

Regulating Body Temperature

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Temperature Affects Function of Organisms

- The function of cell components changes with temperature

PROTEINS - protein shape changes with temperature and this affects its function. In particular enzymes work best at certain temperatures (Analogy - why does yeast make bread rise more quickly at warm temperatures than cold temps ? Why do egg whites solidify when heated to much ?)

LIPIDS – the fluidity of membrane lipids changes with temperature and this also affects function of the cell membrane (analogy butter melting and solidifying)

- Most mammalian cells function best at temperatures between 30 and 40 °C although different specialised organisms have evolved that can function anywhere between zero and 100 degrees.
- Organisms that can constantly maintain optimal temperatures will be maximally effective all the time and so will have an advantage of organisms that don't.



How do we gain and lose heat ?

- Heat can be gained or lost at the areas where the body is in contact with the environment i.e skin and lungs mainly
- Heat can be gained or lost from the environment in a range of ways

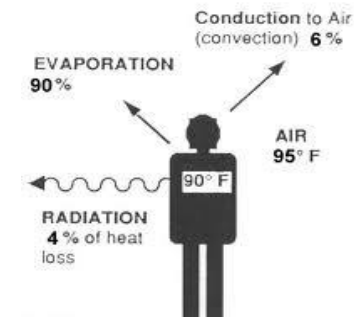
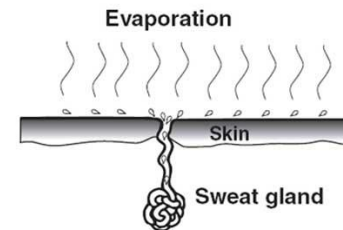
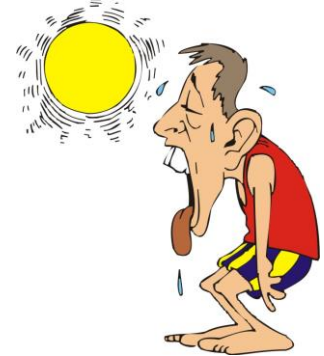
Convection. Increased rate of heat transfer use to air movement. This is why cold air feels much colder when there is a wind blowing i.e. wind chill and how a fan makes you cooler

Conduction. Heat transfers more easily if the body is in direct contact the media that conduct heat well. For example water conducts heat much better than air. Think of a hot bath compared to being in air the same temperature or why hypothermia sets in much more quickly in water than in air of the same temperature. Also explains the rapid cooling effect of ice.

Radiation Absorption of heat indirectly from the sun or heat sources such as fire.

Evaporation It takes energy to turn water into steam so this can dissipate heat on the skin. This is how sweat cools the body. Think also about how cool you feel after being sprayed with water on a hot day.

- **Heat production** – The process of making ATP produces heat which helps increase core body temperature. This is important as many organisms aim for a body temperature well above ambient temperature and this provides a way to keep body temperatures high.





NWS Windchill Chart



		Temperature (°F)																	
		40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
Wind (mph)	Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
	5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
	10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
	15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
	20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
	25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
	30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
	35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
	40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
	45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
	50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97	
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98	

Frostbite Times 30 minutes 10 minutes 5 minutes

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T= Air Temperature (°F) V= Wind Speed (mph)

Effective 11/01/01

Mechanisms for regulating temperature

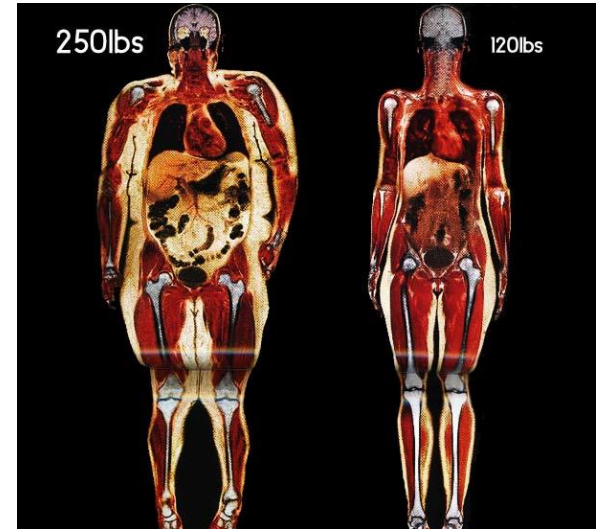
Many organisms have mechanisms to regulate their temperature to optimise the operating temperature and ensure that lethal temperatures are not reached.

Mechanisms involved in regulating the amount of heat exchanged with the environment

1. Involuntary mechanisms

- **Insulation** with fat layers to reduce heat loss by convection. A lot of human fat is deposited just below the skin where it is most useful for this purpose. Blubber is particularly effective in stopping heat loss in marine mammals.

- There is a considerable amount of **water evaporating** from the lungs (about 500 ml per day). Just breathe on a piece of glass and you will see how much water vapour there is in your breath.



Active mechanisms for regulating body temperature

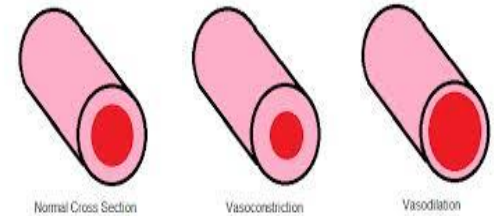
Vasoregulation – Blood is the major means for moving heat around the body. Vasoconstriction (restriction of blood vessel diameter) restricts flow of blood to the skin in cold conditions and so restricts heat loss by convection while vasodilation (expansion of blood vessel diameter) increases blood flow to the skin and so releases more heat. In humans reddish color to the skin shows high blood flow to skin while bluish tinge shows reduced blood flow.

Piloerection - raising fur or feathers to create a layer of non-moving air between the environment and the skin. Human hairs also rise but have rather little effect as they are so small but we do see the goose bumps which are a sign we are responding to cold.

Sweating- this increases the amount of water on the skin available to evaporate, This will cool the skin.

Panting - increases convection and evaporation mediated heat loss from lungs. Important in animal with no sweat glands e.g. dogs.

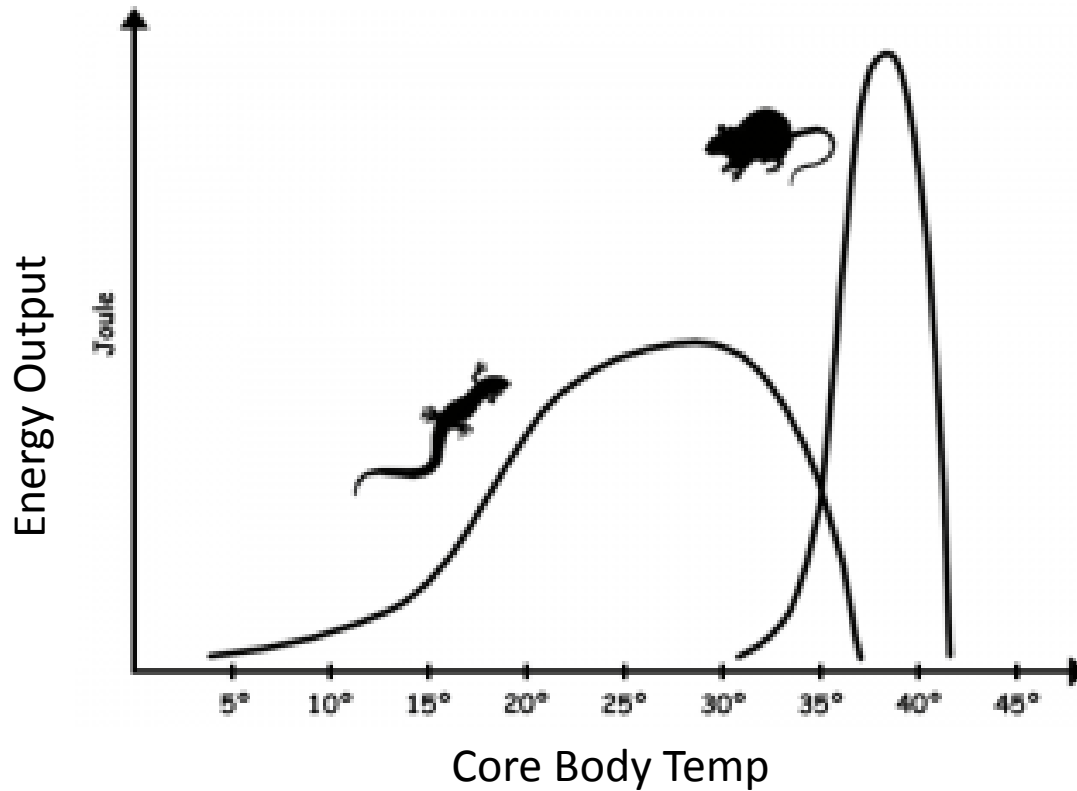
Adaptive behavioral change (shelter, clothing , posture, turning on the air conditioning). Thermal imaging camera image at right clearly illustrates how clothes stop heat loss.



Ectotherms vs Endotherms

- **Ectotherms** (sometimes called cold blooded animals) have no direct way to regulate core body temperature so are dependent on their environment. They can use adaptive techniques like basking in sun or hiding in shade to control body temperature. Some ectotherms such as fish take advantage of the fact that ocean temperatures don't change as much as atmospheric so they can adapt to a relatively small range of temperatures while other (e.g. lizards) can exist over a wide temperature range.
- **Endotherms** (sometimes called warm blooded animals) have a range of mechanisms to actively control body temperature. Importantly they have methods to increase internal heat production in response to cold. Most mammals and birds are in this category.
- Some endotherms (called **homeotherms**) can tightly control their body temperature which means they can be active at maximum efficiency all the time. This means they can exist in a wide range of different environments but their body adapts to working at a narrow range of temperatures so they need to tightly control it.
- Organisms that can't tightly control their temperature are called **poikilotherms**.

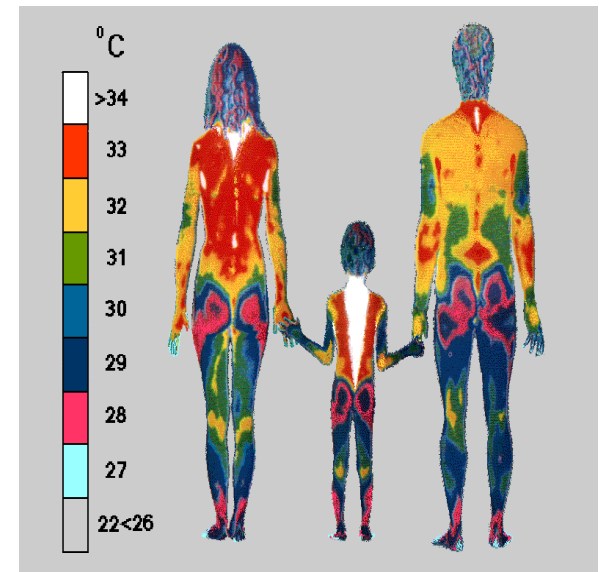




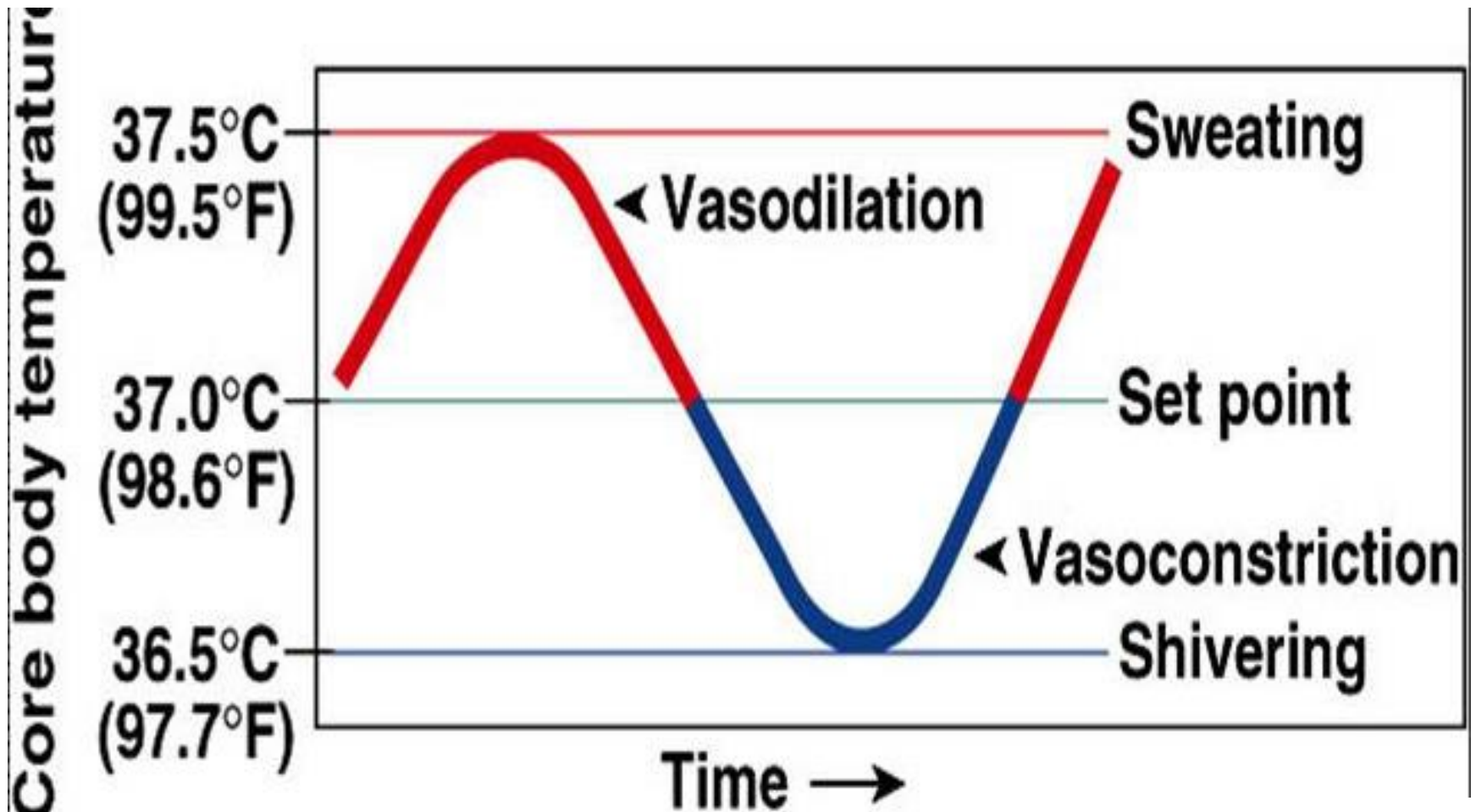
Sustained energy output (Joule) of a poikilotherme (a lizard) and a homeotherm (a mouse) as a function of core body temperature. The homeotherm has a much higher output, but can only function over a very narrow range of body temperatures.
Credit: Petter Bøckman Wikimedia Commons

Control of Human Body Temperature

- Humans maintain a core body temperature of around 37 °C but the temperature at the skin will be significantly lower due to contact with the environment, especially in regions with poor circulation.
- There is a variation of +/- about 1 °C during the day but if temperature gets above 41 for sustained periods then death will result



In humans there are homeostatic mechanisms controlling temperature at around 37 °C



COGNITIVE AND MOTOR PERFORMANCE

Ataxia
Stupor Apathy
Amnesia; Errors in Judgment

Manual Dexterity
Tracking Skills
Threshold of Decrement
Errors in Judgment

MOTOR FUNCTION

COGNITIVE FUNCTION

Cognitive Function
Suggested Functional Limit

HYPOTHERMIA

CORE BODY TEMPERATURE (°C)

HYPERTHERMIA

30 31 32 33 34 35 36 37 38 39 40 41 42

PHYSIOLOGICAL RESPONSES

Bradycardia
Cessation of Shivering
Decrease in Respiratory Minute Volume
Tachycardia
Tachypnea
Maximum Shivering Thermogenesis
Increase in Metabolic Rate

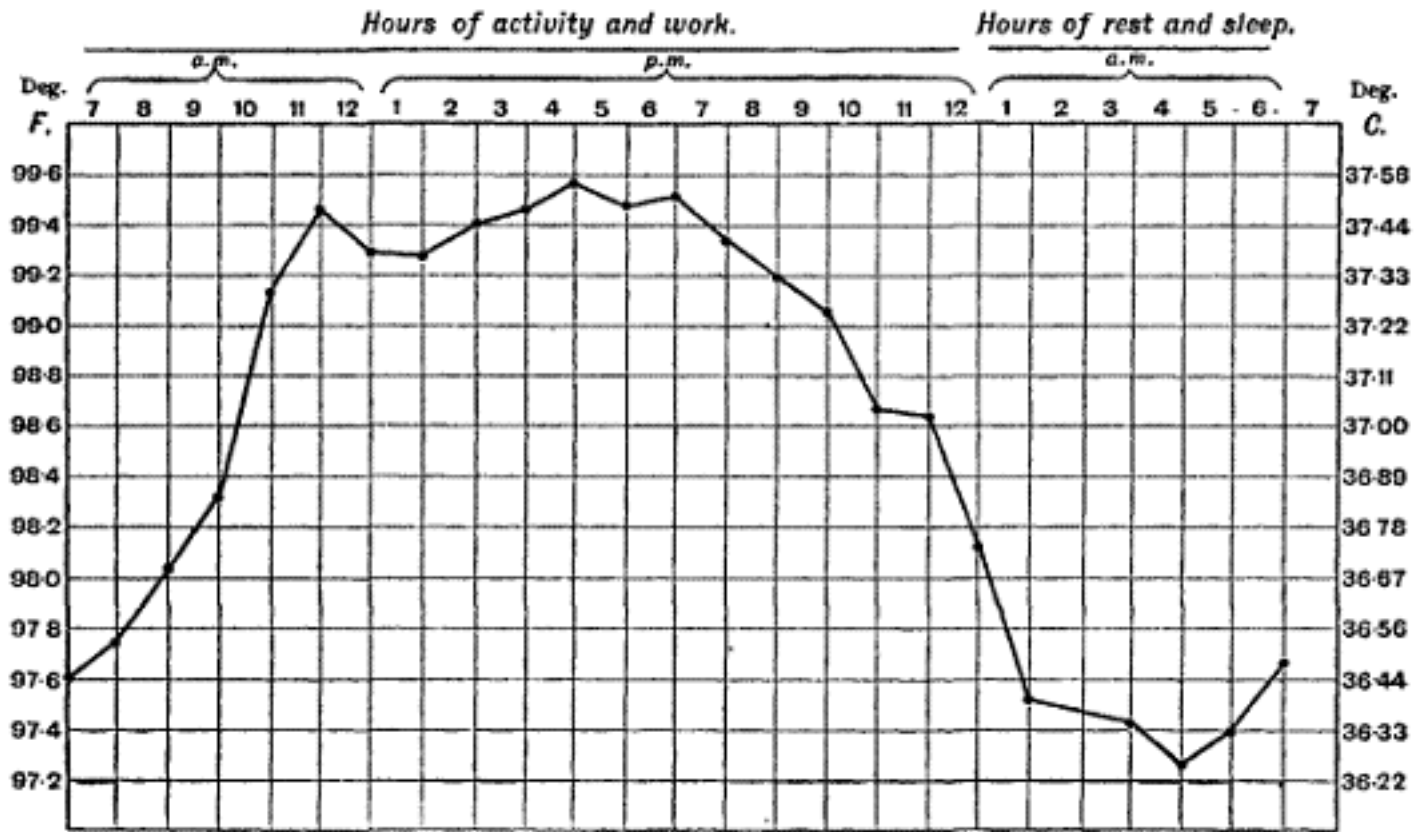
Onset of Sweating
Fever from Exercise

Cessation of Sweating

Temperature Regulation Impaired

Temperature Regulation Impaired

Body Temperature in Humans Varies Naturally Over the Course of the Day



Heat Production- Endotherms

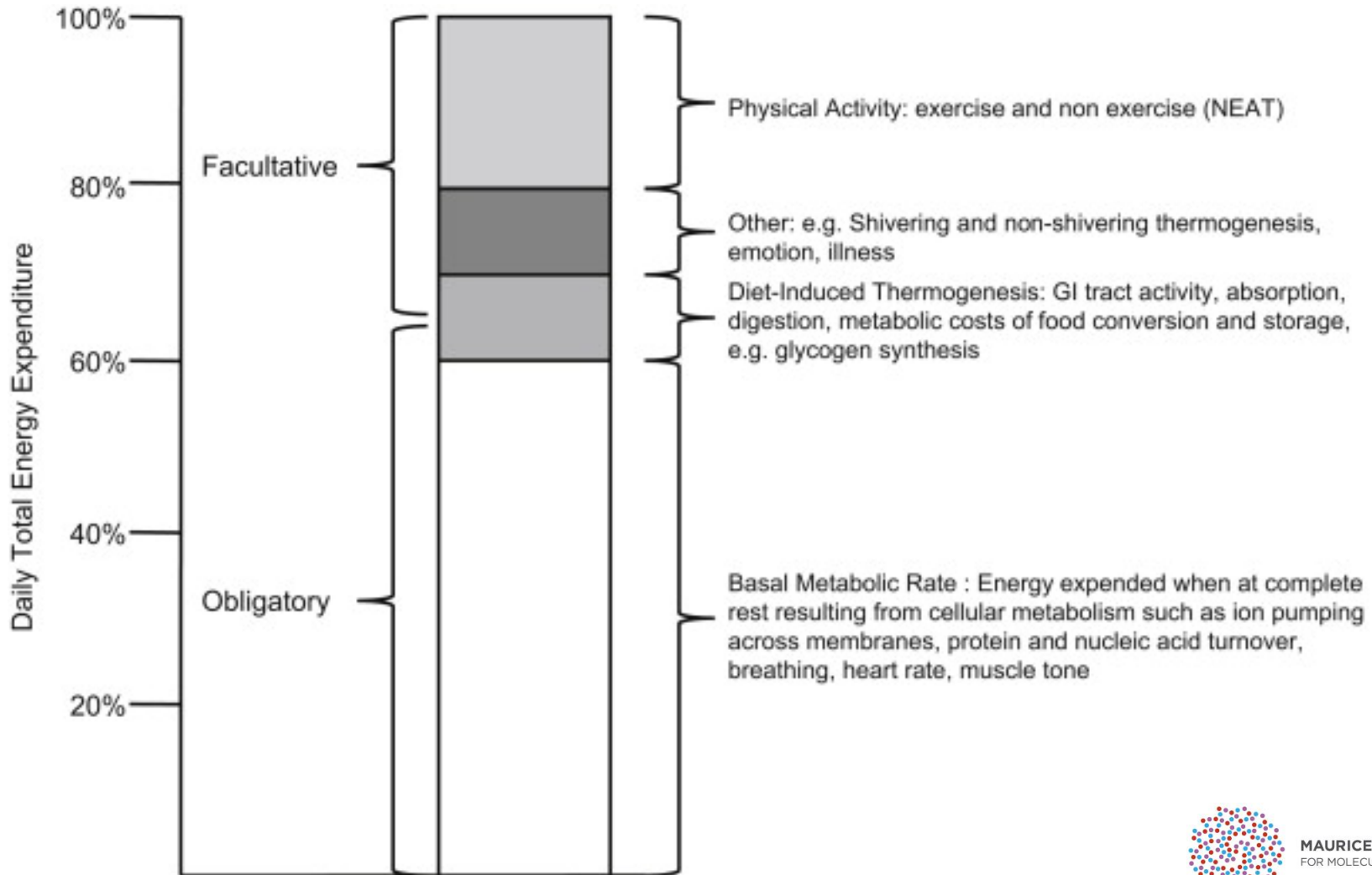
All heat production is in mitochondria

Five drivers of energy use

- Basal metabolic rate – constant energy production just to keep cells alive. Use most of our energy
- Voluntary – e.g. exercise
- Non-voluntary – e.g. shivering
- Cost of food digestion
- Non-shivering thermogenesis – uncoupled respiration only really in Brown Fat



In humans most energy is used maintaining basal metabolic rate



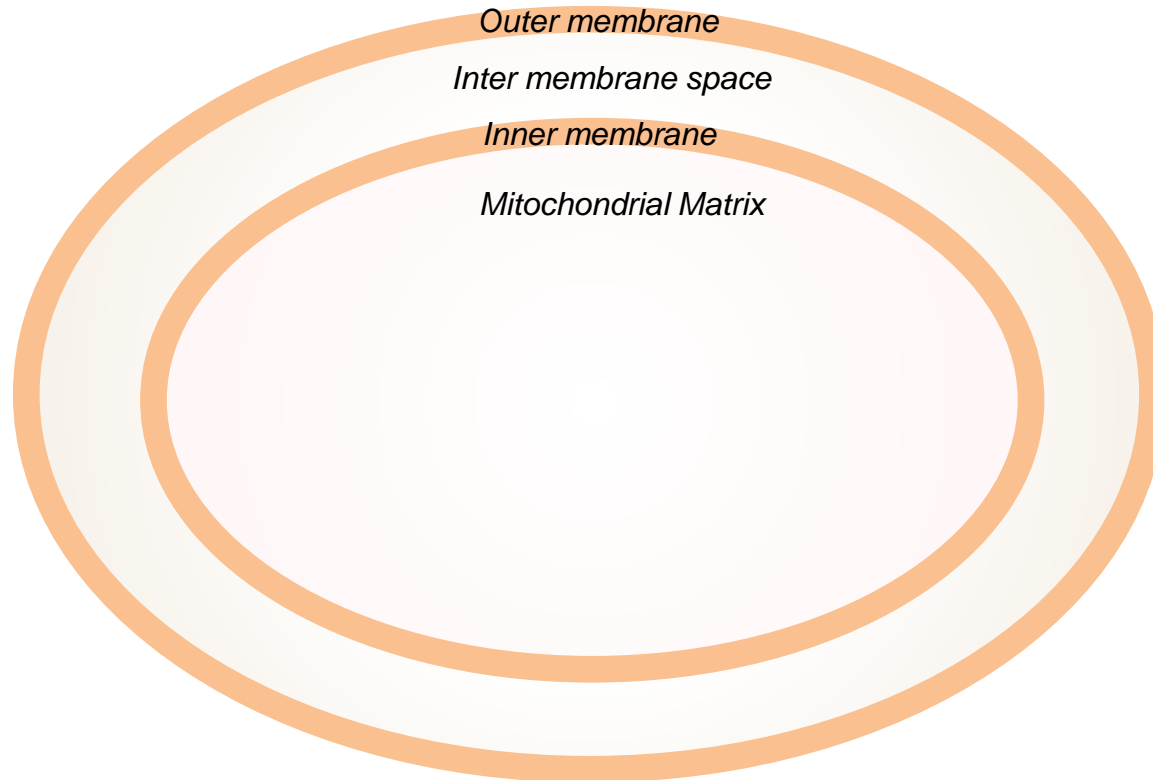
Mitochondria are Unique Organelles that Regulate Energy Production and Use in The Cell

They are like a coal fired power station in that they use fuel and oxygen and they generate electrical energy and heat and CO₂ as a byproduct



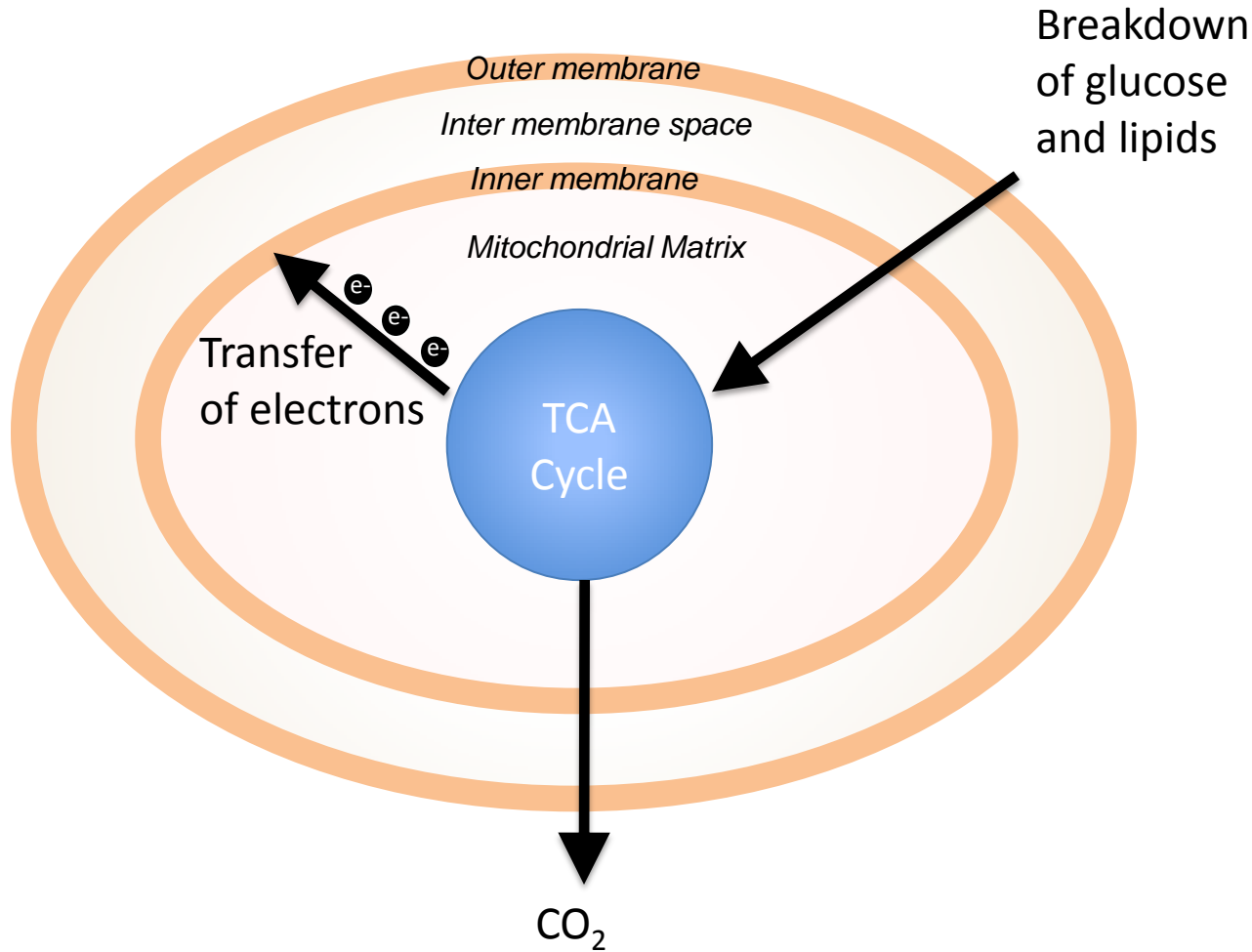
Mitochondria are Unique Organelles that Regulate Energy Production and Use in The Cell

Mitochondria are double membraned organelles found in all eukaryotic cells that play a critical role in energy regulation within cells



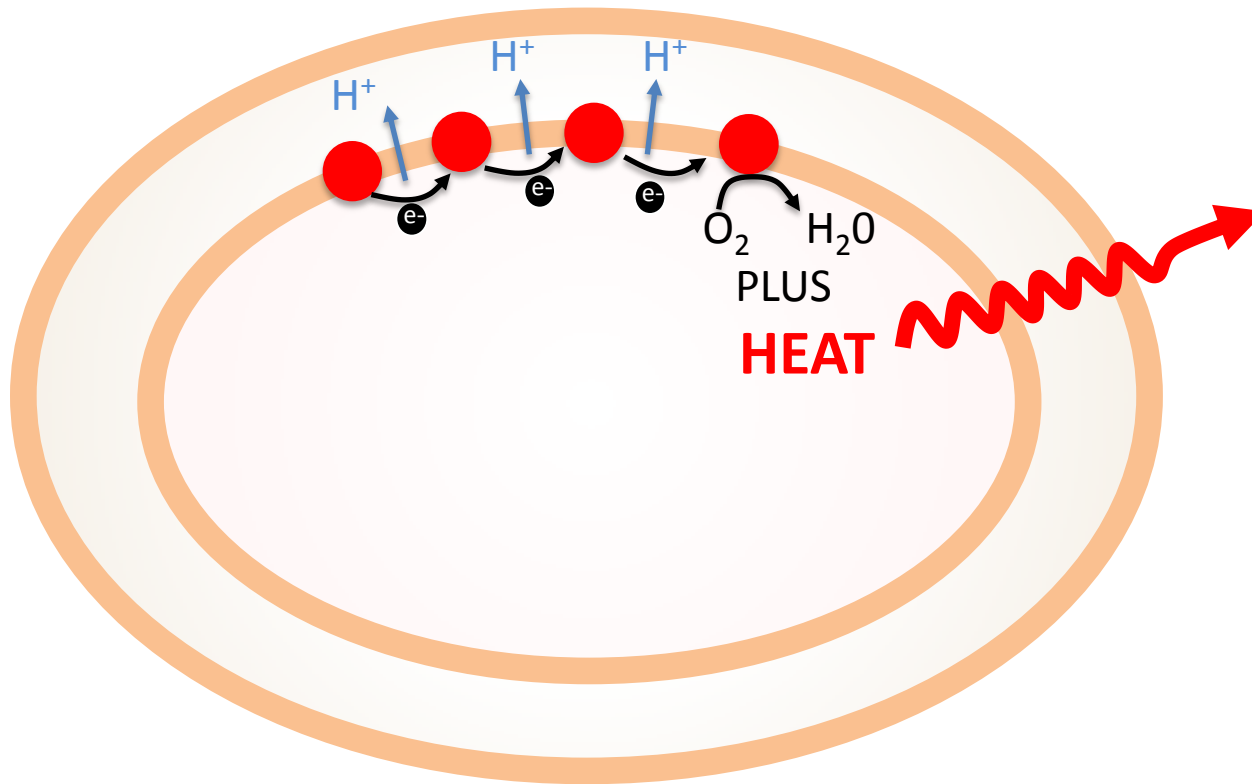
How the Mitochondria Couples Production of ATP and Heat

Step 1 TCA Cycle Uses Lipids and Glucose
and Release CO₂ and Electrons



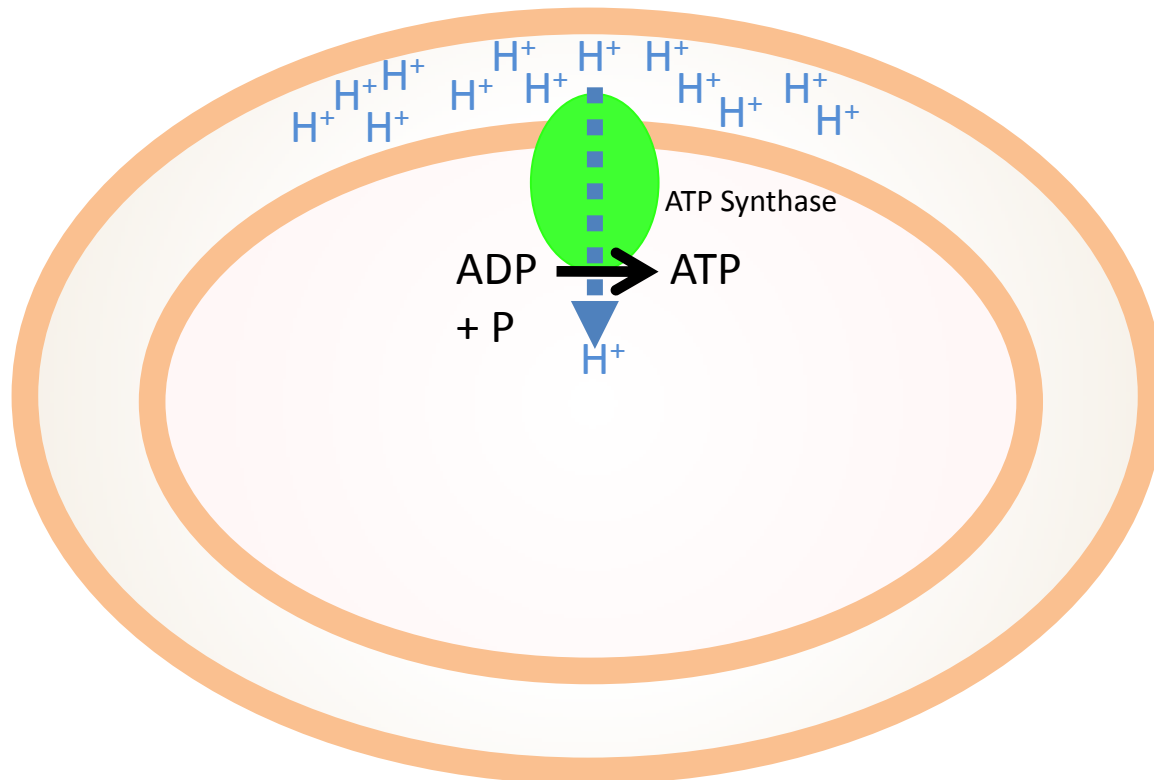
How the Mitochondria Couples Production of ATP and Heat

Step 2 Electrons Transferred to Oxygen , Heat Generated
And H^+ Ions are Pumped Across Membrane



How the Mitochondria Couples Production of ATP and Heat

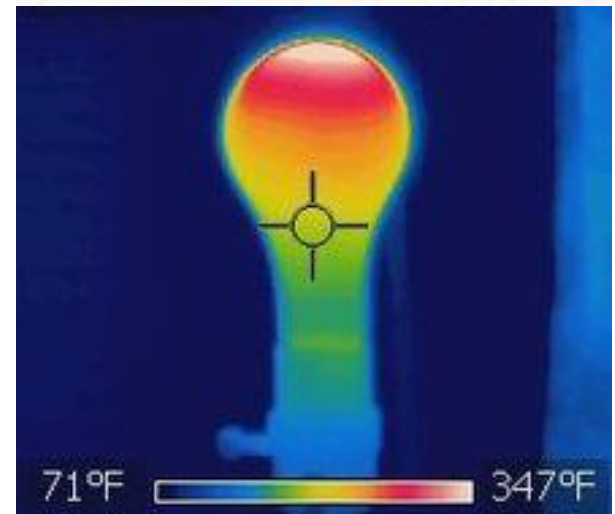
Step 3 The H^+ ions that are transported out during oxygen use and heat production are pumped back across the membrane and in doing so they drive the production of ATP by an enzyme called ATP synthase



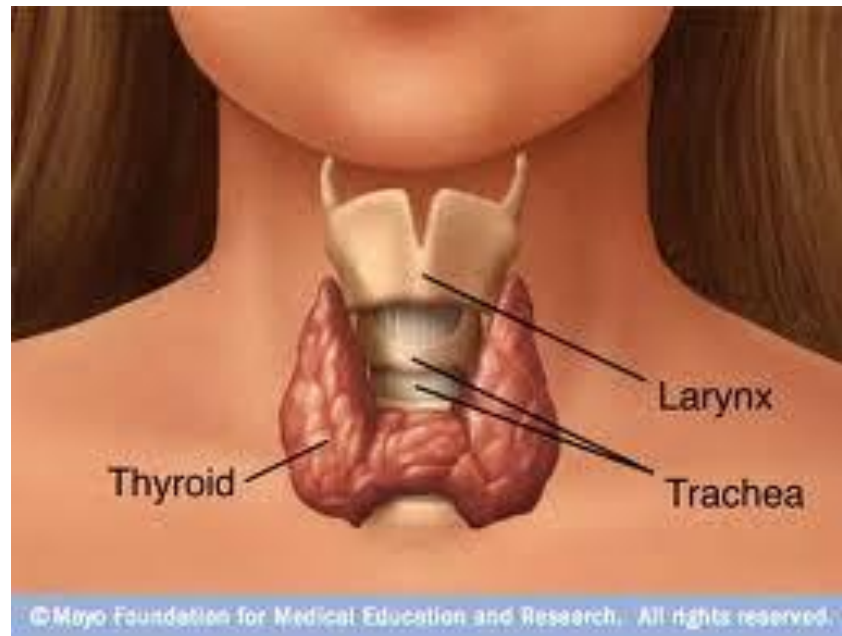


Basal Metabolic Rate

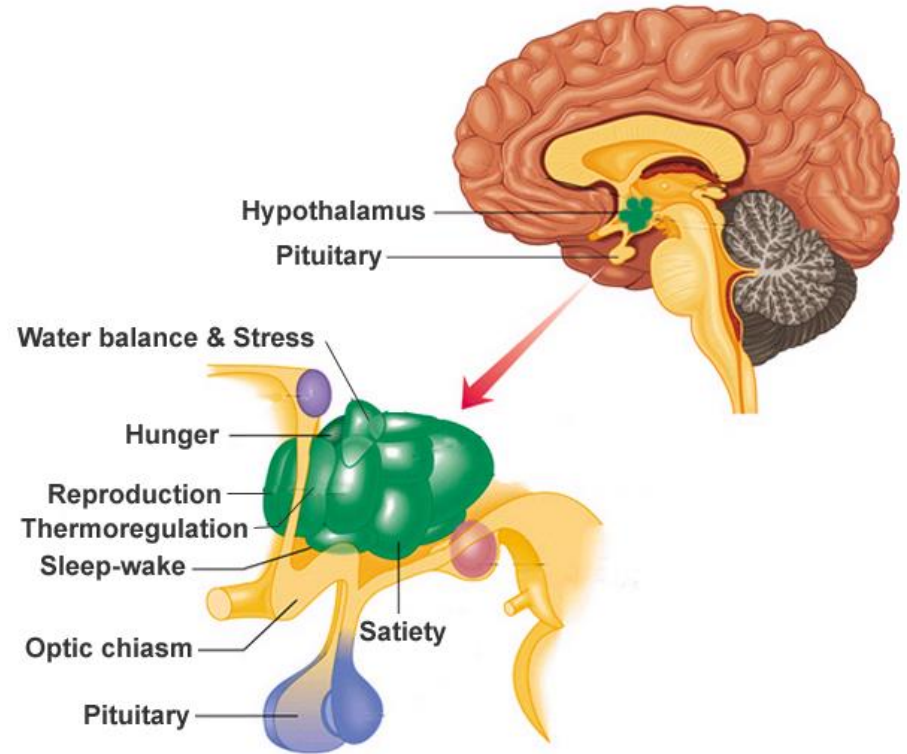
- In nearly all cases our body temperature is above that of the surroundings so we have to continually produce heat
- We produce the equivalent of about 100W light bulb.
- The engine for doing this is Basal Metabolic rate (BMR) and this is controlled in large part by Thyroid Hormone which is mostly produced in the thyroid gland.
- Thyroid hormone is an iodinated form of the amino acid tyrosine which is the main reason we need iodine in our diet.
- Defects in thyroid hormone function such as Graves disease affect the bodies temperature sensing mechanisms e.g too much TH production results in increased heat production and so subjects often feel hot and flushed.



Thyroid Gland Controls Basal Metabolic Rate



Hypothalamus is the area of the brain that regulates homeostatic mechanisms controlling core body temperature



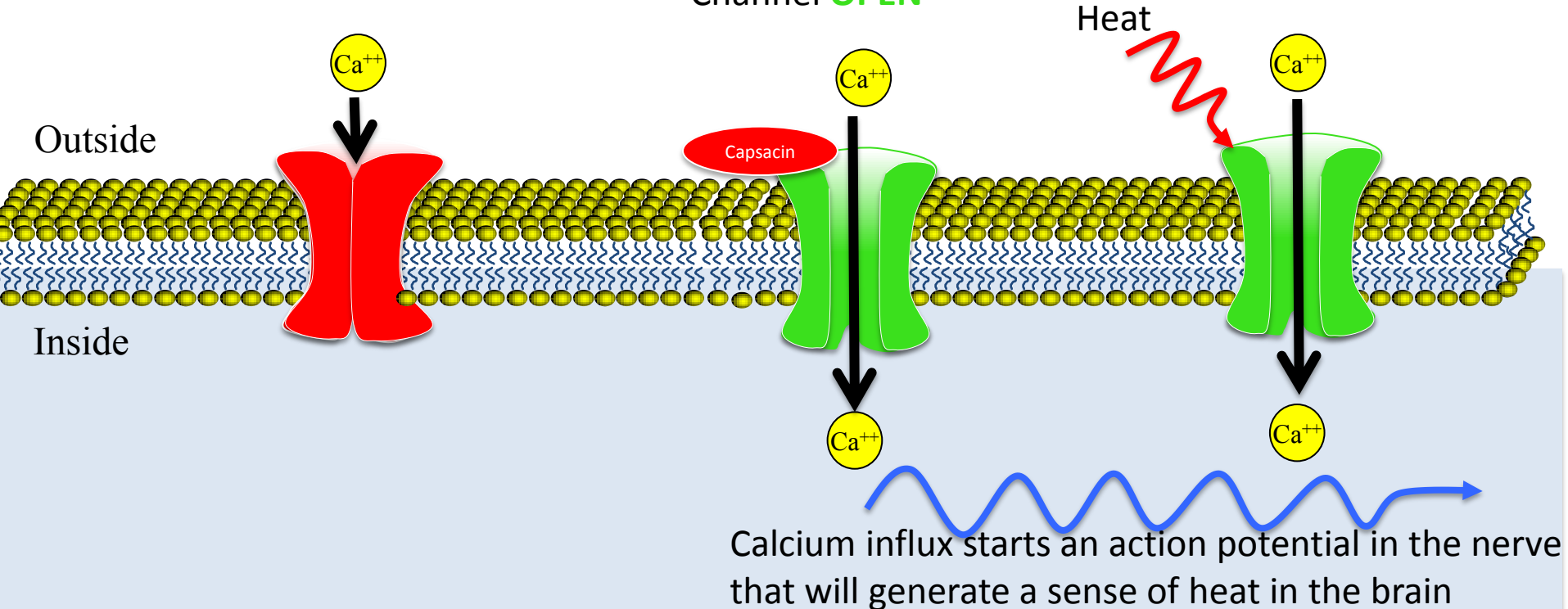
How do we sense small changes in temperature and react so quickly ?

Trp Channels Allow Calcium to Get Into Neurons In Response to Temperature Changes and This Activates the Neuron

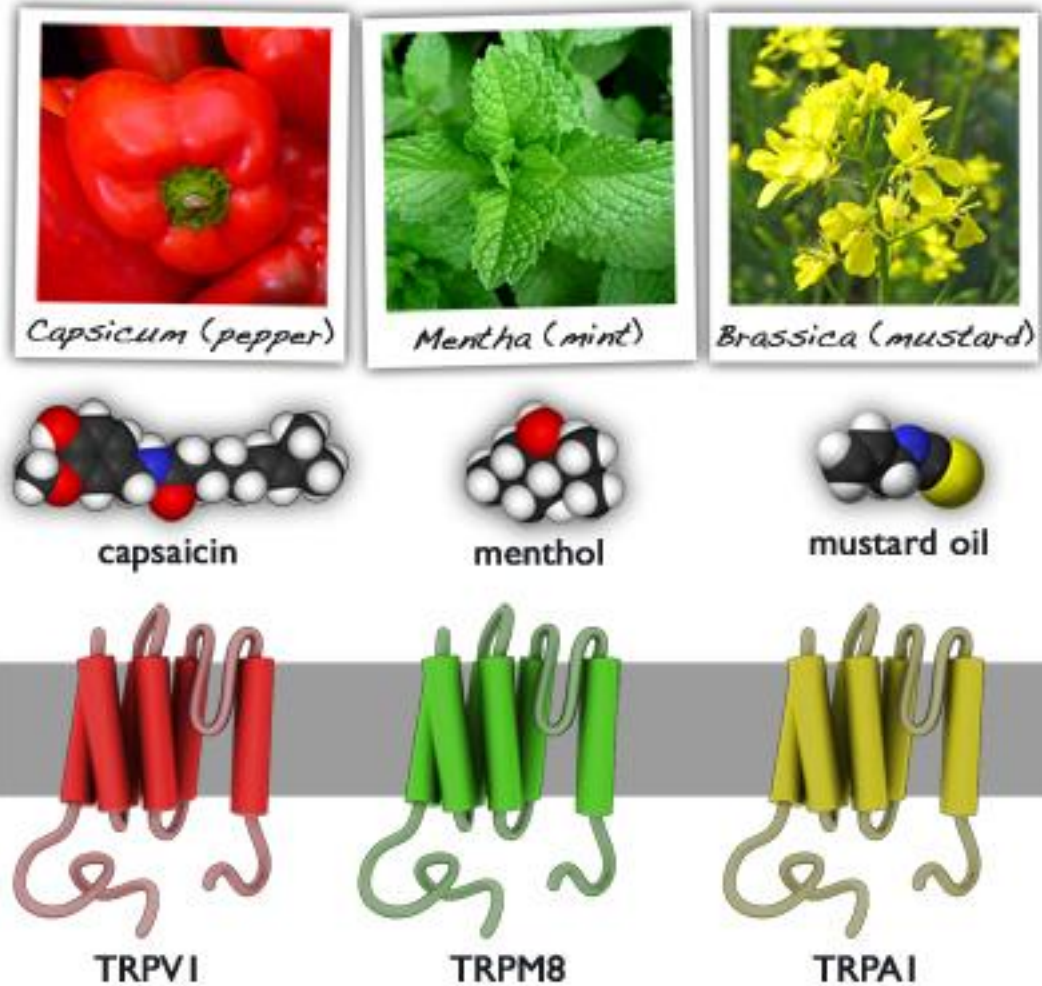
Non Ideal Temperature
No chemical ligand
Channel **CLOSED**

Non Ideal Temperature
PLUS chemical ligand
Channel **OPEN**

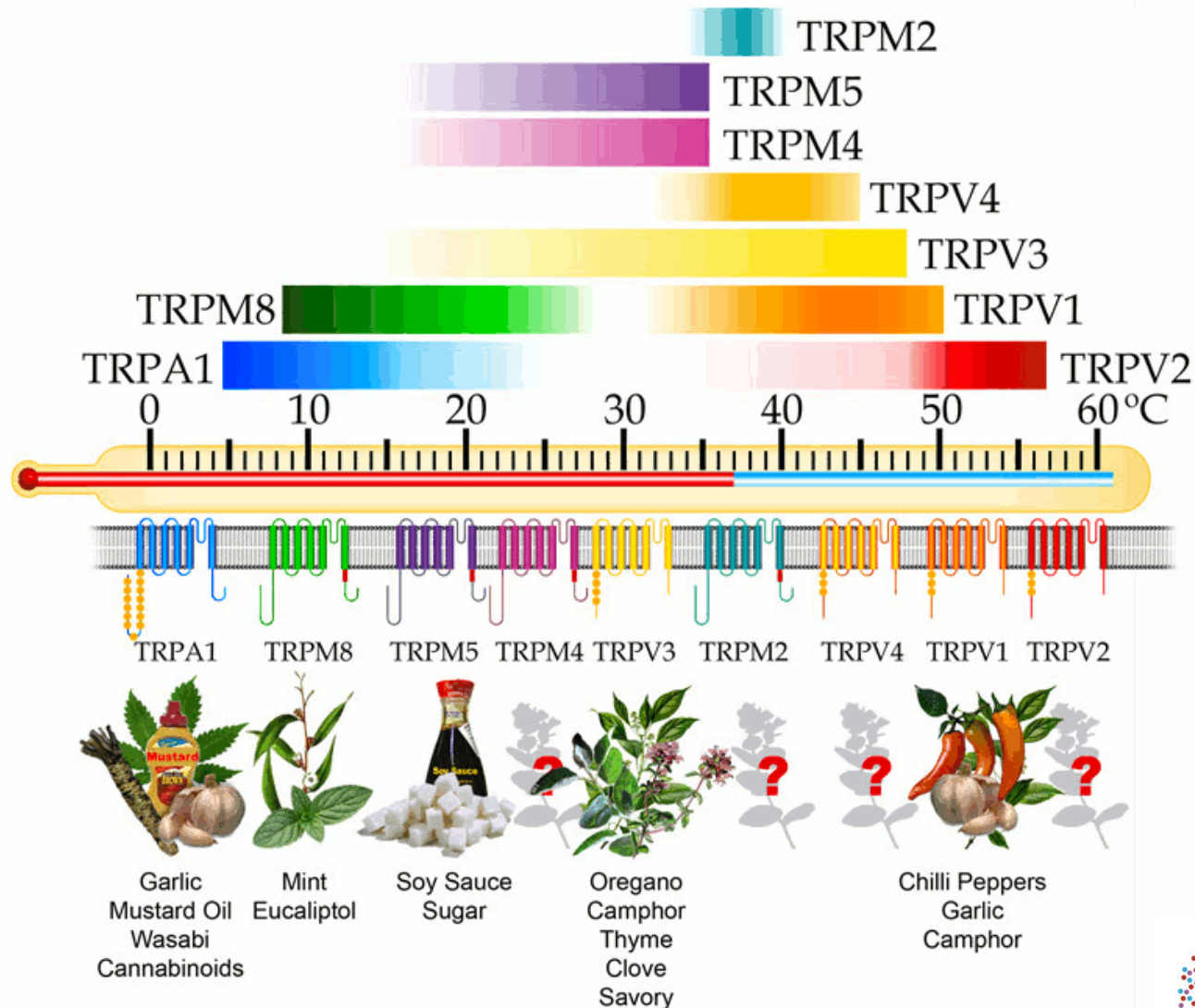
Ideal Temperature
No chemical ligand
Channel **OPEN**



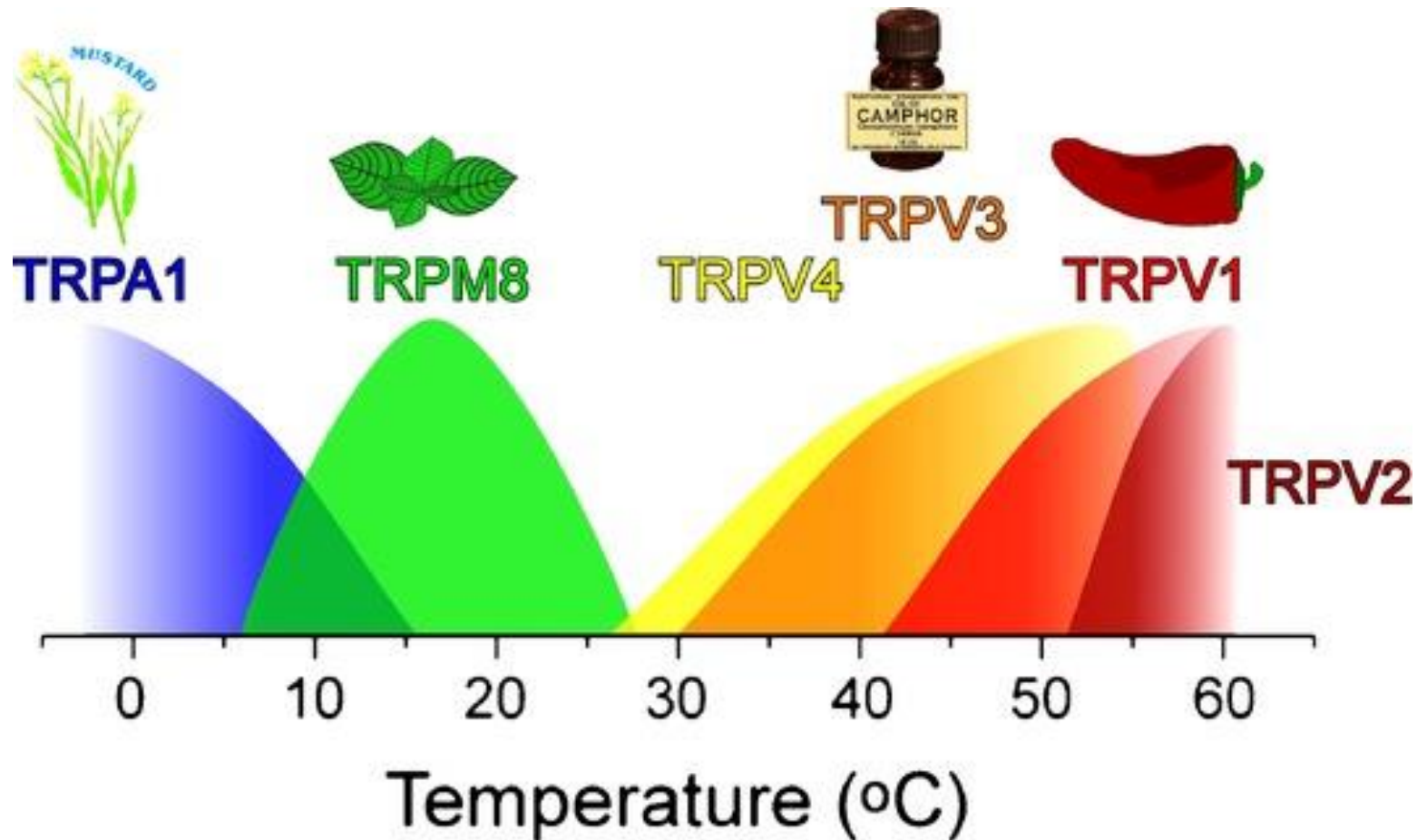
The receptors-channels that respond to changes in heat also respond to some chemical signals and generate false sense of hot or cold



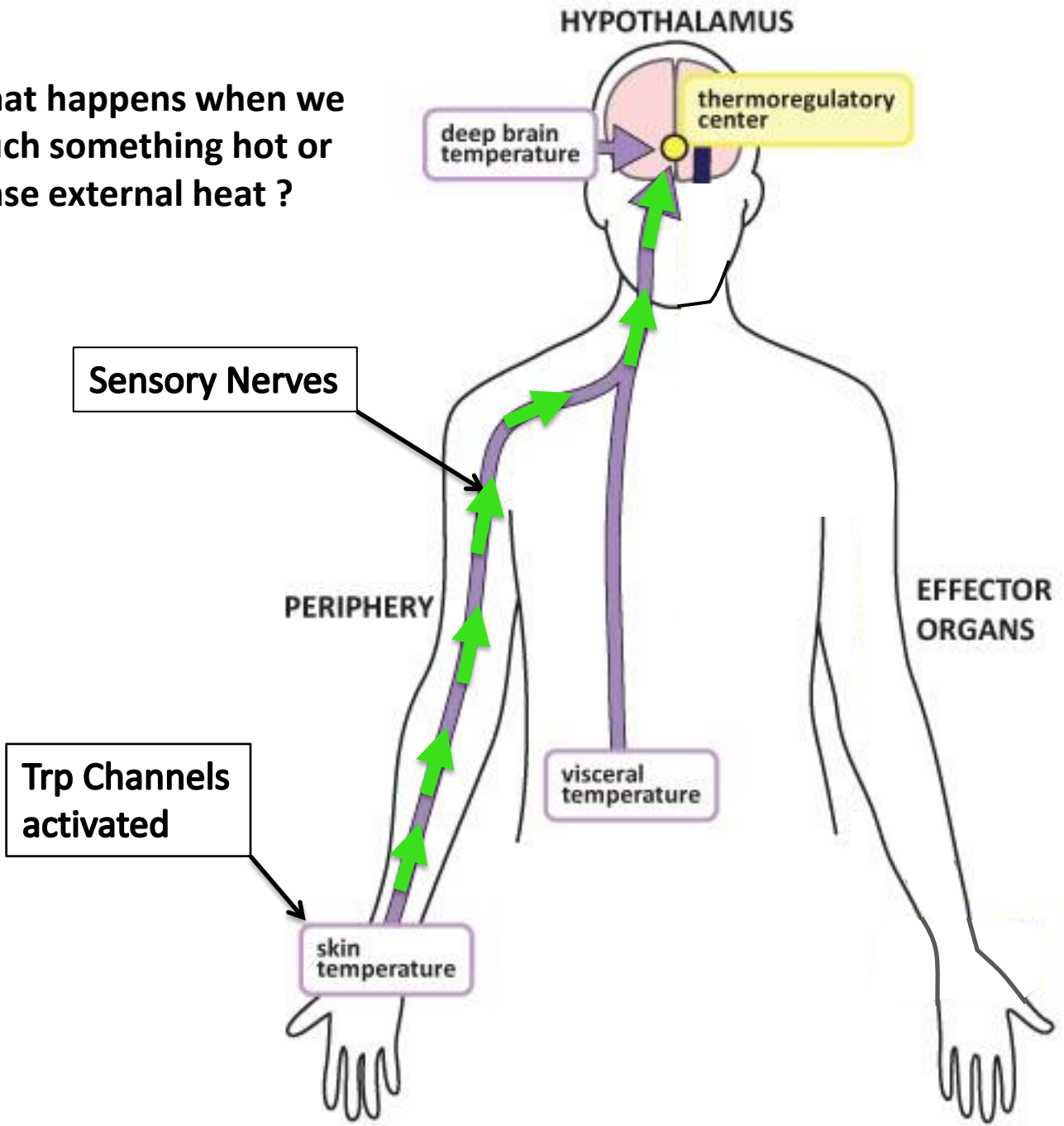
Trp channels sense heat but also many other things ?



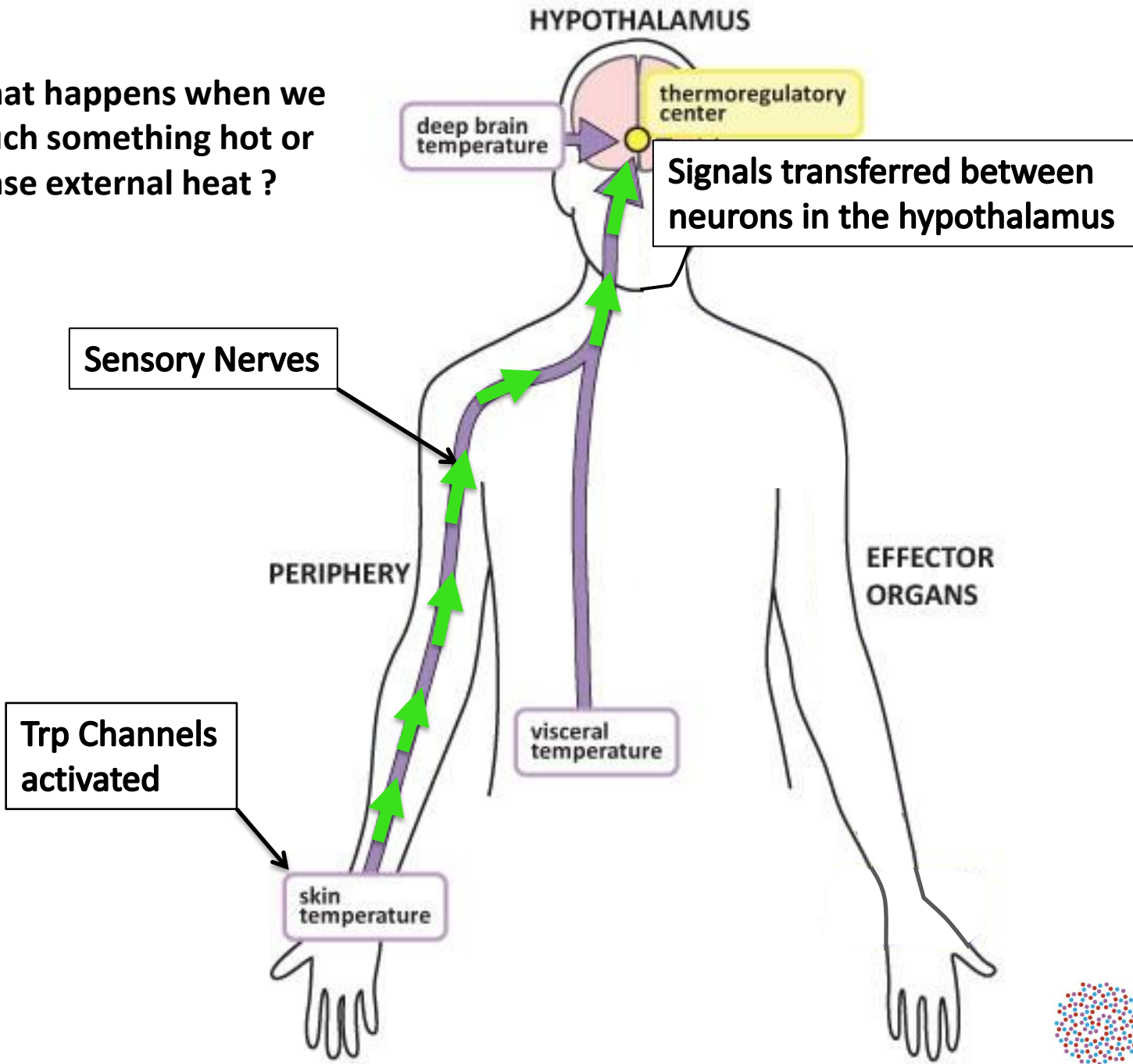
There are many temperature sensitive TRP channels and these also cross react with other molecules



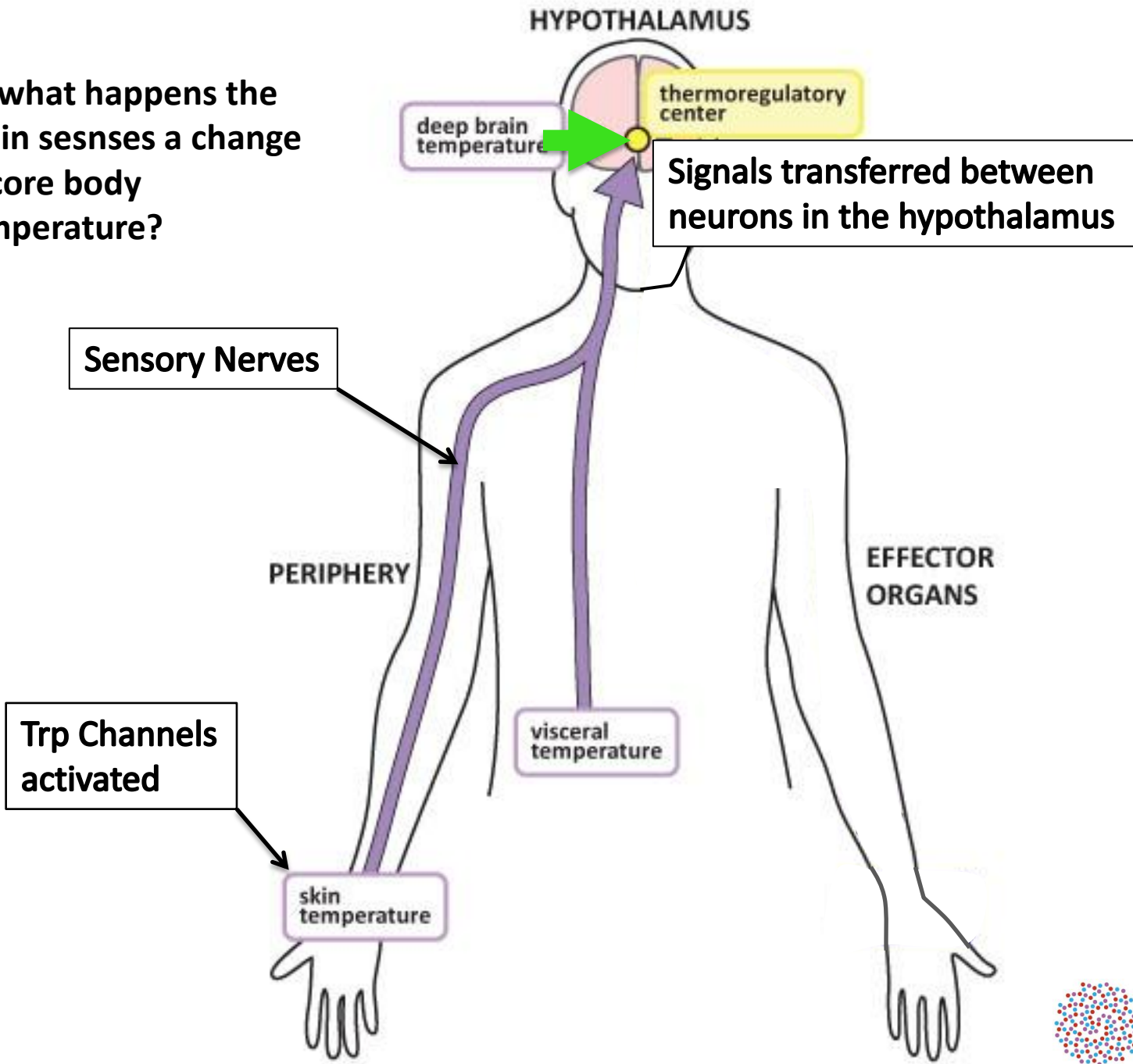
What happens when we touch something hot or sense external heat ?



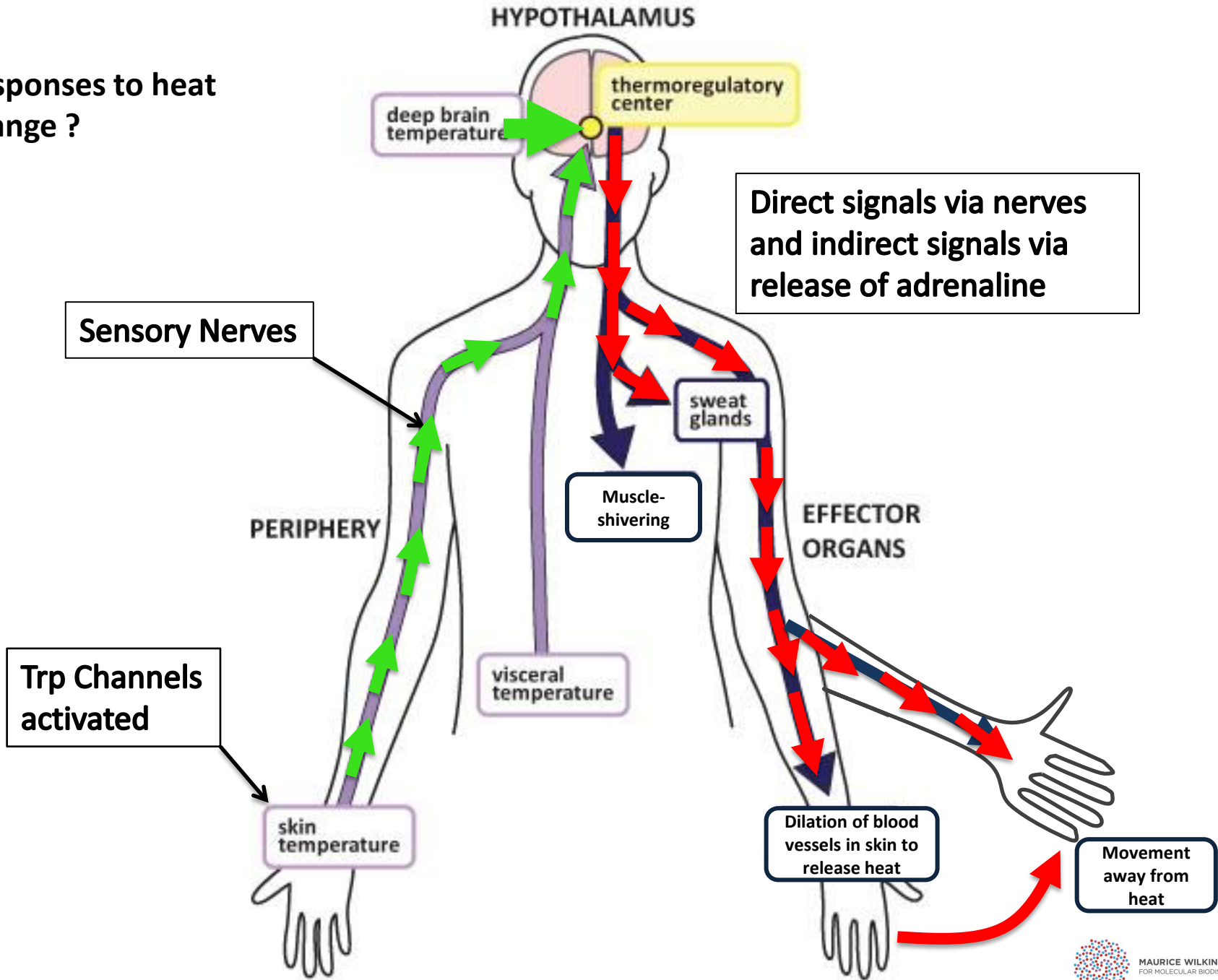
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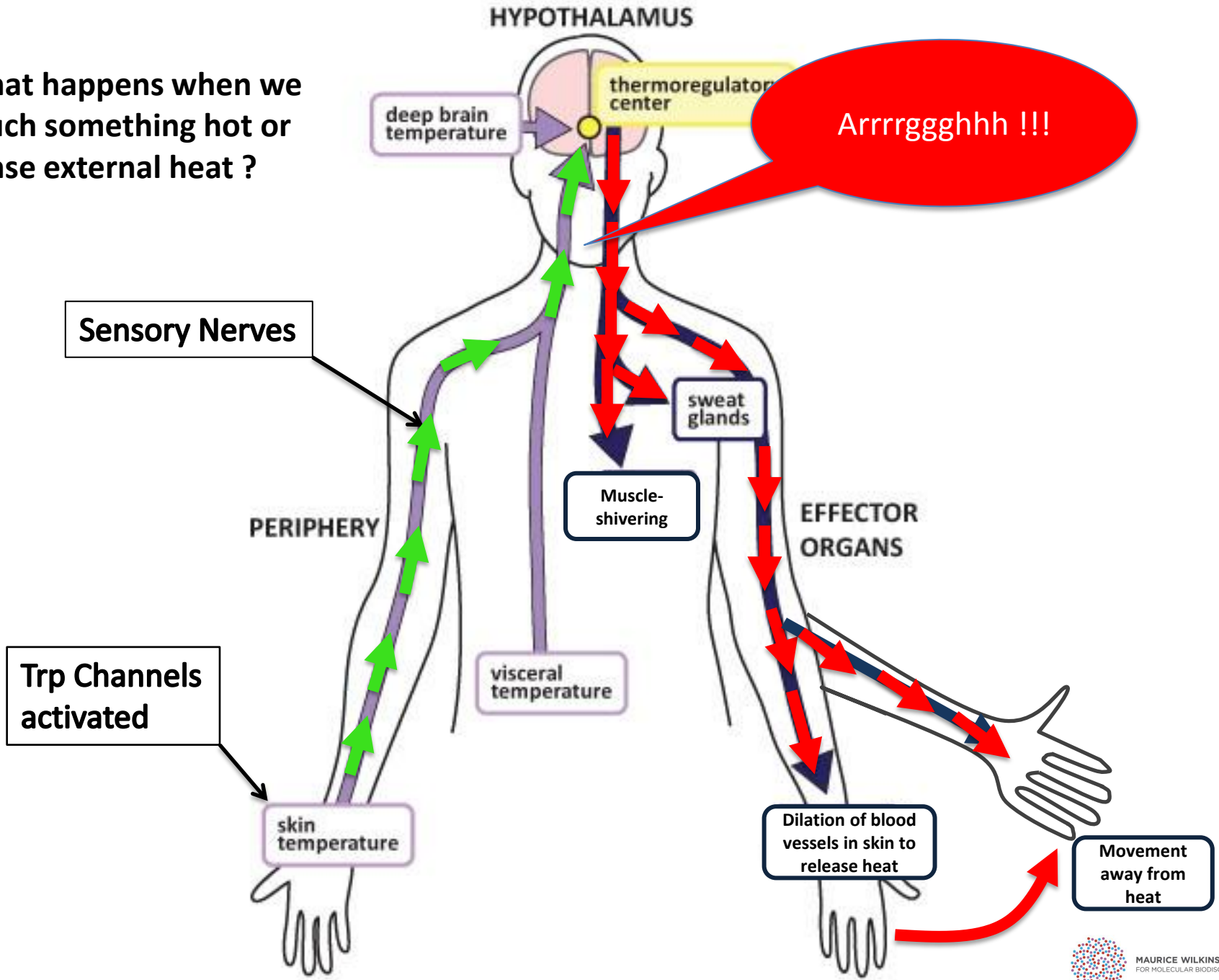
Or what happens the brain senses a change in core body temperature?



Responses to heat change ?

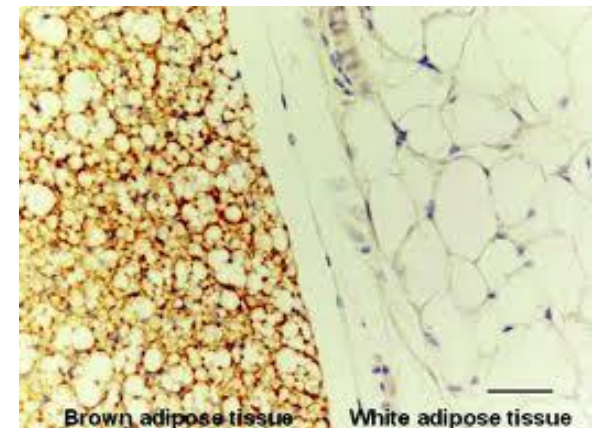


What happens when we touch something hot or sense external heat ?

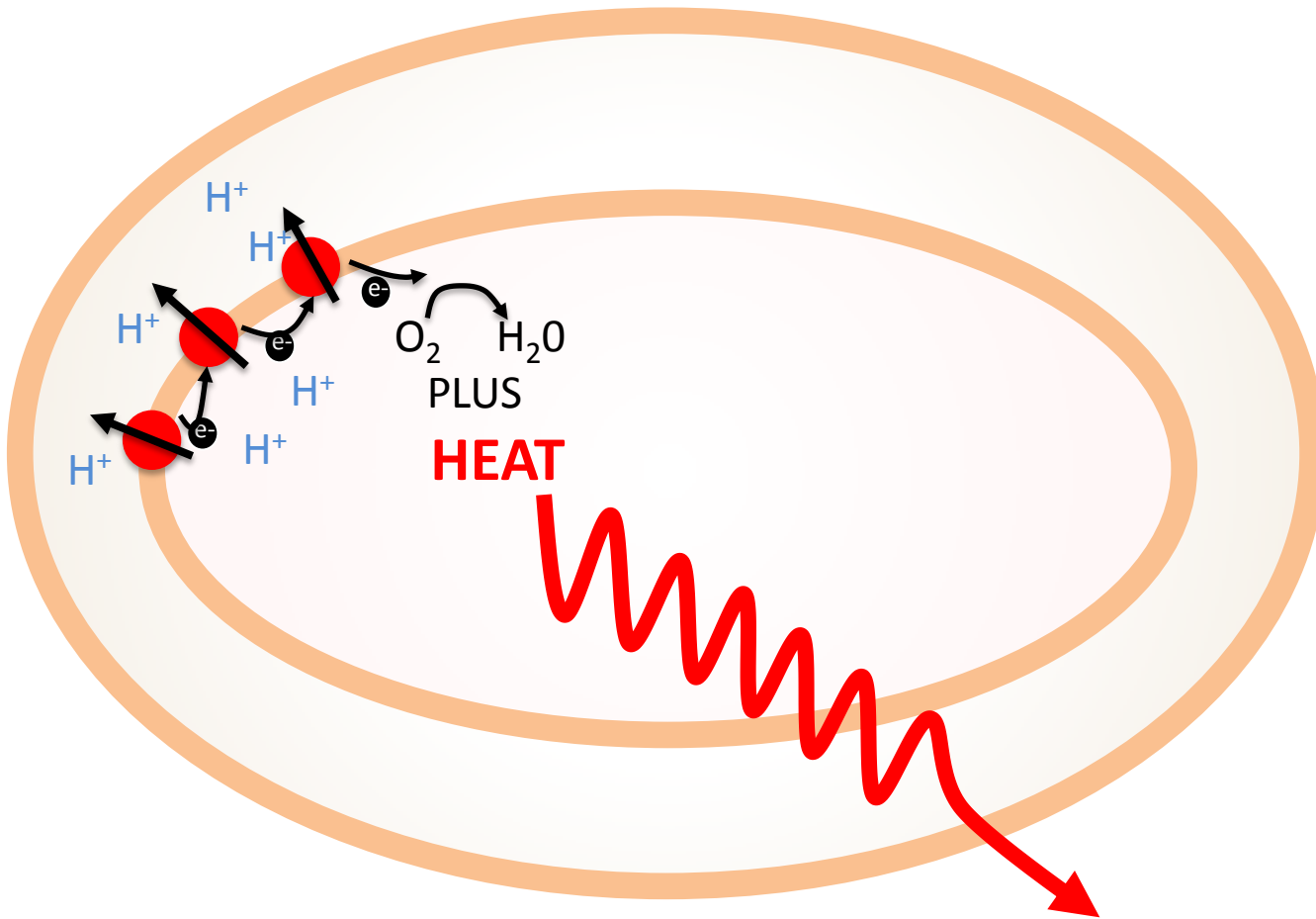


Brown Fat – How to Make Heat Without Having to Make ATP

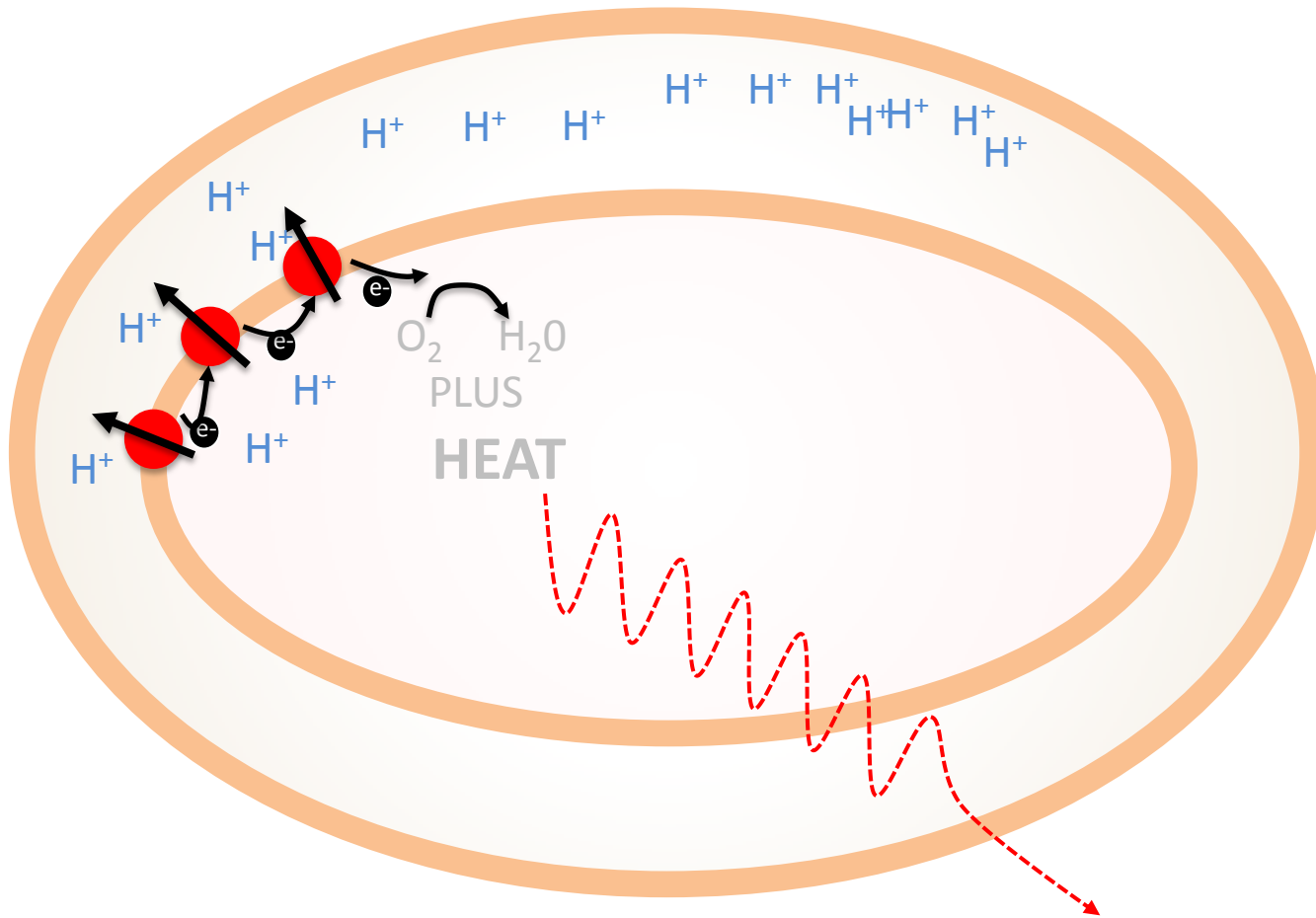
- Normally the process for making heat is tightly coupled to our need for ATP.
- This means that if we want to make more heat we have to use more ATP which is why we shiver as this generates heat.
- **BUT** in some circumstances we can bypass this if our mitochondria have a protein called uncoupling protein (see diagram)
- This is usually only found in a special type of fat called “brown fat”
- It is called brown fat because it appears brown because it is packed with huge numbers of mitochondria which have lots of iron so appear brown.
- Brown fat is found in many mammals that live outside in colder climates and is particularly important as a source of heat during hibernation
- In humans brown fat is found in babies where it can be 25% of all fat and allows babies to produce heat before they develop the ability to shiver but there is controversy as to whether adults have any at all.
- It is calculated that even as much as 50 grams of brown fat could make a huge difference to body mass
- More research is needed to understand the role of brown fat in adults



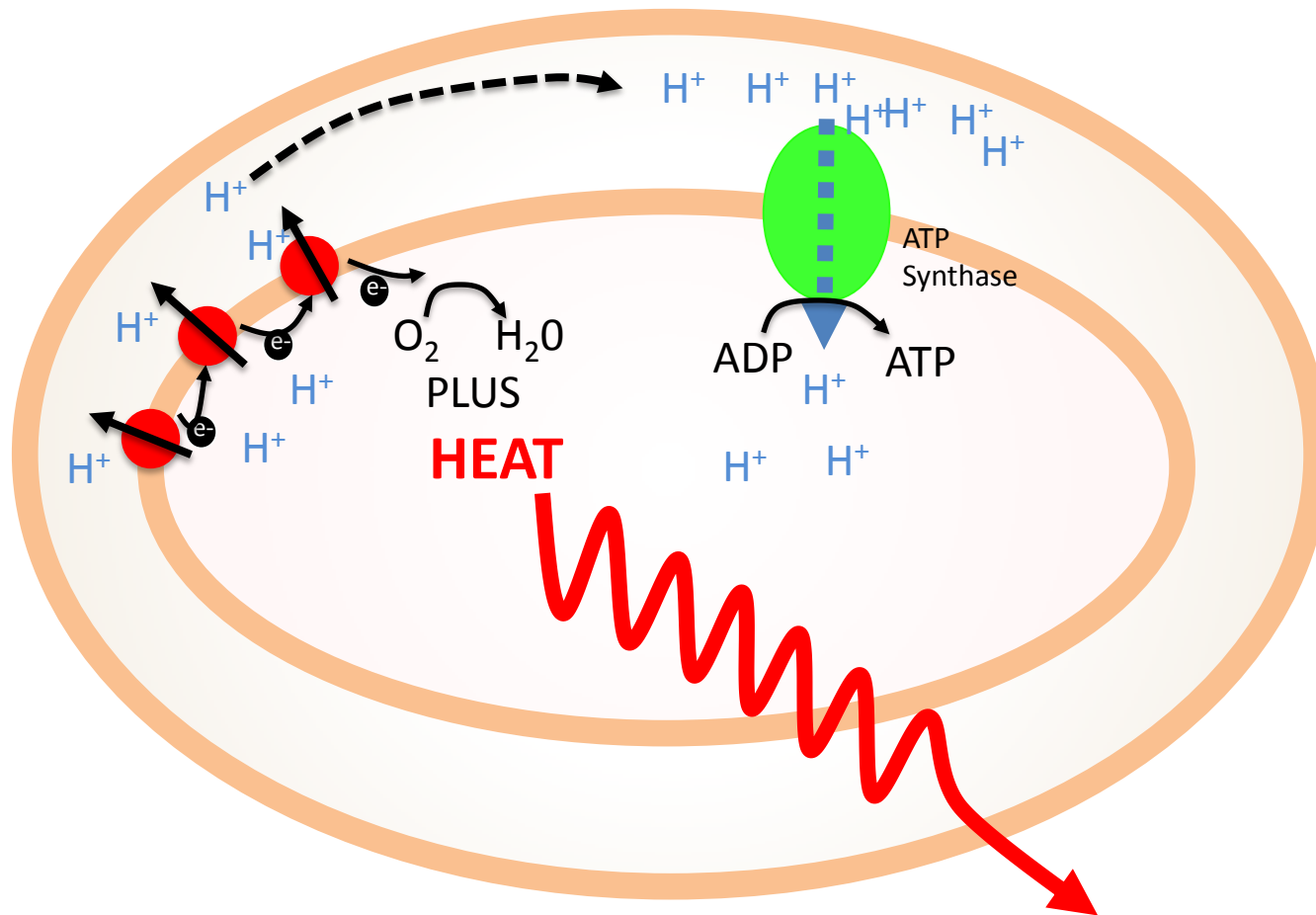
1. Electrons Transferred to Oxygen , Heat Generated and H⁺ Ions are Pumped Across Inner Mitochondrial Membrane



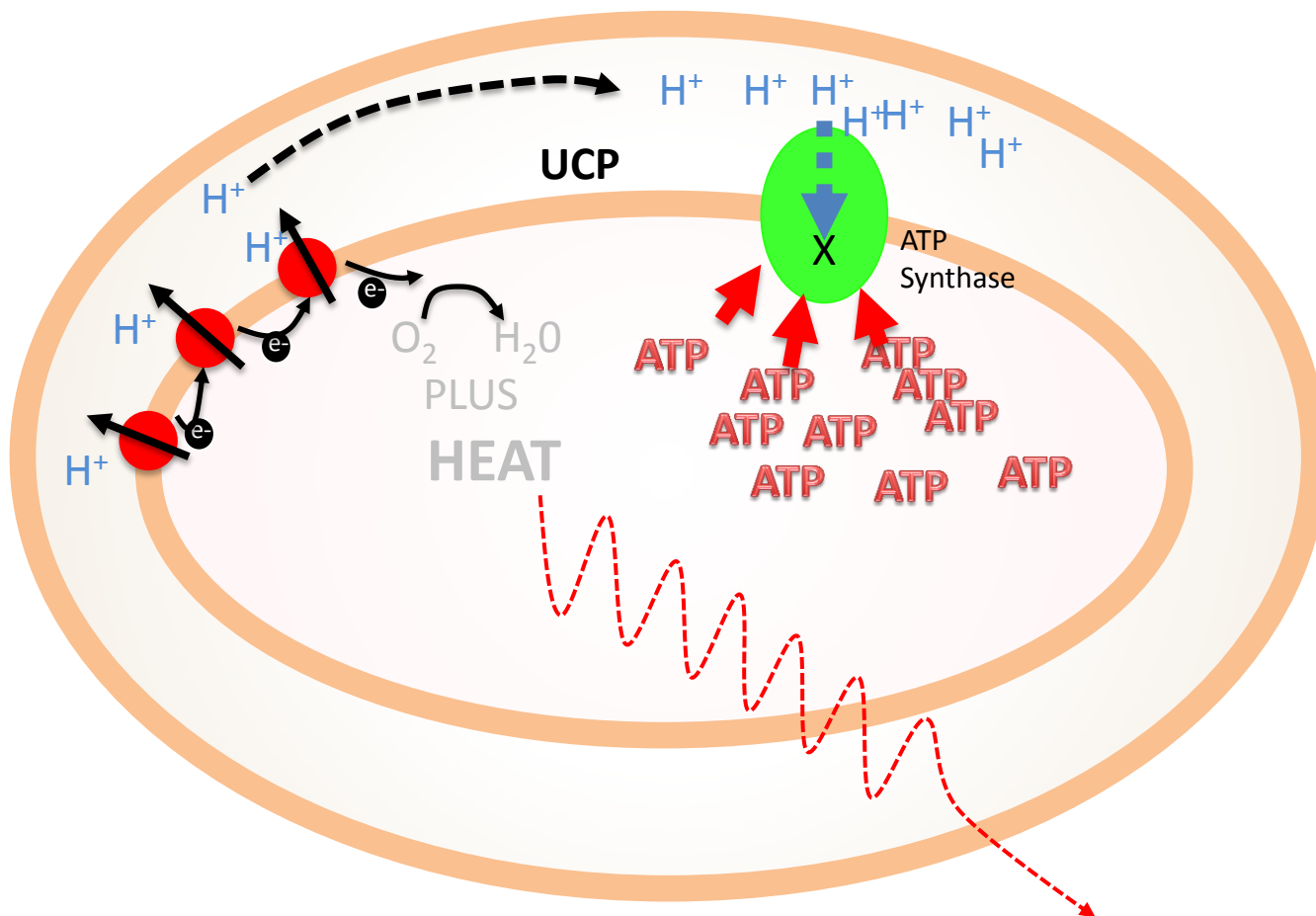
2. If H^+ gradient builds too much the more H^+ can't be pumped so oxygen can't be converted to H_2O so heat production stops



3. Normally the H^+ in the inter-membrane space is pumped back into the mitochondrial matrix by a molecule called ATP-synthase and this simultaneously generates ATP while restoring the balance of H^+ ions on each side of the membrane and so allowing oxygen use and heat production to continue

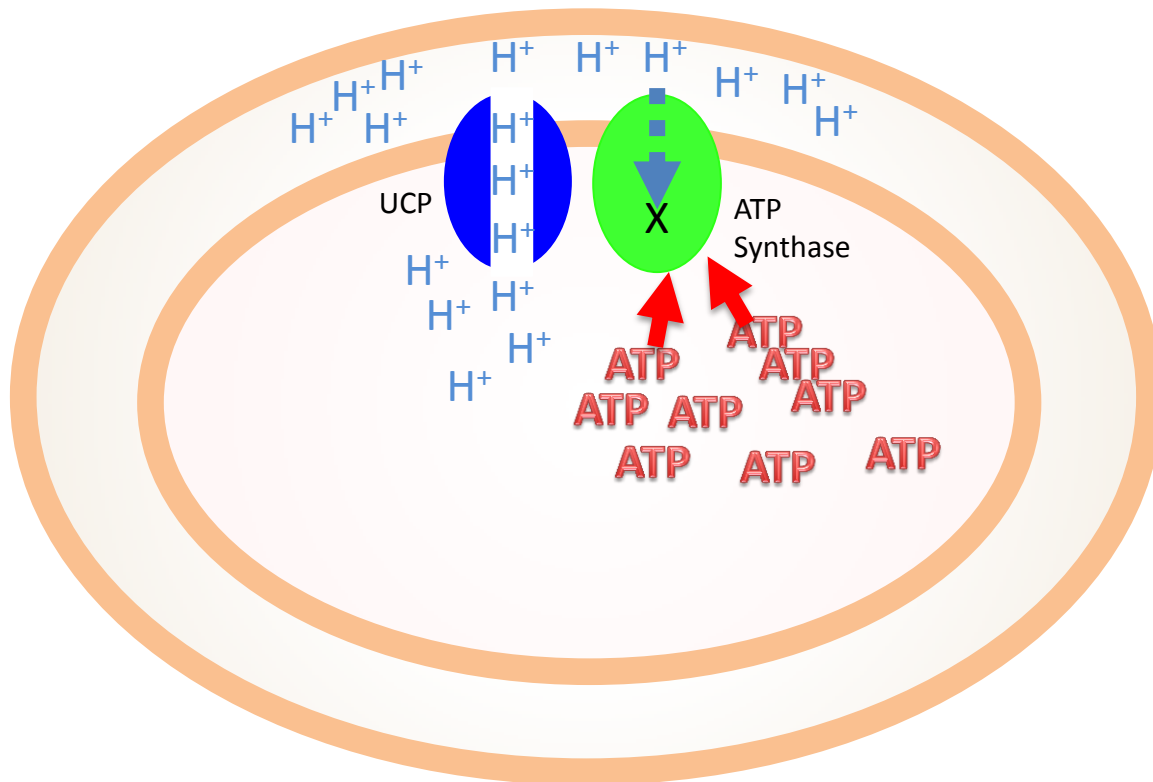


4. But if we don't use the ATP it builds up in the mitochondrial matrix and this stops ATP synthase from working and now we also get a build up of H⁺ ions in the inter-membrane space which in turn stops oxygen use and heat production. We therefore normally have to do work to use the ATP before we can make more heat (e.g muscle contraction such as shivering will use the ATP)

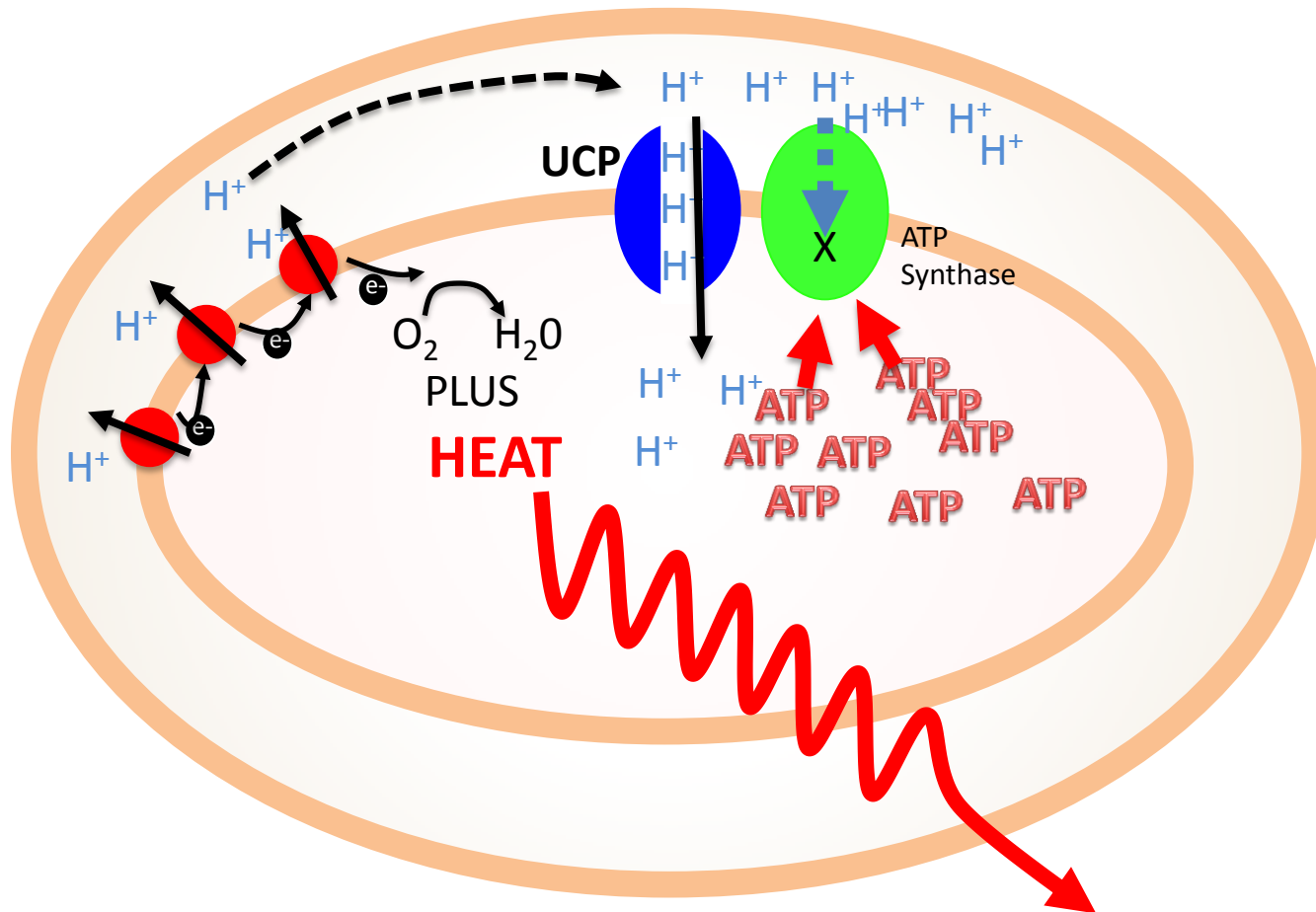


Can We Make Heat Without Having to Make ATP ?

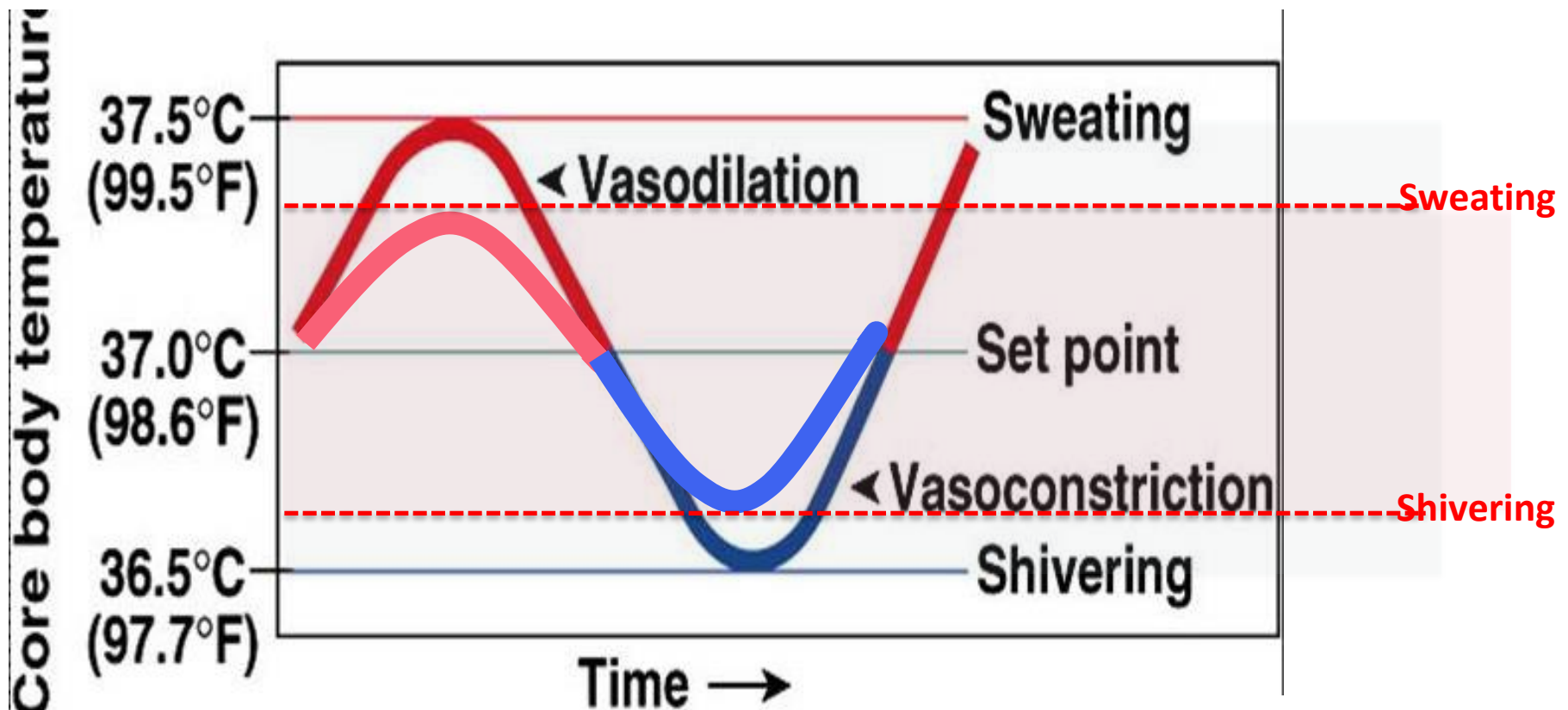
If Uncoupling Protein is present in mitochondria then H^+ ions are pumped back across the membrane even when ATP levels are already high



This means heat production can continue even though ATP levels are high i.e it means we can burn energy to produce heat without doing any work !!! Essentially this only happens in **brown fat**. If it happened in all tissues we would burn all our energy and do no work which would be very wasteful of energy.



During Menopause Women May Become More Sensitive to Changes In Core Body Temperature and so Over-React to Small Changes



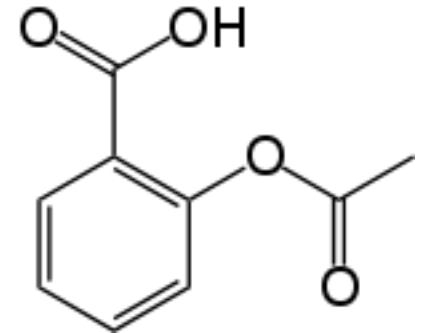
Fever

- One of the major ways that the body responds to insults like infection by producing compounds called prostaglandins.
- Prostaglandins are lipids that are modified by enzymes called cyclooxygenases (COX1 and COX2)
- In the brain they change the set point of the hypothalamus and so allow core body temperature to rise.



How Does Aspirin Reduce Fever ?

- The bark from willow trees was traditionally used as a medicine to lower fever and relieve pain so in 1800s people sought to identify the active ingredients.
- Active ingredient was isolated in 1850s and identified as salicylate.
- In 1899 Bayer introduced a more effective modified form called acetylsalicylic acid under the trade name Aspirin.
- It acts by blocking COX enzymes and so blocks the production of prostaglandins and reduces the driver of high temperature so the body then resets to a normal temperature.
- Paracetamol and ibuprofen work in a broadly similar way but also have additional effects



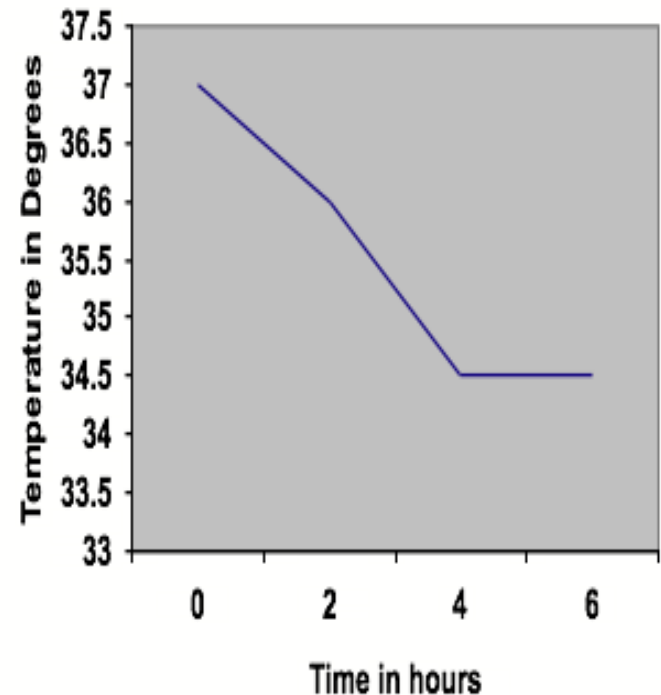
Frostbite

- The blood vessels in the skin (particularly in hands and feet) constrict in very cold conditions to preserve core body heat.
- If this is prolonged it starves the cells peripheral tissues of nutrients and also of their heat supply (remember blood is the best way to transfer heat around the body). When nerve cells stop working no signal get sent to the brain i.e. fingers and toes go numb.
- If this happens for a short time it can be reversed but if it happens for longer times the cells will die (i.e frostbite).



Anesthetics and body temperature

- Hypothermia is a major side effect of many types of anesthetics
- Some anesthetics cause vasodilation and thus allow heat loss
- Some impair muscle movement via nerves and so block the ability to induce a shivering response
- Heat loss due to radiation, especially during open surgery



Temperature changes after induction of general anesthesia



Extension questions for students

- Why do wind and water cool the body more quickly ?
- Why do we get a fever and how do drugs lower temperature during a fever ?
- What effect do anesthetics have body temperature ?
- How does brown fat work ?
- Why doesn't cold water reduce the burning sensation of chilli peppers but it does reduce the burning sensation of heat ?
- How does menopause produce hot flashes ?

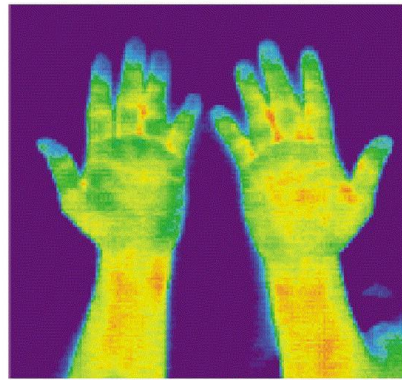


Effect of Bee Venom Injection on Body Temperature

1 min before



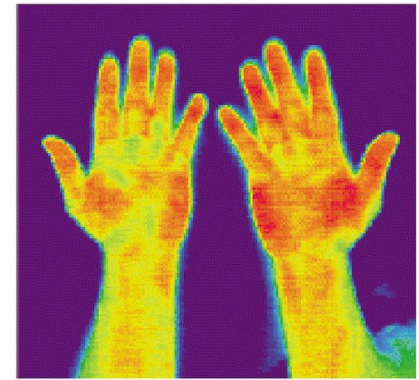
1 min after



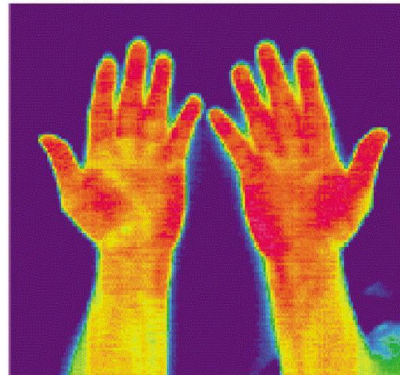
3 min after



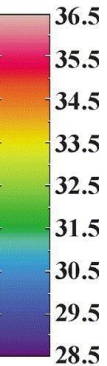
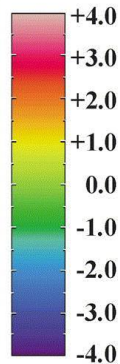
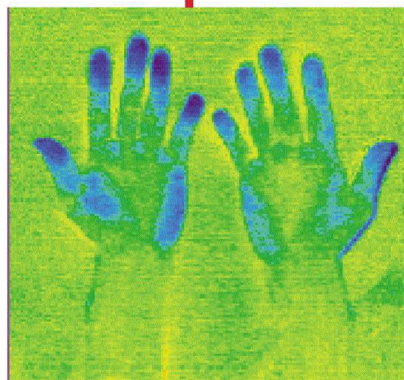
5 min after



10 min after



30 min after



Differential Thermogram

1min after minus 1 min before