CALORIMETRIC BIOSENSORS

Enthalpy change for some enzymes

Enzymes	Reactants	$-\Delta H$ (kJ·mol^{-1})
NADH dehydrogenase	NADH	225
β-Lactamase	Penicillin G	115
Catalase	Hydrogen peroxide	100
Glucose oxidase	Glucose	80–100
Hexokinase	Glucose	75
Lactate dehydrogenase	Sodium pyruvate	62
Urease	Urea	61
Cholesterol oxidase	Cholesterol	53
Uricase	Urate	49
Trypsin	Benzoyl-L-arginine amide	29

A large number of enzyme-catalyzed reactions are exothermic with a significant evolution of heat, normally $\Delta H \sim -10$ to -200 kJ mol^{-1}.

The relations among the heat generated, enthalpy change, and temperature change under adiabatic conditions can be expressed :

$$Q = -n_p \Delta H$$
$$Q = m C_p \Delta T$$
$$\Delta T = \frac{-\Delta H n_p}{m C_p} \text{----------(1)}$$

Where

Q is the total heat evolved during a catalytic reaction,

ΔH is the molar enthalpy change,

n_p is the number of moles of the product,

ΔT is the temperature change,

C_p is the heat capacity, and

m is the mass of the system in which the reaction takes place.

Conventional mercury-based thermometers are less sensitivity.

More sensitive temperature transducers are:

1) Thermopile (or thermocouple) and
2) Thermistor

Thermopile transducer: The potential difference (ΔV) depends on the pair number of thermocouples (n), the Seebeck coefficient (ε), and the temperature difference (ΔT):

$$\Delta V = n\varepsilon\Delta T$$

Substituting ΔT from equation 1: $\Delta V = n\varepsilon \frac{-\Delta H n_p}{mC_p}$

Hence, for the adiabatic environment, the ΔH produced by an enzymatic reaction in a biosensor can lead to a direct change in potential (ΔV).

Up to 80% of the heat generated in the reaction can be registered

Thermistor transducer:

It is a combination of *thermal* and *resistor*, implying that it is a type of resistor whose resistance is dependent on temperature. (**resistors** are used to reduce current flow).

The relationship between resistance and temperature is linear, assuming, as a first-order approximation,

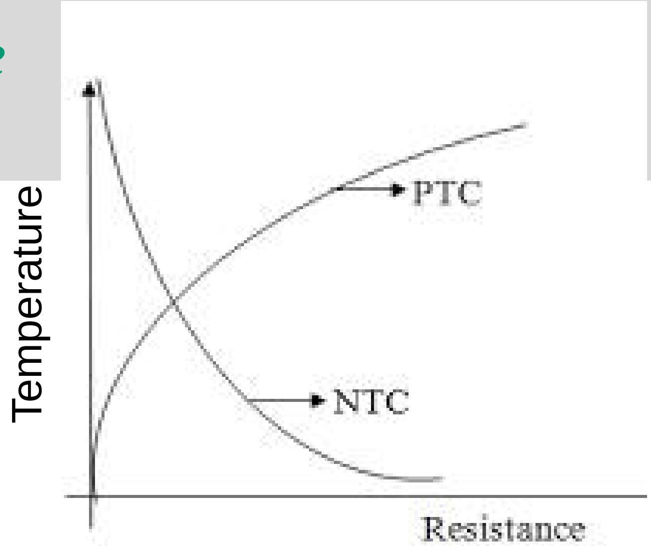
$$\Delta R = k\Delta T$$

Where ΔR is the change in resistance , ΔT is the change in temperature , and k is the first-order temperature coefficient of resistance.

Two major types of thermistors are available, depending upon the decrease or increase in resistance with increasing temperature.

Negative temperature coefficient (NTC) type

Positive temperature coefficient (PTC) type



Example: *A thermopile transducer for the detection of organophosphate pesticides*

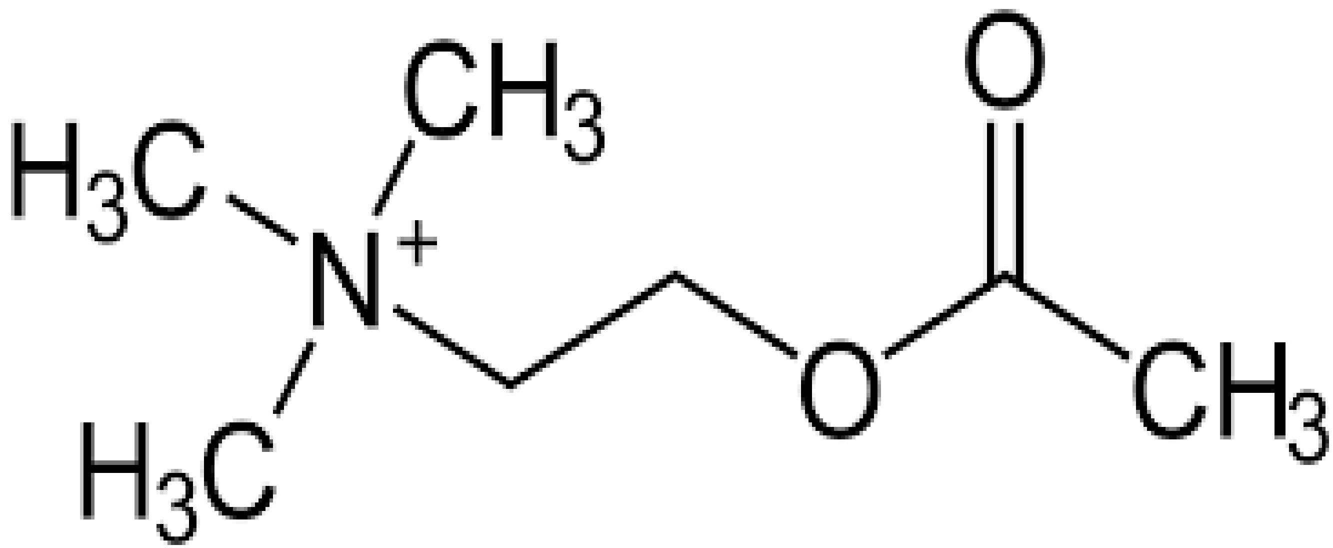
Organophosphates include insecticides (malathion, parathion, dichlorvos, etc), nerve gases (soman, sarin, tabun, VX), Herbicides (tribufos [DEF], merphos) etc

Organophosphate poisoning can be divided into three broad categories:
(1) muscarinic effects,
(2) nicotinic effects
(3) central nervous system effects.

Symptoms: increased saliva and tear production, diarrhea, nausea, vomiting, small pupils, sweating, muscle tremors, and confusion, respiratory paralysis and even death.

Organophosphates irreversibly inhibit acetylcholinesterase(AchE) preventing to break acetylcholine (neurotransmitter)**.**

Acetylcholine (neurotransmitter)



Acetylcholine is the **chief neurotransmitter of the parasympathetic nervous system**, the part of the autonomic nervous system (a branch of the peripheral nervous system) that contracts smooth muscles, dilates blood vessels, increases bodily secretions, and slows heart rate

Neurotransmission under normal situation (when no inhibitors/ organophosphates):

- Acetylcholine (ACh) is synthesized from choline and acetyl-CoA through the action of choline acetyl-transferase in **cholinergic neurons**.

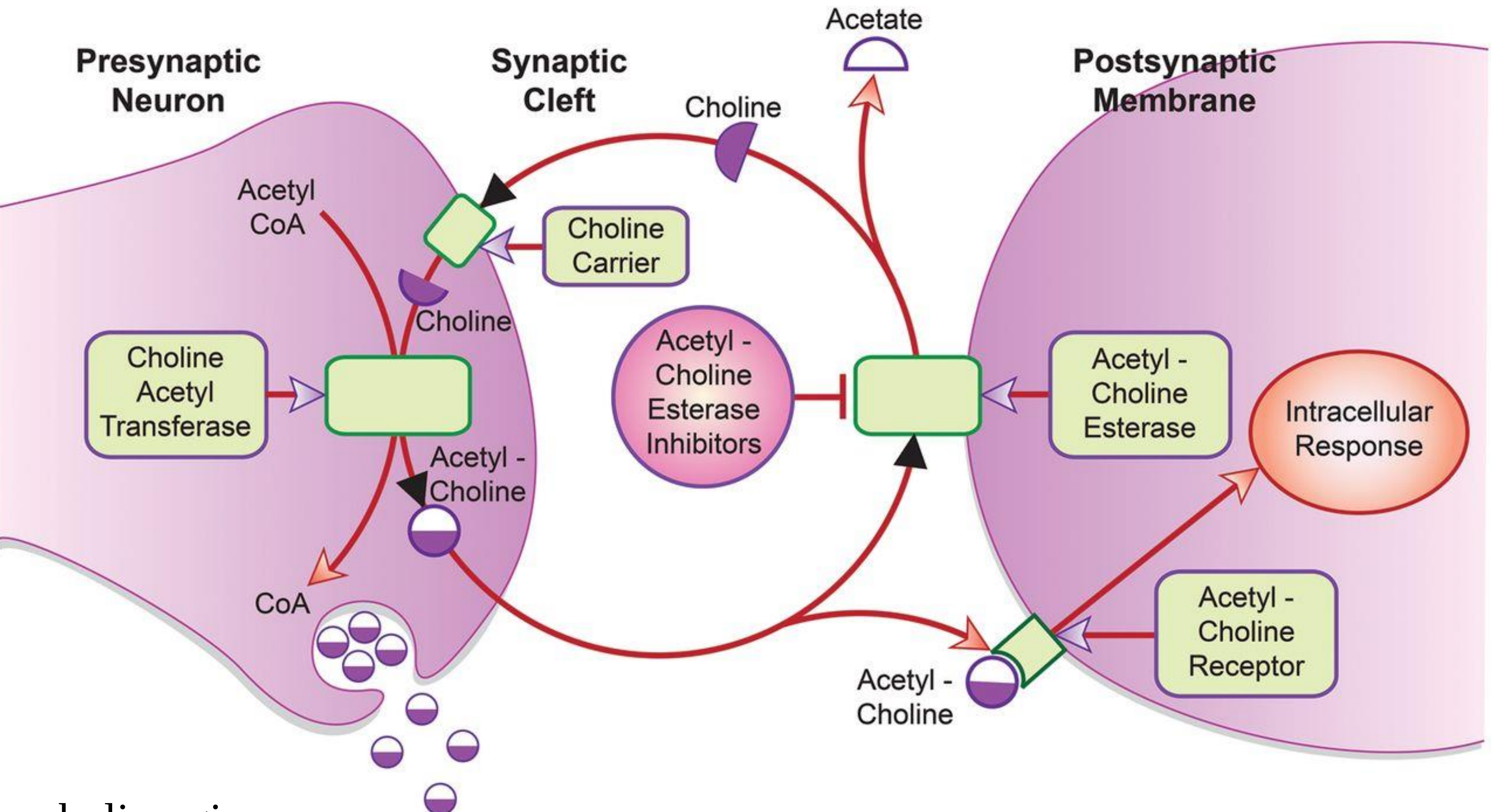
- When an action potential reaches the terminal button of a presynaptic neuron a voltage-gated calcium channel is opened, that stimulates the exocytosis of Ach into the synaptic cleft.

- ACh is released from the nerve into the synaptic cleft and binds to ACh receptors on the post-synaptic membrane, relaying the signal from the nerve.

- AchE which is located on the post-synaptic membrane, terminates the signal transmission by hydrolyzing ACh.

- The liberated choline is taken up again by the pre-synaptic nerve and ACh is synthetized by combining with acetyl-CoA through the action of choline acetyltransferase.

Acetylcholine formation and function



cholinergic neurons

http://traumagency.blogspot.com/2015/09/organophosphate-poisoning.html

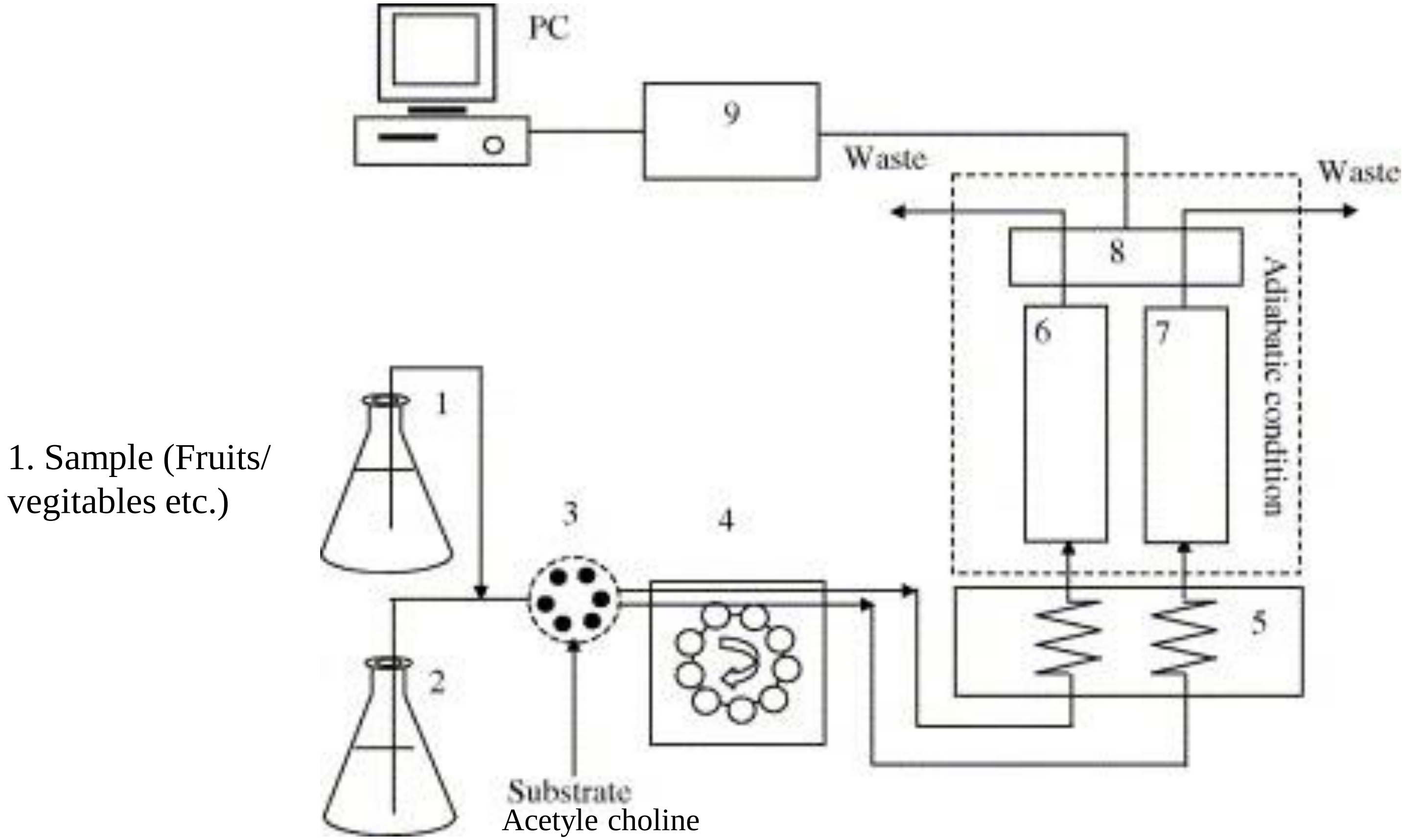
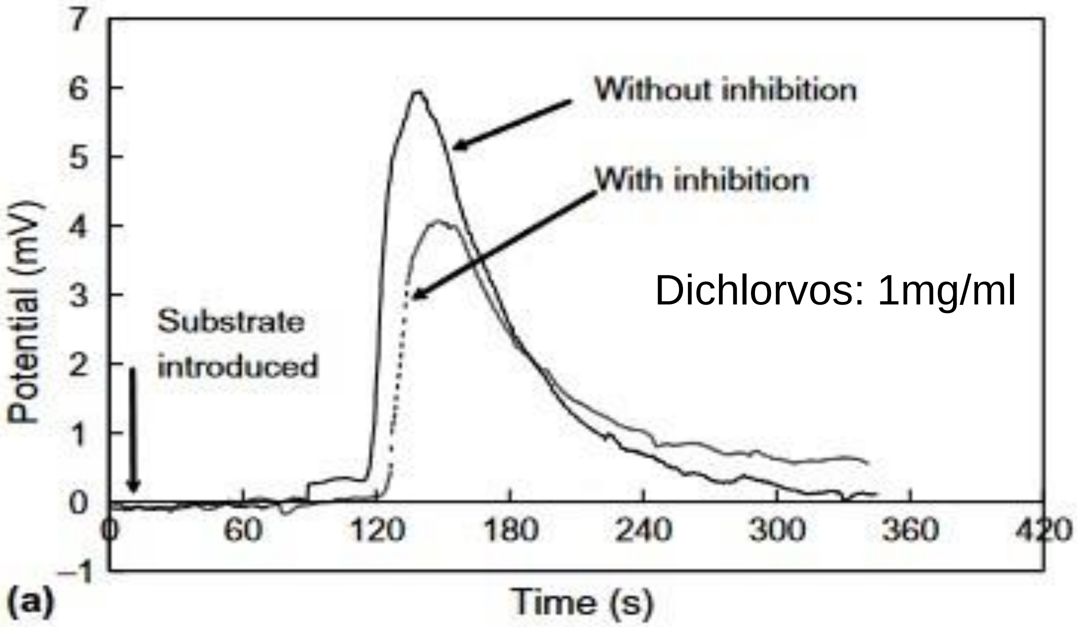
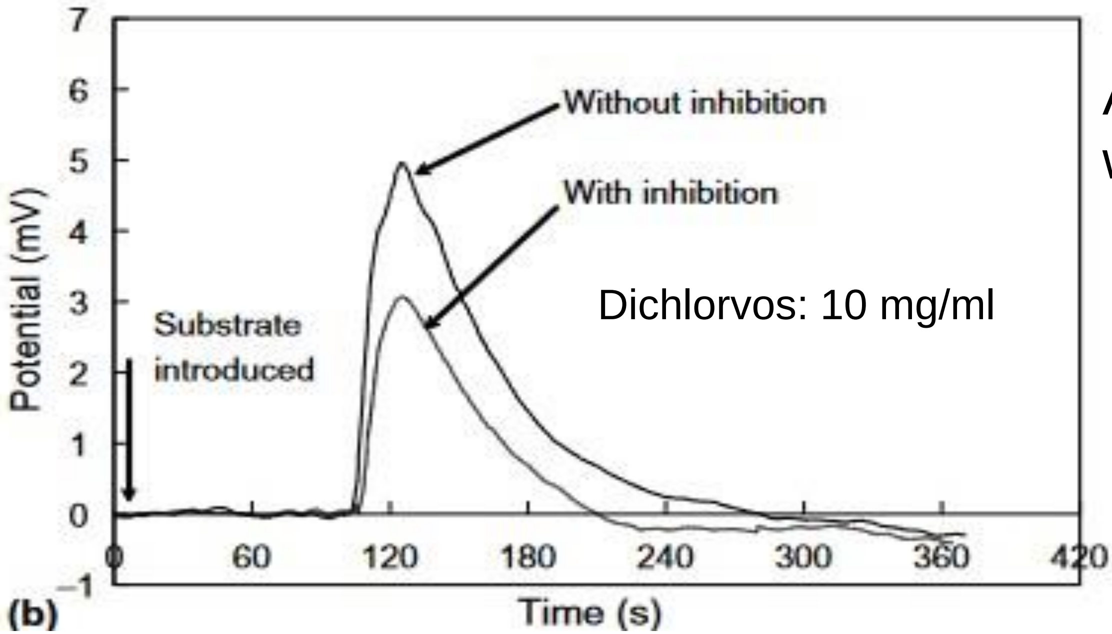


Fig. A type of flow injection calorimetric biosensor. (1) sample container; (2) buffer container; (3) injection valve; (4) peristaltic pump; (5) thermoelectric thermostat; (6) enzyme reaction cell; (7) reference cell (*with inactivated enzyme*); (8) thermopile sensor; (9) A/D convertor.



Strength of inhibition (R):

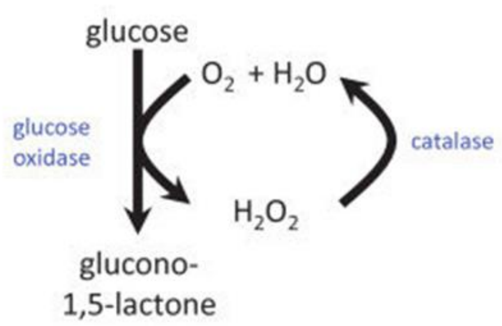
$$R = \frac{A_1 - A_2}{A_1}$$

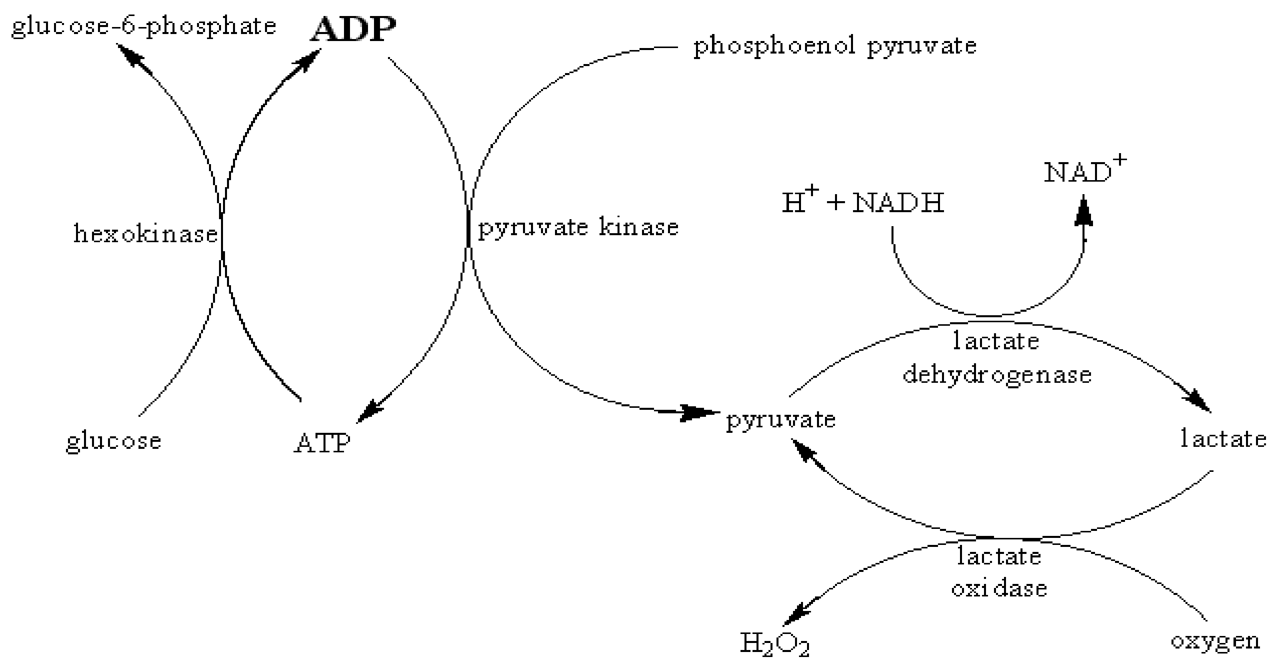


A1 and A2 are voltage signal without and with Dichlorvos.

- **The sensitivity (10^{-4} M) and range (10^{-4} - 10^{-2} M) of calorimetric biosensors are low.**
- **The sensitivity c**an be **i**ncreased by increasing heat output by the coupled reaction steps all of which contribute to the heat output.

Example: The sensitivity of the glucose sensor using glucose oxidase can be more than doubled by the co-immobilization of catalase within the column reactor in order to deprotonate the hydrogen peroxide produced.





In spite of the +Ve enthalpy (absorbs heat) of the pyruvate kinase reaction, the overall process results in a 1000-fold increase in sensitivity

- Such reaction systems do, however, have the serious disadvantage in that they increase the probability of the occurrence of interference in the determination of the analyte of interest.
- T**he advantages of the calorimetric biosensor are its general applicability and the possibility for its use on turbid or strongly coloured solutions.**
- **The most important disadvantage is the difficulty in ensuring that the temperature of the sample stream remains constant** (± 0.01°C).

Commercially available device: Of the thermal biosensors only the enzyme thermistor is commercially available. Example: **Thermal assay probe** developed by ThermoMetric Co., Sweden.

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