete waste products

Living systems work within the framework of the laws of thermodynamics

Source of biomolecules

Two of the key characteristics of life:

- Reproduction
- Growth and development

A few key components of a cell

- DNA, protein, carbohydrates, lipids
- Cyclic AMP, GTP, …

From where do organisms get these biomolecules?

Slide from Lecture 5

Growth media

Minimal medium consists of
- inorganic salts,
- glucose and
- biotin (a vitamin)

in agar, a support medium

Complete medium consists of
- minimal media,
- all 20 amino acids and
- a few other nutrients

in agar, a support medium

Slide from Lecture 5

BB101 Biology
March – June 2023
Lecture 05

Central dogma

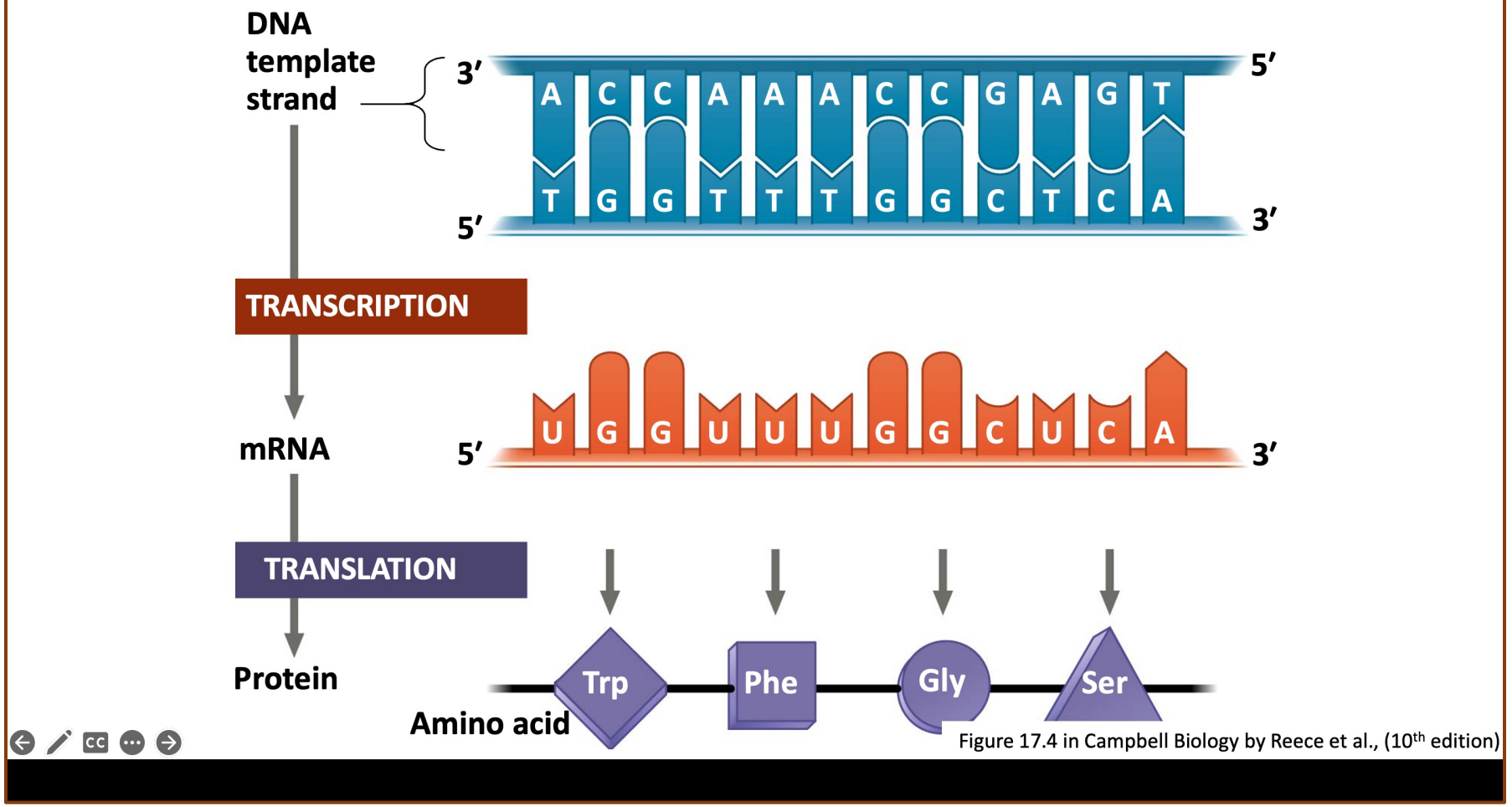


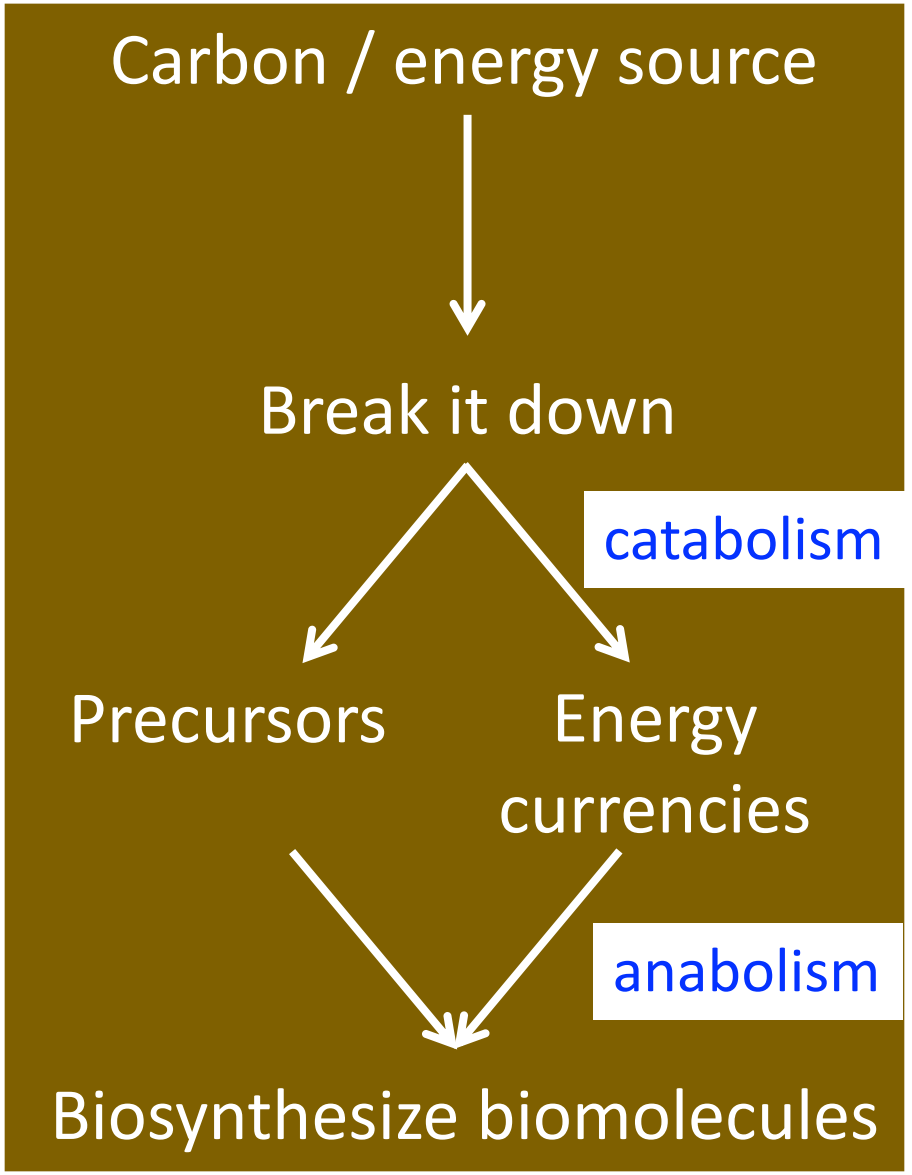
Figure 17.4 in Campbell Biology by Reece et al., (10th edition)

Central Dogma is about the flow of information

Metabolism makes a cell alive

Extract and biosynthesize

- Metabolism as a whole manages the energy and material resources of a cell
- Catabolism – breaking down energy and/or carbon source to precursors to extract energy
- Anabolism – use energy and precursors to build up required biomolecules
- Examples of each from previous lectures?



Concept 8.3 of Campbell Biology by Reece and others (10th edition)

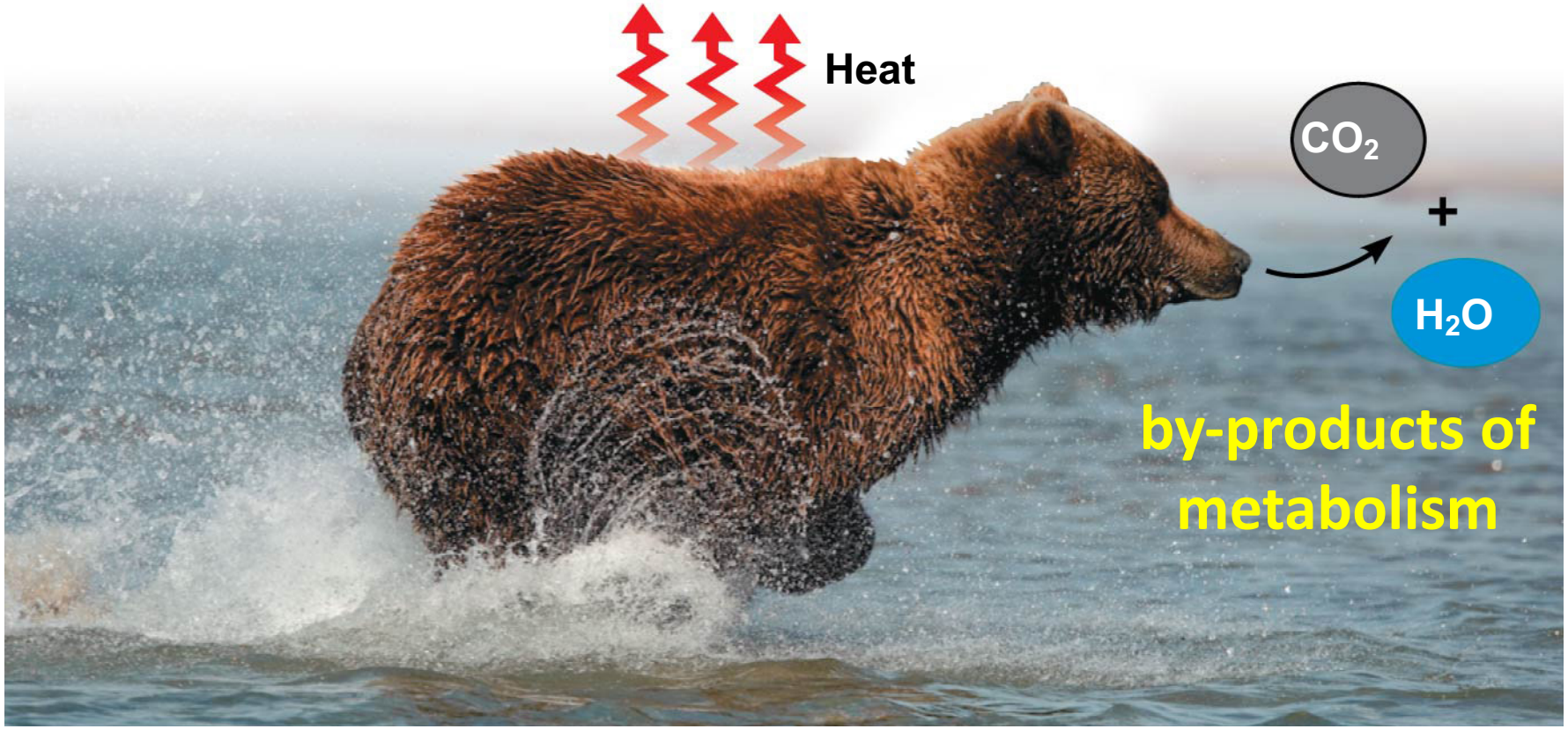
Interconversions of energy forms

First law of thermodynamics

Energy can be transferred or transformed, but cannot be created or destroyed

The brown bear “metabolizes” the fish it is eating to extract precursors for biomolecules as well as required energy

Life and disorder

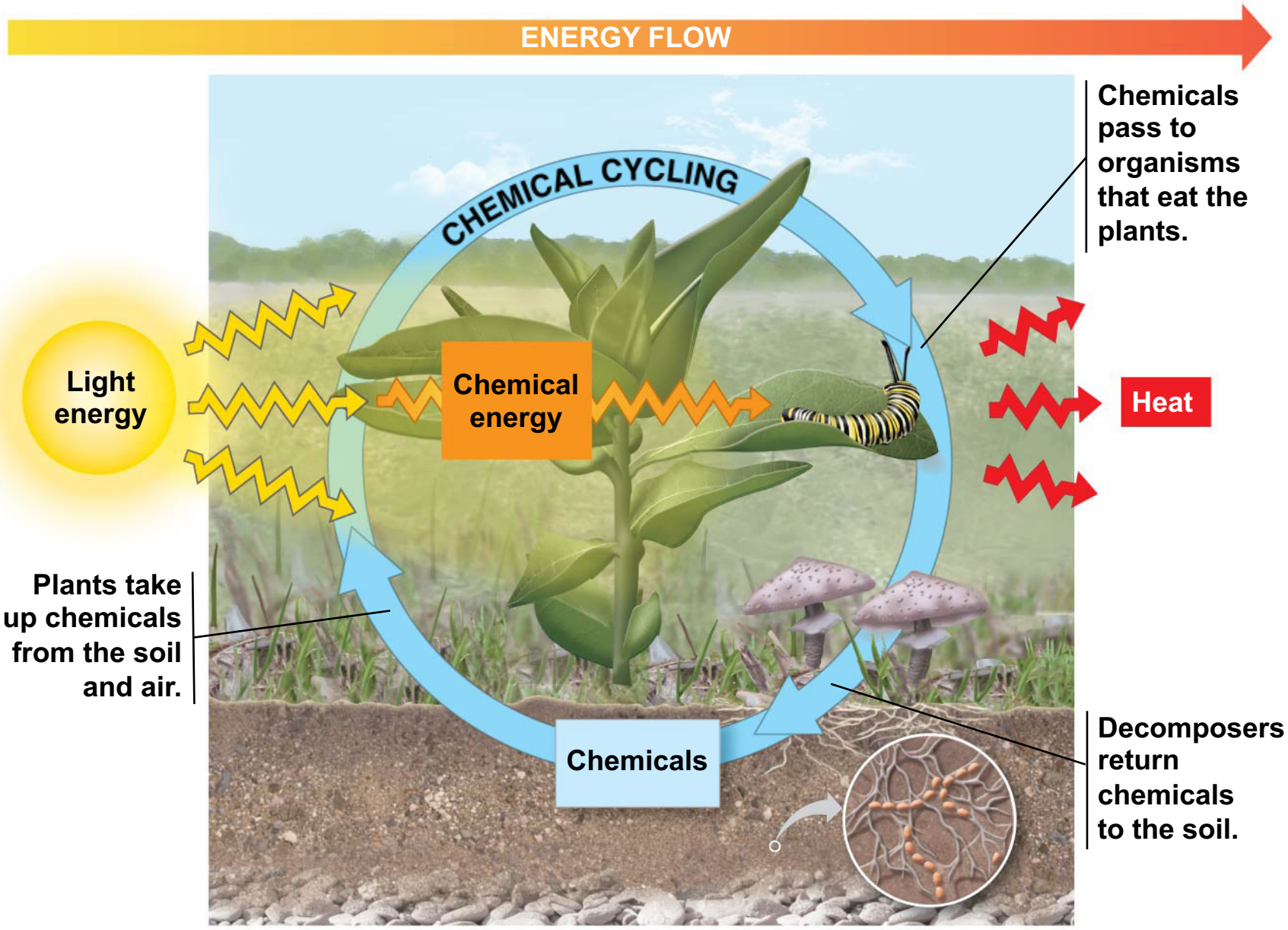


Second law of thermodynamics: every energy transfer or transformation increases the disorder (entropy) of the universe

Organisms are “organized” at the cost of the system.

Concept 8.3 of Campbell Biology by Reece and others (10th edition)

Energy and matter are connected on the planet



Energy and carbon cycles

Figure 1.9 of Biology. A global approach

Today's topics

- Why does a cell need metabolism?
- Concept of energy currencies
- Standard and cellular conditions
- An overview of respiration

Figure 1.15 of Campbell Biology by Reece and others (10th edition)

Barter system

Utility of currency (money)

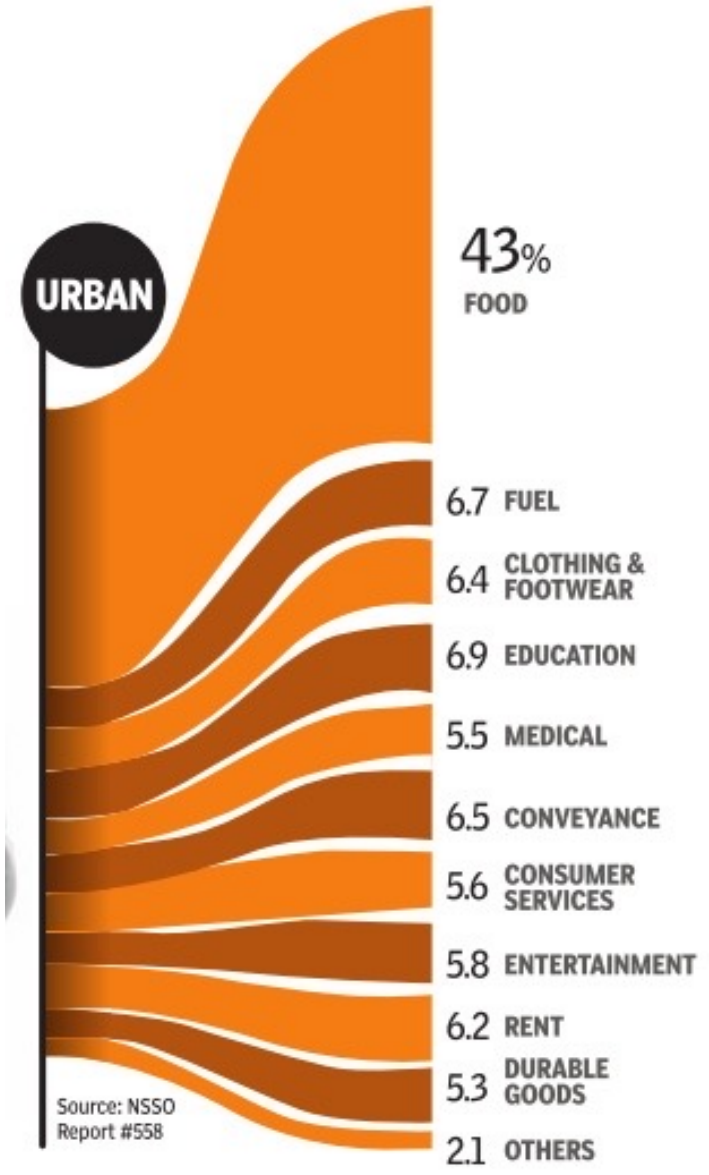
I want your product

I don’t want your product

You don’t want my product

No barter, only money

- Quantify goods and services in terms of “currencies”
- Exchange goods and services for “currencies”



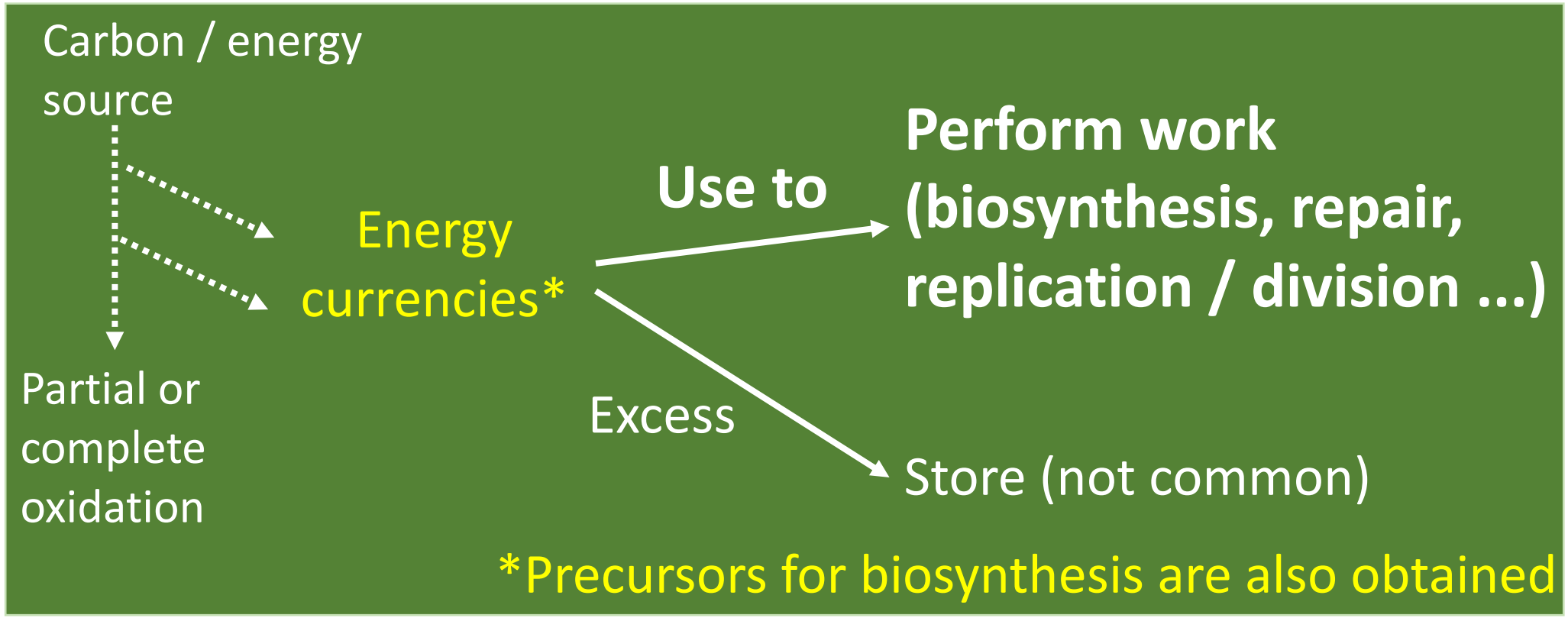
http://indpaedia.com/ind/index.php/Household_expenditures:_India

https://www.dnaindia.com/personal-finance/report-minimum-basic-salary-of-private-employees-to-rise-from-rs-15000-to-rs-21000-2901507

No barter, only money

Organisms metabolize energy source (nutrient) and extract "useful energy" in the form of energy currencies

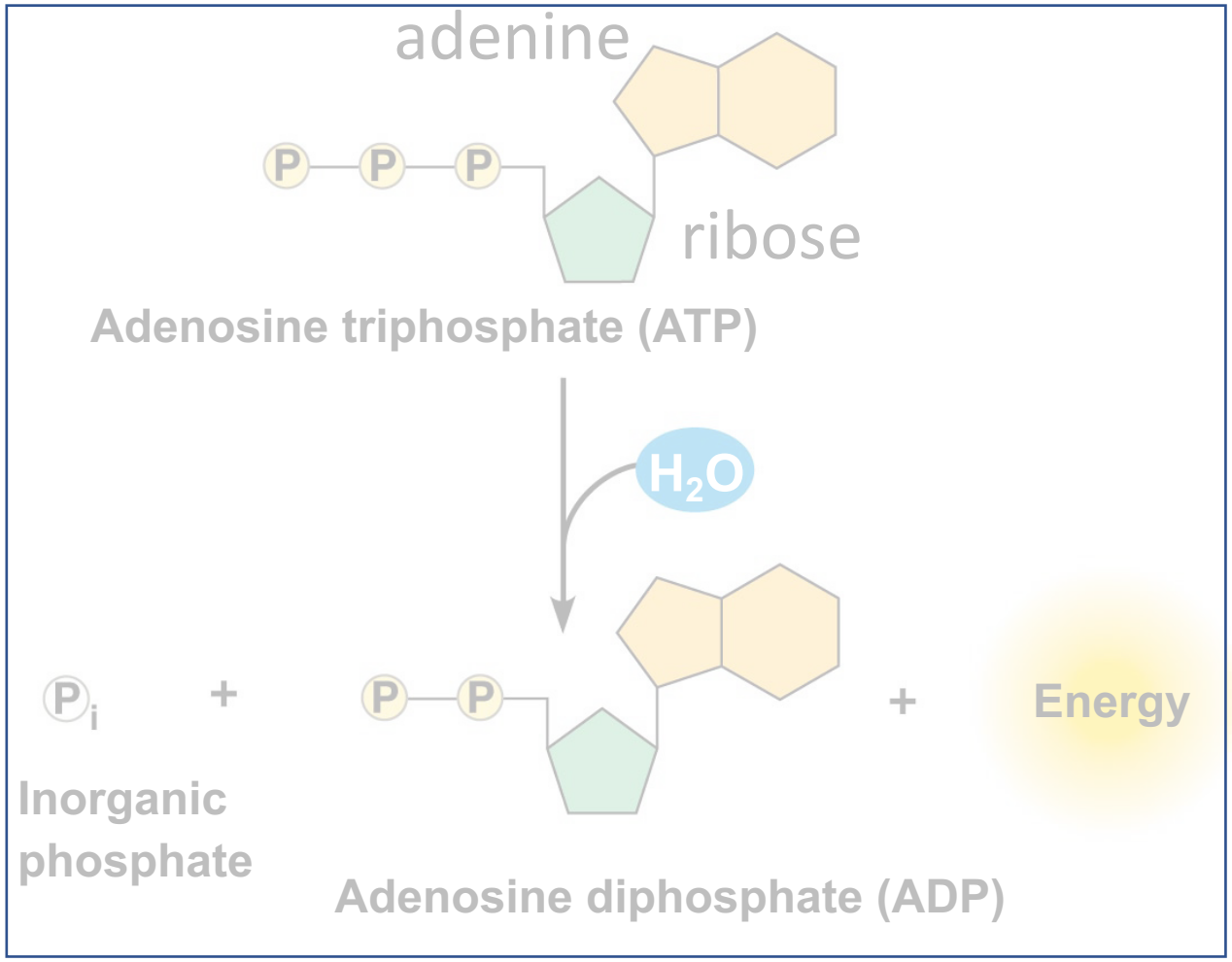
Energy extracted is utilized for performing "work"



Types of energy currencies

- Compounds such as ATP
  - (high energy bond containing compounds)
- Electrochemical / chemical gradients
  - Differences in the concentrations on two sides of a membrane
- Compounds with “high” redox potentials
  - Reduction-oxidation reactions may be seen as energy transduction (= converting from one form to another) reactions

Adenylate pool is a widely used energy currency



ATP: an energy shuttle

Energy is released upon hydrolysis

Energy comes from the chemical change to a state of lower free energy

Note: Adenylate pool (AMP, ADP, ATP), rather than ATP, is the energy currency

Figure 8.9 of Campbell Biology by Reece and others (10th edition)

NAD: electron shuttles as energy currencies

$$NAD^+ + 2H^+ + 2e^- \rightleftarrows NADH + H^+$$

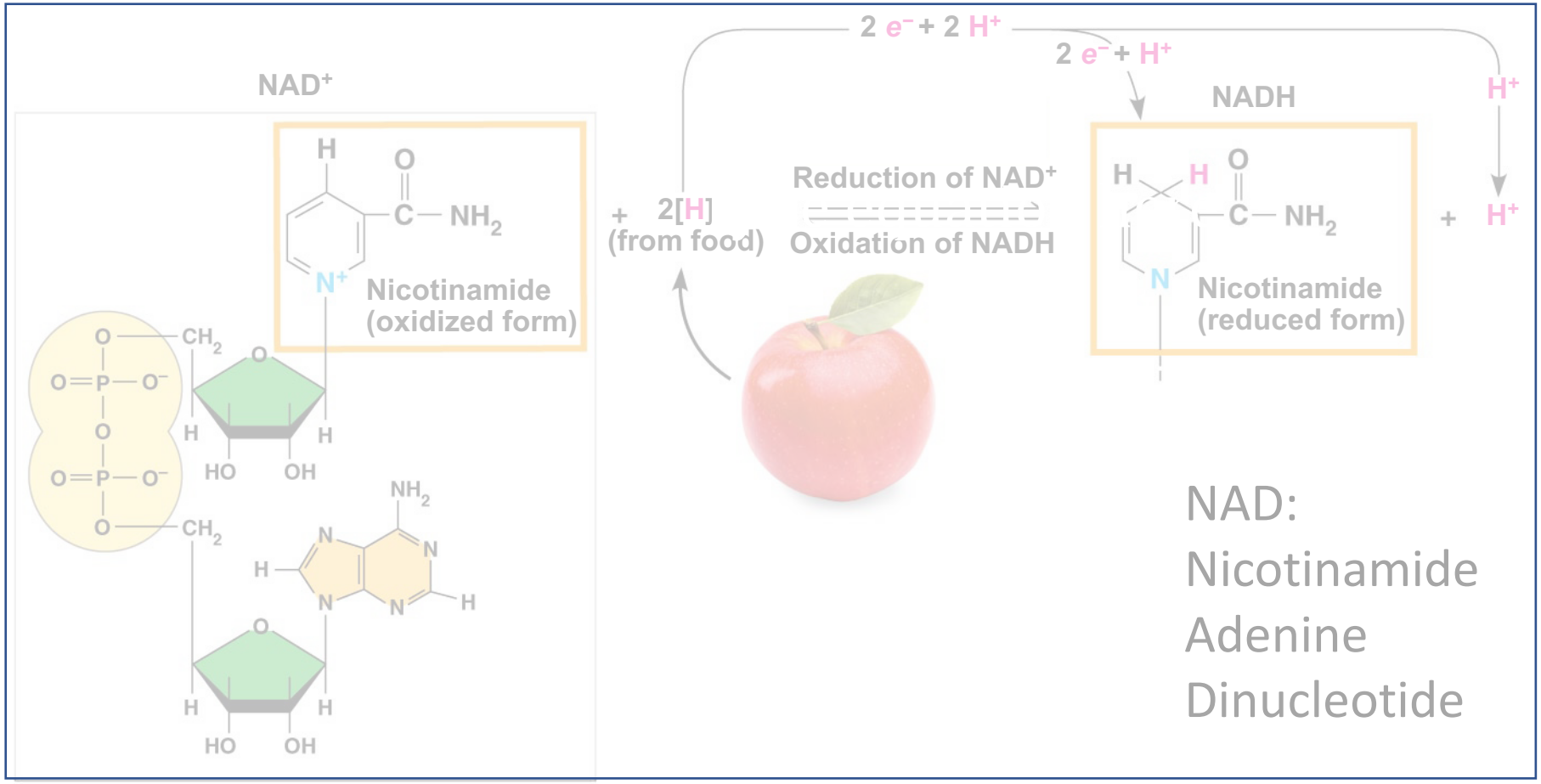
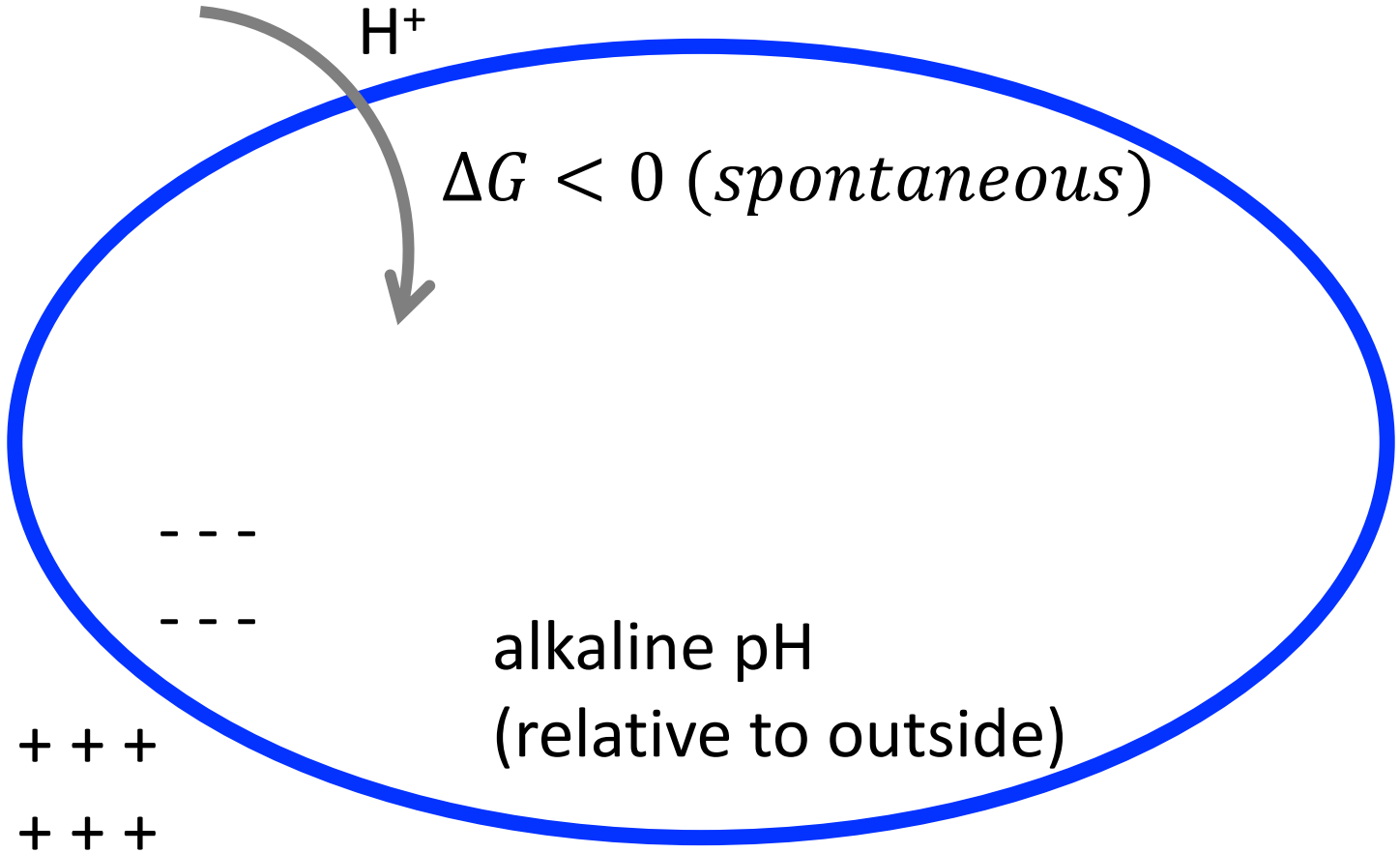


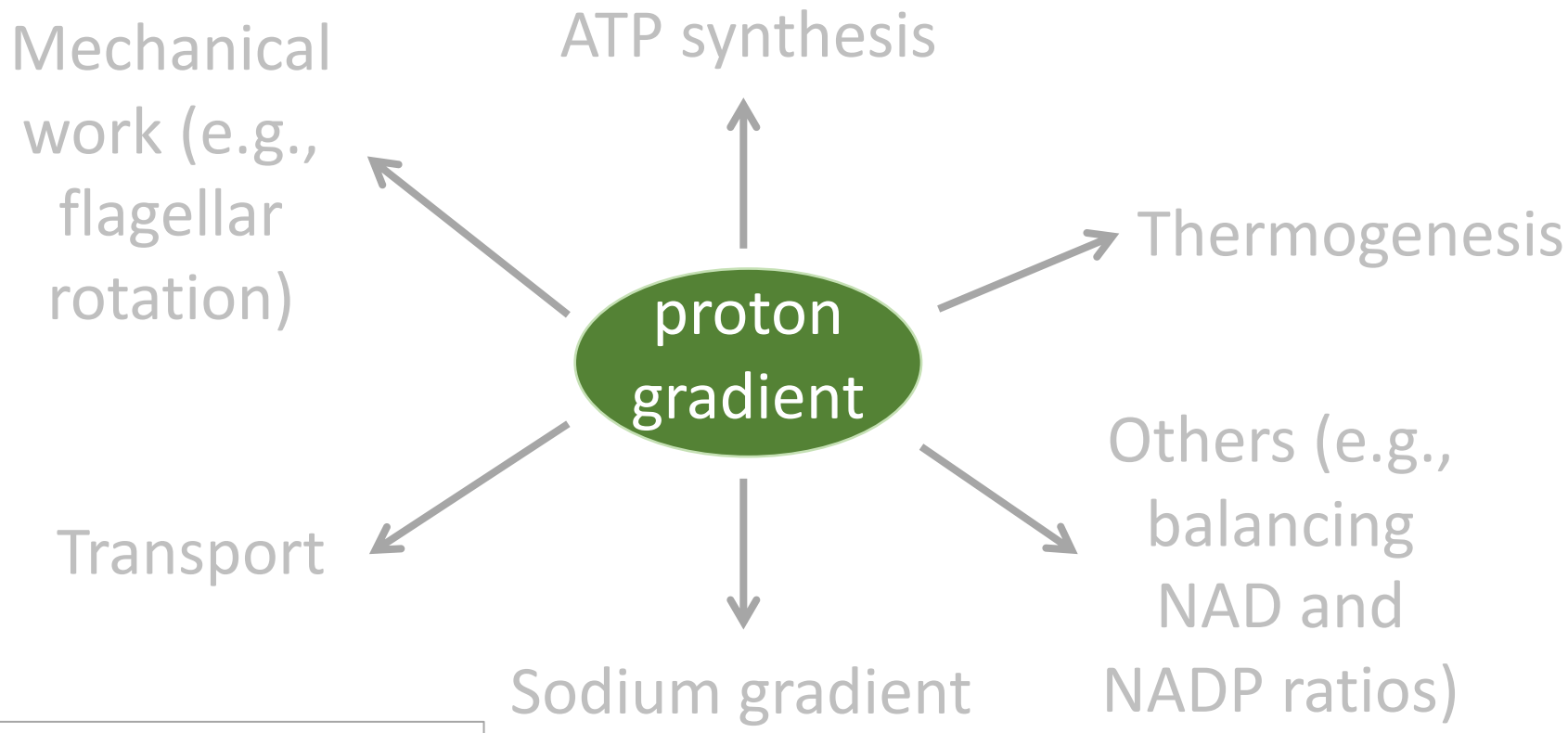
Figure 10.4 of Biology. A global approach

Ion gradients as energy currencies



G: Gibbs free energy
Amount of energy used for doing work

Proton gradient: an ancient energy currency



Proton gradients evolved before ATP
Primitive life conditions had pH gradients

A semi-permeable membrane suffices to generate this currency

Why multiple energy currencies?

Thermodynamic requirements impose an upper limit on the amount of energy that can be stored using one type of energy currency

Cash (liquidity)

Gold (stability)

Stock market (returns)

https://www.zeebiz.com/hindi/stock-markets/stocks/live-updates-stock-market-live-on-30-september-2022-sensex-nifty-dow-jones-nasdaq-sgx-nifty-and-asian-markets-updates-97984

https://financepost.in/sebi-proposes-framework-for-gold-exchange/

http://media.indiatimes.in/media/content/2016/Nov/reuter_1479816288.jpg

Kibber, an exotic Himalayan village where barter system is still in vogue

Our Correspondent

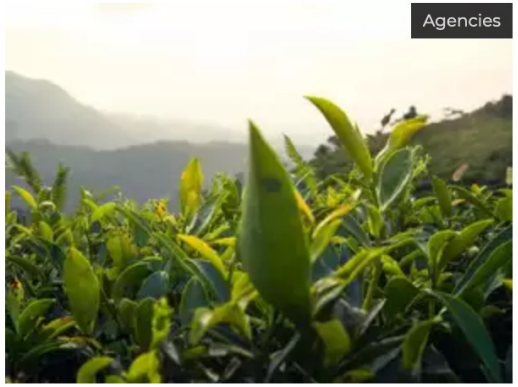
Published: September 19, 2019 07:49 AM IST | Updated: September 19, 2019 09:07 AM IST

ETPrime

Barter trade agreement between Sri Lanka and Iran to hit India's tea exports to West Asian nation

By Sutanuka Ghosal, ET Bureau • Last Updated: Jan 13, 2022, 01:36 PM IST

Synopsis
Sri Lanka will send orthodox tea or whole leaf teas to Iran to pay off its oil purchase dues. Iran buys orthodox teas only for its domestic consumption and India has been one of the biggest suppliers of orthodox teas to the West Asian nation.



India's tea exports in the first 10 months of 2021 fell 8.7% year-on-year to 157.20 million kg and the figure is unlikely to have crossed 180 million in the entire 2021, according to industry executives.

India's tea exports to Iran, which have halved compared to the pre-pandemic period in 2019 due to payment problems, are set to take a further hit this year as Sri Lanka has entered into a barter trade agreement with Iran to pay off its earlier debts against oil purchases.

Sri Lanka will send orthodox tea or whole leaf teas to Iran to pay off its oil purchase dues. Iran buys orthodox teas only for its domestic consumption and

Today's topics

- Why does a cell need metabolism?
- Concept of energy currencies
- Standard and cellular conditions
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Figure 1.15 of Campbell Biology by Reece and others (10th edition)

$\Delta G^{0\prime}$ and K_{eq}

- $\Delta G^{0\prime}$ and K_{eq} are characteristic constants of a reaction
- Are defined for standard conditions:
  - Initial concentrations of reactants = 1 M
  - Initial concentrations of products = 1 M
  - T = 298 K
  - Pressure (where applicable) = 1 atm
  - $[H_2O] = 55.5\ M$
  - $[H^+] = 10^{-7}\ M$

$\Delta G^{0\prime}$ and K_{eq}

$$A \rightarrow B \qquad \Delta G^{0\prime} = -RTlnK_{eq}$$

K_{eq}	$\Delta G^{0\prime}$	Reaction
1	= 0	Is at equilibrium
< 1	> 0	Is endergonic Will NOT take place, ever
> 1	< 0	Is exergonic (also called as spontaneous) Will take place How long to reach equilibrium is not known

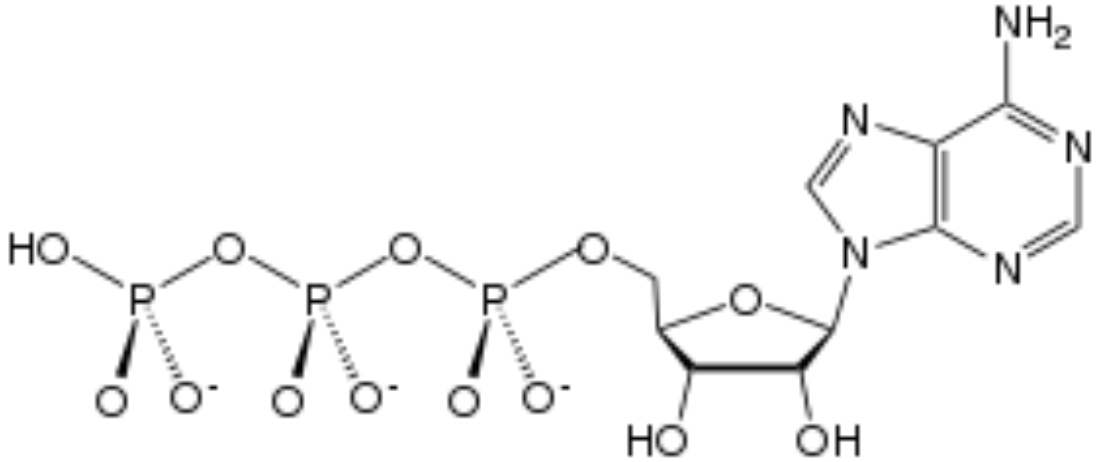
$\Delta G^{0\prime}$ and K_{eq}

- A matter of nomenclature...
  - Exergonic and endergonic – with respect to free energy change

    not to be confused with...
  - Exothermic and endothermic – with respect to heat (or enthalpy)

Value of a currency

By spending this currency note, we can buy goods / services worth Rs. 200



By hydrolyzing a mole of ATP, how much work can a cell get to do

https://en.wikipedia.org/wiki/Adenosine_triphosphate

Under standard conditions...

$$ATP + H_2O \rightarrow ADP + P_i \qquad \Delta G^{0\prime} = -32kJ/mol$$

- Standard conditions: 1M initial concentrations – not realistic
- ΔG under cellular conditions?

Under cellular conditions...

"Free energy" available to a cell from hydrolysis of a molecule of ATP is *dependent* on the number of molecules of ATP, ADP and P_i present

$$\Delta G = \Delta G^{0\prime} + RTln\frac{[ADP][P_i]}{[ATP]}$$

Value of each currency note

- "Value" of a currency note is *independent* of the total number n (n = 1, 2, 3, ...) of such notes
- Suppose you spend "one note" of Rs. 2000
- The value of the "next note" of Rs. 2000 still remains the same

http://media.indiatimes.in/media/content/2016/Nov/reuter_1479816288.jpg

Free energy of ATP hydrolysis

Manufacturer Supply Pure ATP Powder

from Xi'an Lyphar Biotech Co., Ltd.

Price US $135-180. **Minimum Order** 1 Kilogram. **Location** China (Mainland). **Company** Xi'an Lyphar Biotech Co., Ltd.. **Response Rate** . **Mf** C10H16N5O13P3. **Other Names** Adenosine triphosphoric acid. **Other Name** Triphosadenine. **Purity** 99%. **Type** Auxiliaries and Other Medicinal Chemicals. **Grade Standard** Cosmetic Grade,Food Grade,Medicine Grade,Medicine Grade,Food Grade

USD 135.00

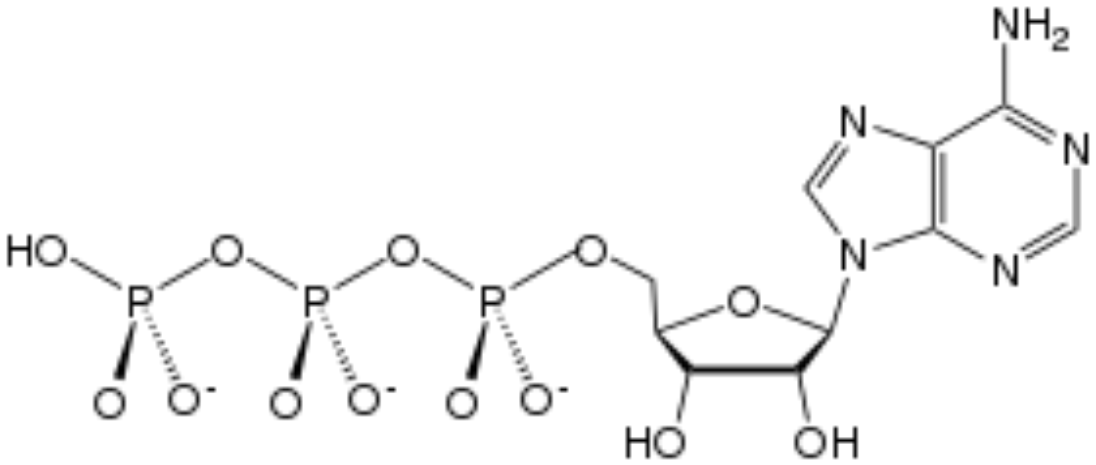
Minimum order is only **1 Kilogram**

Buy Now

screen shot of the supplier's web site

If we buy pure ATP, place it in a beaker and carry out hydrolysis, what will be the ΔG value?

Value of each ATP (hydrolysis)



$$\Delta G = \Delta G^0 + RTln\frac{[ADP][P_i]}{[ATP]}$$

- "Value" of a mole of ATP i.e., the amount of free energy available to the system by hydrolysing a mole of ATP is *dependent* on the concentrations of ATP, ADP, and Pi

https://en.wikipedia.org/wiki/Adenosine_triphosphate

Free energy of ATP hydrolysis

"Free energy" available to a cell from hydrolysis of a molecule of ATP

is *dependent* on the number of molecules of ATP, ADP and P_i present

$$\Delta G = \Delta G^{0\prime} + RTln\frac{[ADP][P_i]}{[ATP]}$$

As the reaction proceeds, the concentration of ATP will decrease and that of ADP and P_i will increase. The "free energy" of ATP undergoing hydrolysis keeps changing!

Value of each currency note

- Can we spend each and every "note" of Rs. 2000 shown here?
- Of course, yes!

http://media.indiatimes.in/media/content/2016/Nov/reuter_1479816288.jpg

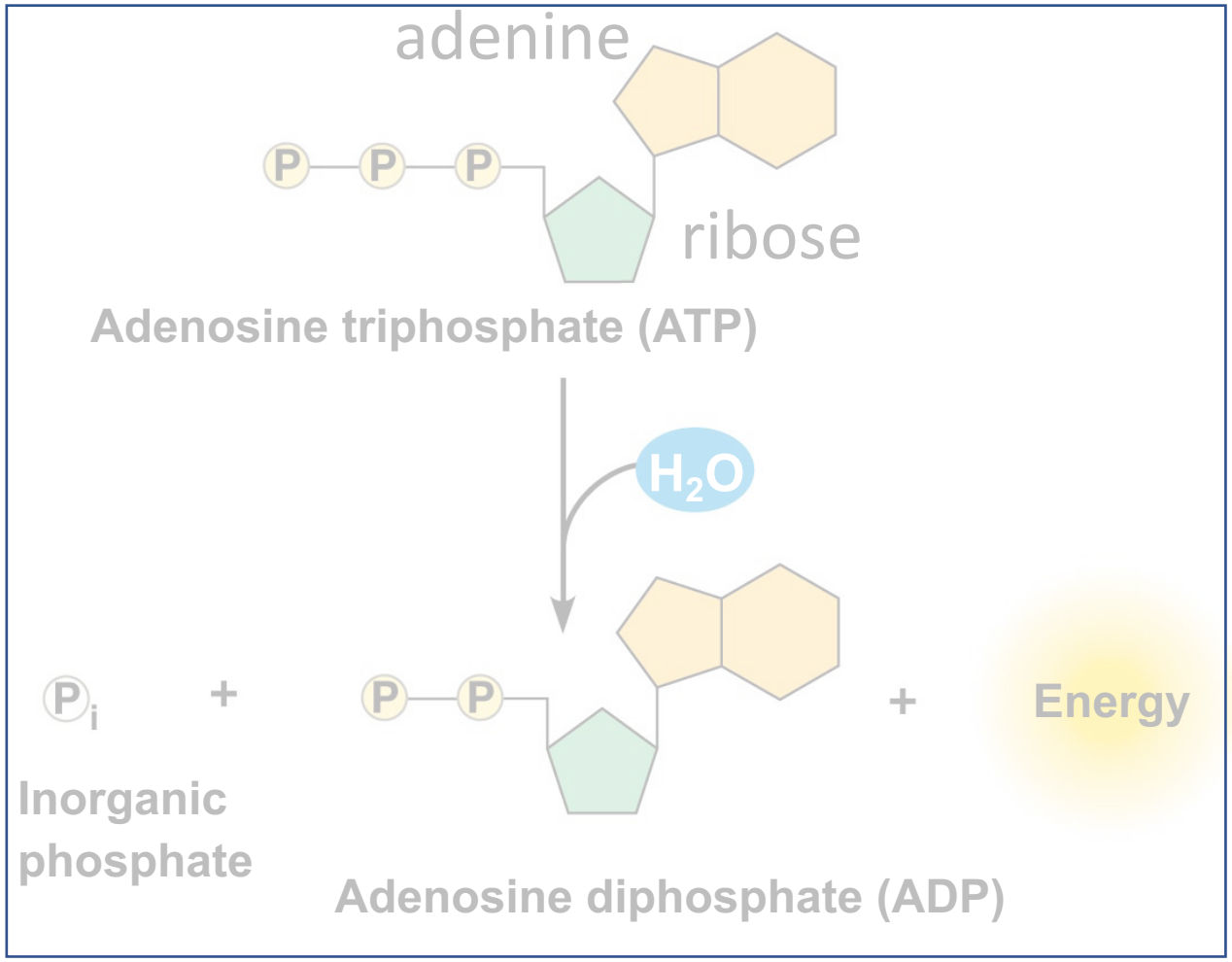
Free energy of ATP hydrolysis

- Suppose we start with ATP

  place it in a beaker and

  carry out hydrolysis...
- Will each and every molecule of ATP get hydrolyzed?
- Of course, no!
- Reaction reaches equilibrium and no more net hydrolysis of ATP!

ATP hydrolysis releases energy



ATP hydrolysis continues to release energy

IF AND ONLY IF

ATP is continuously replenished

AND

ADP, P_i are continuously depleted

Figure 8.8 of Campbell Biology by Reece and others (10th edition)

Currency: used by cells and by humans

How to continuously
replenish ATP and
deplete ADP and P_i?

Simple:
Use ADP and P_i to synthesize ATP

- Humans can accumulate unlimited amount of "currency"
- In contrast, cells cannot store unlimited amount of energy currency
  - Do NOT take an anthropocentric perspective
  - Adaptations for storing energy, need for storing energy, etc.

Equilibrium is death

When the system is at equilibrium, free energy is not available any more
If free energy is not available, then work cannot be done

- Cells are not in equilibrium; they are open systems experiencing a constant flow of materials
- A defining feature of life is that metabolism is never at equilibrium

Today's topics

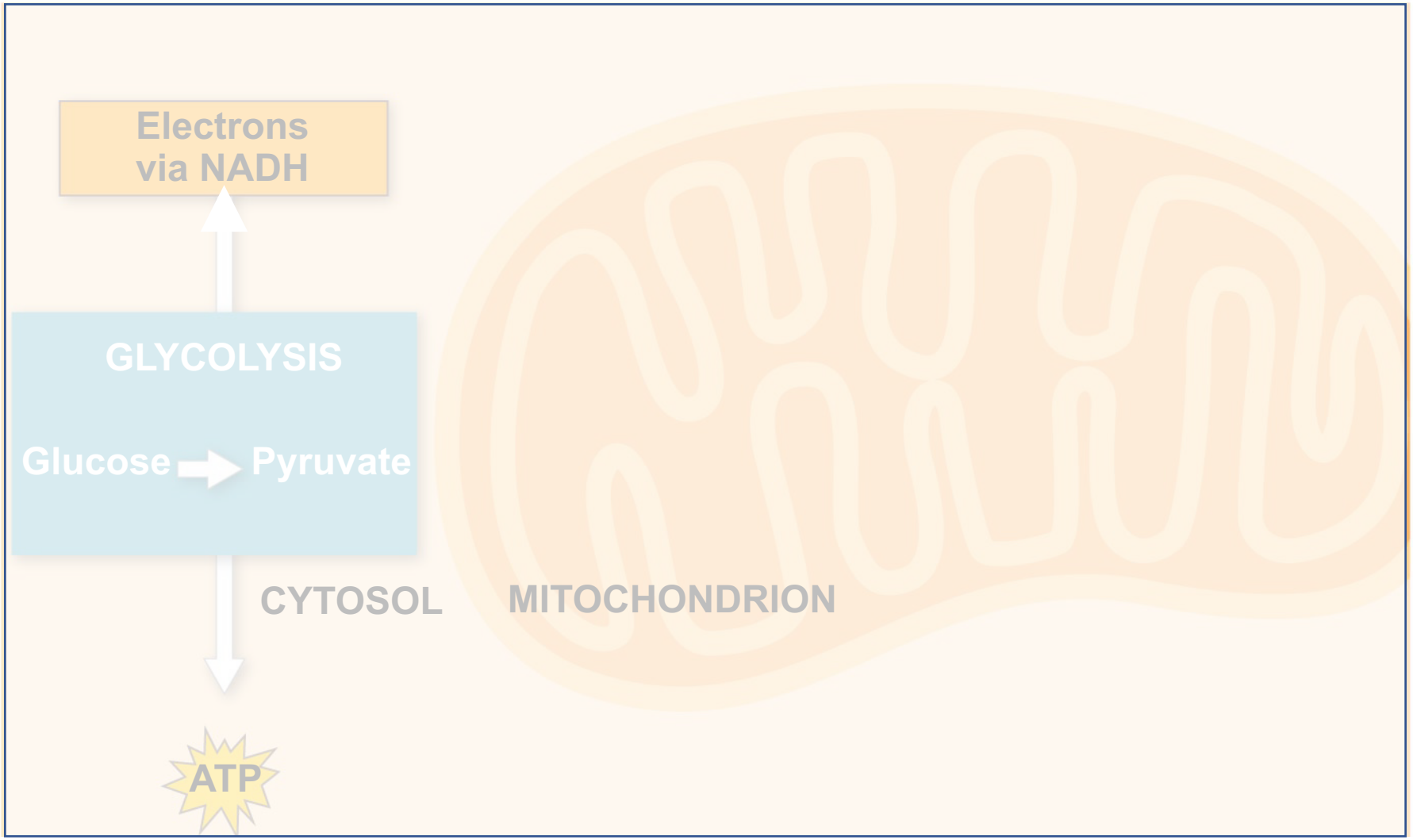
- Why does a cell need metabolism?
- Concept of energy currencies
- Standard and cellular conditions
- An overview of respiration

Figure 1.15 of Campbell Biology by Reece and others (10th edition)

Respiration

- In day-to-day life
  - Breathing in and out of air
- In Biology
  - Complete oxidation of glucose (to carbon dioxide)
  - (can be any other source of carbon / energy)

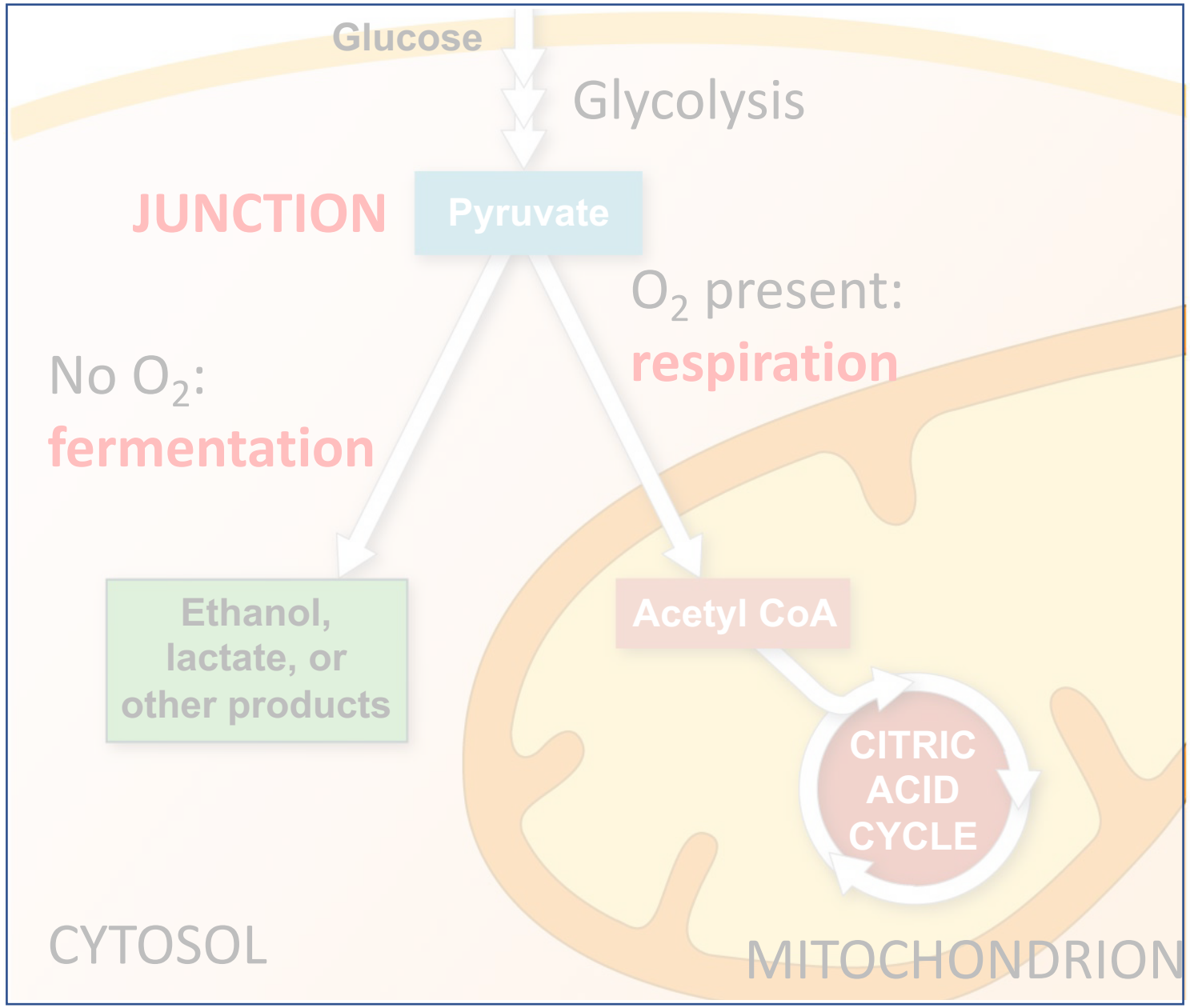
Cellular respiration: stage 1 of 3



Glycolysis: breaking down of glucose to pyruvate

Figure 9.6 of Campbell Biology by Reece and others (10th edition)

Fermentation or respiration?



- Fate of pyruvate?
- Complete oxidation
  - Respiration
- Partial oxidation
  - Fermentation
  - Muscle cells (intense exercise)
  - Ethanol, lactate, ... are products

Figure 9.18 of Campbell Biology by Reece and others (10th edition)

Warburg effect

Otto H. Warburg
(1883-1970)
Image: Wikipedia

Cancer cells: high rate of glycolysis
Possible reasons: lack of oxygen
Shut down mitochondria
- Incomplete oxidation – need for precursors
- Avoid generating reactive oxygen species

Angiogenesis: formation of blood vessels
Promoted in cancer – to get more oxygen

Cancer cells – heterogeneous
Some ferment, others respire – depends upon their location relative to blood vessels

Pathway: common; Regulation: different

Yeast prefers fermentation even when oxygen is available
Fermentation to respiration switch is regulated by glucose

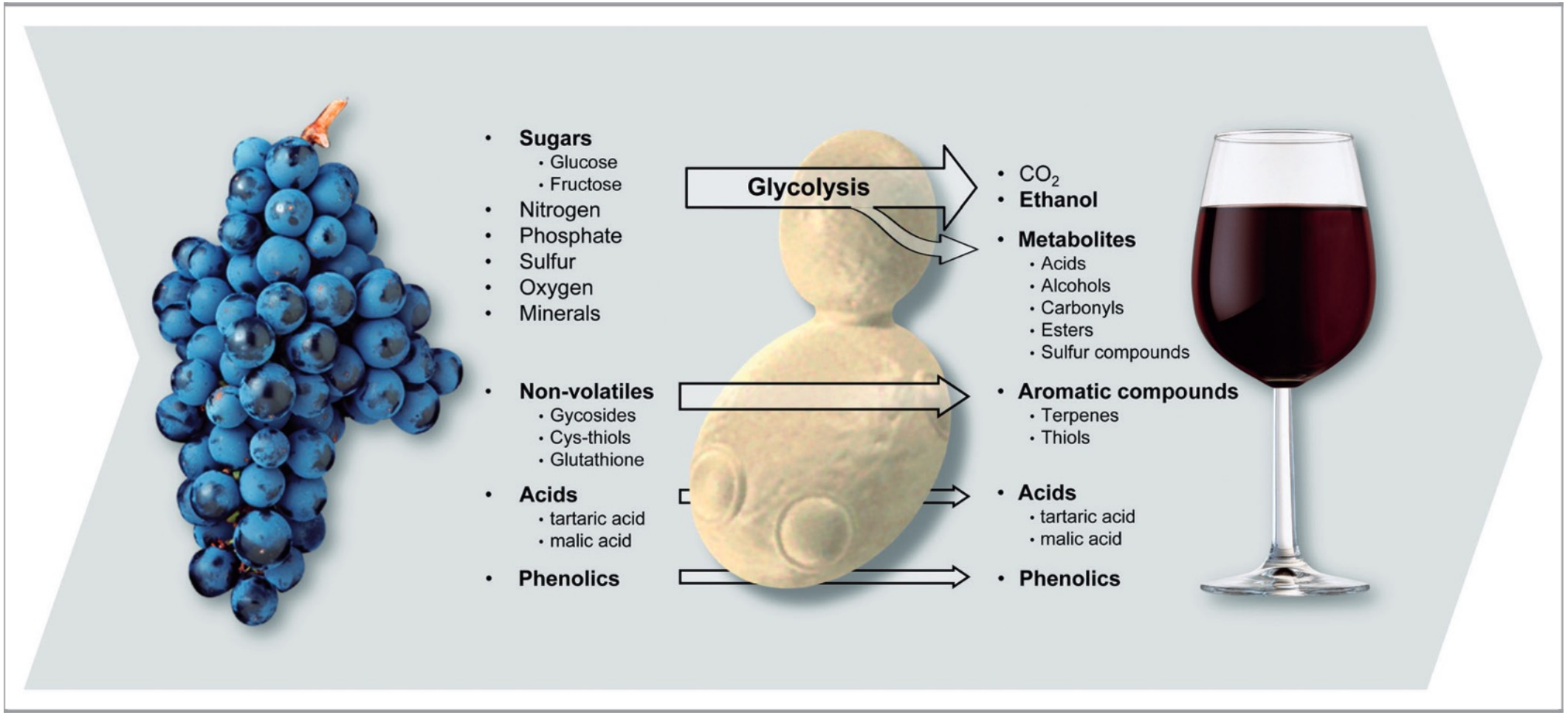
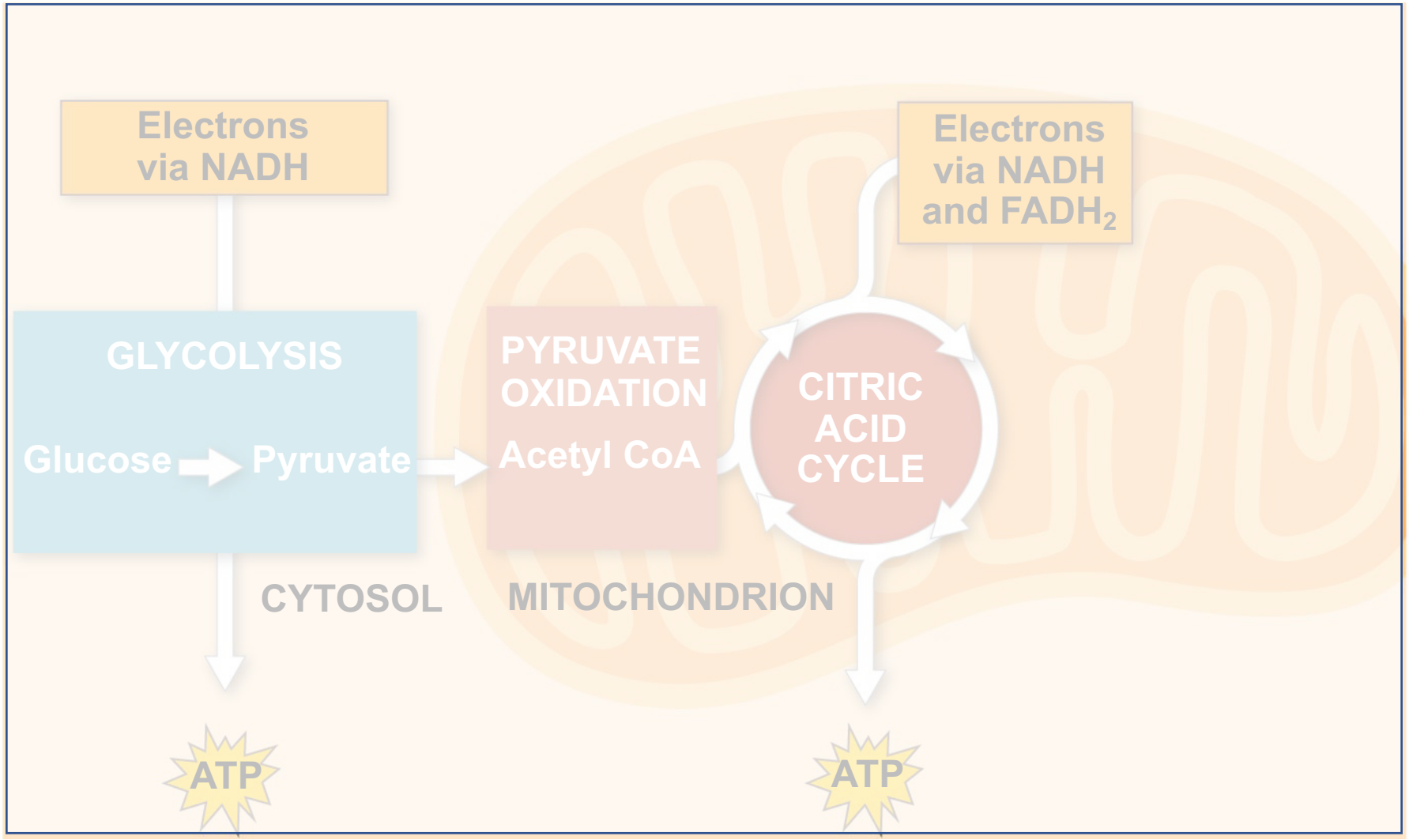


Figure 1 in the research article published in “Bioengineered bugs” (2012, Vol. 3, pp147-156)

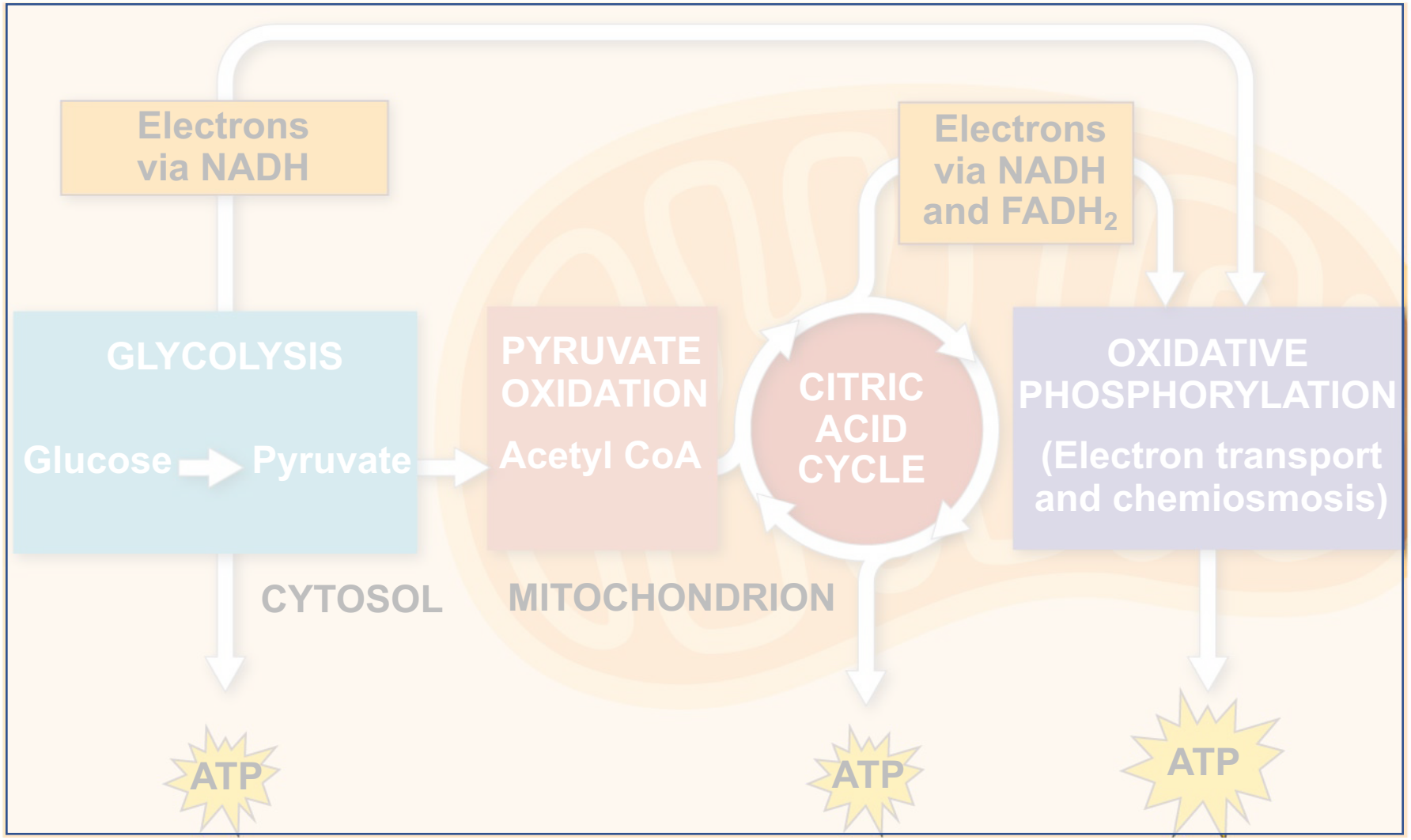
Cellular respiration: stage 2 of 3



Pyruvate to acetyl coenzyme A, then to CO_2 via TCA cycle

Figure 9.6 of Campbell Biology by Reece and others (10th edition)

Cellular respiration: stage 3 of 3



Using NADH to synthesize ATP

Figure 9.6 of Campbell Biology by Reece and others (10th edition)

Chemiosmosis

Peter D Mitchell
(1920-1992)
(Image: wikipaedia)

Proposed in early 1960s that NADH oxidation and ADP phosphorylation are linked by a proton gradient

No one believed him – had to set up lab in a house

Persisted with his idea – designed experiments to prove – culminated in the award of Nobel prize in 1978

IIT Bombay startup
Based on metabolism

KV Venkatesh (Chemical Engineering)

Company: MetFlux Research Pvt. Ltd.

A Systems Biology-based Artificial Intelligence Company