THERMAL BALANCE
(STEADY STATE)

$$\dot{M} \pm \dot{H}_R \pm \dot{H}_C \pm \dot{H}_E + \dot{H}_S = 0$$

M = production of metabolic Q (heat)
it is always + in endot./eterot.

R = RADIATION (depends on surface, material, color)

C = CONDUCTION and CONVECTION (fur, fat..)

E = EVAPORATION

S = FORMS of ACCUMULATION THAT DEPEND on ΔT
(body mass, thermal capacity)

CONVECTION : - very efficacious in aquatic environment.

- the theory is complex

EVAPORATION : - TRANSPIRATION

- PERSPIRATIO INSENSIBILIS

RADIAZIONE TERMICA

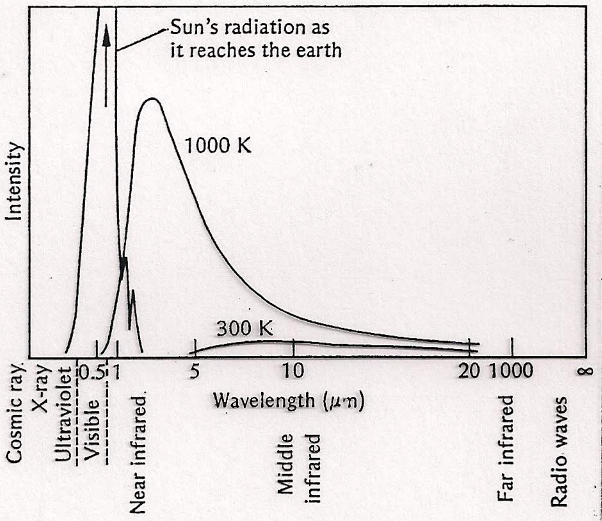


Figure 7.4 The thermal radiation from a body depends on its surface temperature, in regard to both the spectral distribution of the radiation and its intensity. The higher the surface temperature, the shorter is the wavelength and the higher is its intensity. This figure shows the spectral distribution of the thermal radiation from the sun (6000 K), a red-hot stove (1000 K), and the human body (300 K). [Hardy 1949]

↳ WIEN

STEFAN - BOLTZMANN LAW

$$Q_R \propto \sigma T^4 = \varepsilon \sigma T^4$$

units : $\frac{W}{m^2}$

ABSORPTION - REFLECTION - EMISSION

NET TRANSFER BETWEEN TWO BODIES:

$$Q_R = \sigma \varepsilon_1 \varepsilon_2 (T_2^4 - T_2^4) A$$

ε = EMISSIVITY (if they are $\simeq 1$, the approximation is ok)

σ = Stefan-Boltzmann constant

A = effective radiating area

At biological temperatures:

LOSS $\sim$ 300-500 $W m^{-2}$

METABOLIC PRODUCTION ONLY $\sim$ 20 W for a mammal of 10 kg and 1 m^2 of S

BUT THERE IS ALSO ACQUISITION, FROM ENVIRONMENT

E.g. SUN : 1000 W/m^2

ALSO OTHER BODIES

$$W = \frac{J}{s}$$

FOURIER

$$\dot{Q} = -\varepsilon \frac{dT}{dx}$$

per un'area A:

$$\dot{Q} = -\varepsilon A \frac{dT}{dx}$$

Forma semplificata:

$$\dot{Q} = -\varepsilon A \frac{T_1 - T_2}{l}$$

$$= \varepsilon A \frac{T_2 - T_1}{l}$$ → Eq. 16-12 Randall!

ε = conduttività termica del conduttore

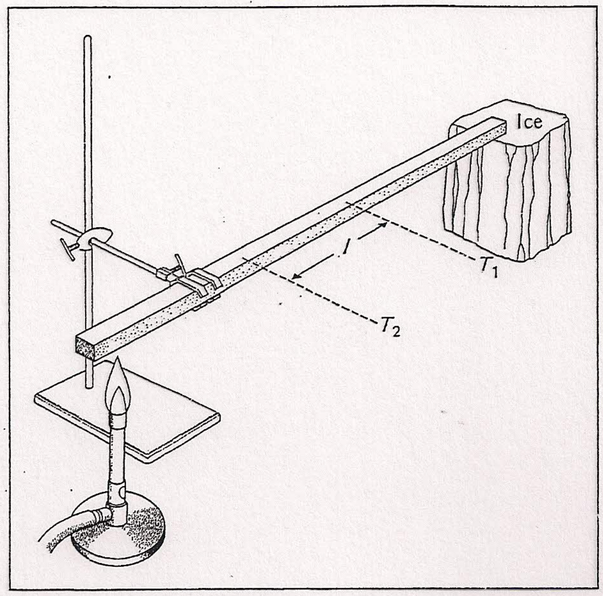


Figure 7.3 Heat flow in a uniform conductor depends on its cross section, the temperature gradient, and the material from which it is made.

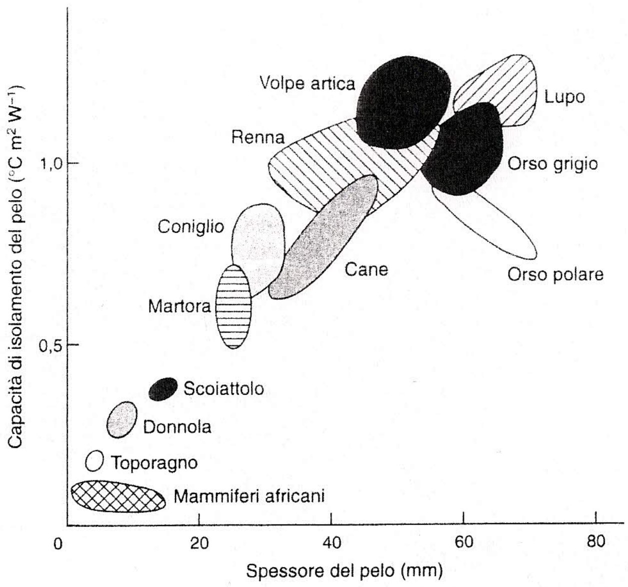
Material	k (cal s^{-1} cm^{-1} °C^{-1})
Silver	0.97
Copper	0.92
Aluminum	0.50
Steel	0.11
Glass	0.002 5
Soil, dry	0.000 8
Rubber	0.000 4
Wood	0.000 3
Water	0.001 4
Human muscle	0.001 1
Adipose tissue	0.000 51
Air	0.000 057
Animal fur	0.000 091

Table 7.3 Thermal conductivities (*k*) for a variety of common materials. [Hammel 1955; Hensel and Bock 1955; Weast 1969]

FEATURES OF FUR (OR INTEGUMENT)

- THE PERCEIVED COLOR IS NOT NECESSARILY A GOOD INDICATOR OF ε in IR
- REFLECTION (BRIGHTNESS)
- PENETRATION
- COMPOSITION (air bubbles, $CaCO_3$ ...)
- REFLECTION / DIFFUSION by PARTICLES

Figura 8.17. Spessore del pelo e sua capacità di isolamento termico. I mammiferi di piccola mole hanno necessariamente un pelo corto con capacità isolante relativamente scarsa. Notare che gli esempi si riferiscono a specie dei climi temperati freddi e polari; il pelo dei mammiferi che vivono in Africa raramente supera i 15÷20 mm di lunghezza e diminuisce piuttosto che aumentare in funzione della taglia corporea, essendo soltanto 0,5 mm nella più grossa delle antilopi (vedi capitolo 14). (Dati da SCHOLANDER *et al.*, 1950; HOFMEYR & LOUW, 1987).



CONDUCTION

STRATEGIES TO CONTROL THERMAL EXCHANGES

1) AVOIDANCE

- Migration
- Microhabitat
- Thermal INERTIA (FIGURE)
- QUIESCENCE (many forms)

2) TOLERANCE

- VERY VARIABLE (TABLE)
  (less in vertebrates, more in animals of temperate zones)

- $T_{PREF.}$: similar in nature and in the lab.
  May vary with activity in ectotherms.

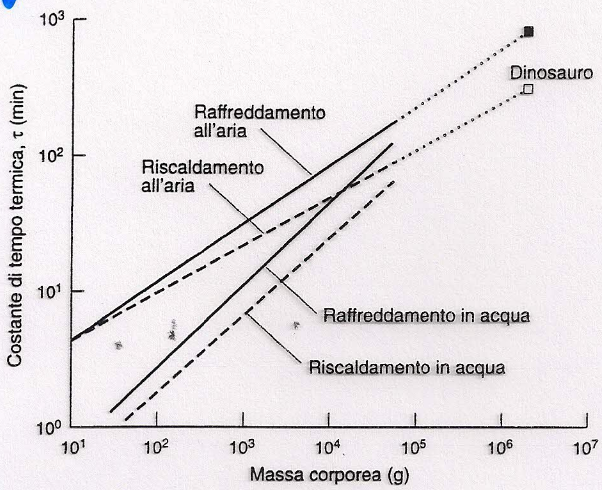
- THERMAL AMPLITUDE OF EXECUTION
  (ΔT_{body} within which the capacity of executing a task is > 80%)

- CRITICAL TEMPERATURES
  E.g. UTC (upper), LTC (lower)
  TL_{50} (50% of survival)

3) ACCLIMAT./ADAPT.

THERMAL TIME CONSTANT τ (min)

↓



← BODY MASS (g)

Figura 8.23. Correlazione tra la costante di tempo termica (τ) e la dimensione corporea nei rettili. Nelle specie attuali, la costante di tempo è in scala con la massa per quattro ordini di grandezza, variabili a seconda che l'animale stia scaldandosi o raffreddandosi, in acqua oppure all'aria. Il riscaldamento avviene più rapidamente (cioè la costante di tempo è minore) del raffreddamento, specialmente nell'acqua che ha una conduttanza più alta. L'estrapolazione sino alle dimensioni di un grosso dinosauro indica la sostanziale stabilità termica che questi animali devono aver posseduto, con una costante di tempo per il raffreddamento anche di 16 ore.

$\tau = t$ per avere 0.37 delle T iniziale = time constant (time to have 0.37 of initial T)

$\Delta\tau_T \simeq 10$ per un aumento di massa di 100 volte

($\simeq 10$ for a mass increase of 100 times)

UCT = UPPER CRITICAL TEMPERATURE

Gruppo	Esempio (habitat)	UCT (°C)
Procarioti	Batteri (acquatici)	70÷75
	Batteri (termofili)	90÷91
	Cianobatteri	75
Molluschi	*Modiolus* (bivalve AM)	38
	Nassa (gasteropode AM)	42
	Clavarizona (gasteropode AM)	43
Anellidi	*Lumbricus* (verme di terra)	29
Echinodermi	*Asterias* (stella marina AM)	32
	Ophioderma (stella serpentina AM)	37
Crostacei	*Palaemonetes* (gambero costiero/AM)	34
	Porcellio (granchio AM)	39÷41
	Uca (granchio costiero/terrestre)	39÷45
	Armadillidium (oniscoideo terrestre)	41÷42
Insetti	*Lepisma* (collembolo terrestre)	36
	Thermobia (termobia terrestre)	>40
	Sphingonotus (falena terrestre)	41
	Bembex (vespa della sabbia terrestre)	42
	Onymacris (coleottero del deserto)	49÷51
	Dasymutilla (vespa della sabbia terrestre)	52
	Ocymyrmex (formica del deserto)	51,5
	Melophorus (formica del deserto)	54
Aracnidi	*Buthotus* (scorpione terrestre)	45
	Leiurus (scorpione terrestre)	47
Vertebrati		
Pesci	*Pagothenia* (polare AM)	6÷10
	Fundulus (freddo AM)	35
Anfibi	Salamandre (AD/terrestre)	29÷35
	Anuri (AD/terrestre)	36÷41
Rettili	Alligatori (terrestre/AD)	38
	Tartarughe (AM/terrestre)	41
	Lucertole (terrestre/desertico)	40÷47
	Serpenti (terrestre)	40÷42
Uccelli	Passeriformi	46÷47
	Non passeriformi	44÷46
Mammiferi	Monotremi	37
	Marsupiali	40÷41
	Placentati	42÷44

T at which neuromotor control is lost

VCT SPECIFICITY (among species and organs/tissues)

- PATHWAYS WITH DIFFERENT SENSITIVITY
- MEMBRANES / TRANSPORT
- MORE SENSITIVE TISSUES

DEVELOPMENT IS MORE SENSITIVE THAN ADULT STAGES

The V of development does not vary in species of different habitats, as a function of T, at least in marine animals.

OFTEN INCOMPLETE COMPENSATION

Animal	Approximate normal core temperature (°C)	Approximate lethal core temperature (°C)
Monotreme (echidna)	30–31[a]	37[a]
Marsupials	35–36[b]	40–41[e]
Insectivore (hedgehog)	34–36	41[f]
Man	37	43
Eutherian mammals	36–38[c]	42–44[g]
Bird (kiwi)	38[d]	
Birds, nonpasserine	39–40[b]	46[h]
Birds, passerine	40–41[b]	47[i,j]

[a]Schmidt-Nielsen et al. (1966).
[b]Dawson and Hulbert (1970).
[c]Morrison and Ryser (1952).
[d]Farner (1956).
[e]Robinson and Morrison (1957).
[f]Shkolnik and Schmidt-Nielsen (1976).
[g]Adolph (1947).
[h]Robinson and Lee (1946).
[i]Calder (1964).
[j]Dawson (1954).

Table 7.2 Approximate normal and lethal core temperatures of some major groups of mammals and birds. The lethal temperatures are based on observations made under a wide variety of conditions. There is rather consistently an approximately 6 °C interval between the normal and the lethal temperatures for the same animal.

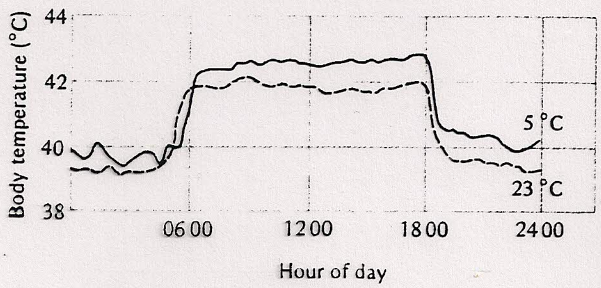


Figure 7.2 When the towhee (a finch, *Pipilo aberti*) is kept at a constant room temperature of 23 °C, its body temperature varies with the light cycle. When the lights come on at 0600 hours, the body temperature rises by nearly 3 °C, to drop again when the lights go off at 1800 hours. If the room temperature is reduced to 5 °C, the body temperature cycle is similar, but at a slightly higher level. [Dawson 1954]

From: SCHMIDT-NIELSEN
ANIMAL PHYSIOLOGY
Camb. UN. PRESS.

DORMANT STATES (DORMANCY)

↓ ACTIVITY
↓ MR

CLASSIFICATION : DURATION
DEPTH (↓ T_{BODY} and V of RECOVERY)

- QUIESCENCE (scarse physiological changes
  quick recovery
  e.g. desert invertebrates)

- TORPOR (↓ MR, ↓ T_{BODY}, RECOVERY with thermogenesis)
  small birds and mammals, e.g.
  birds at 40 °C (day) and 13 °C nocturnal.

- SLEEP

- HIBERNATION
  WINTER SLEEP
  ESTIVATION
  ] SEASONAL TORPOR

- DIAPAUSE (arthropodes, <u>insects</u>)

- CRYPTOBIOSIS (very DEEP metabolic depression)

TORPOR

Thermoregulation remains, but the "SETPOINT" changes

Critical temperature

- DIURNAL/NOCTURNAL
- OR SEASONAL

HIBERNATION (in english, lethargy is used in Medicine)

ANIMALS OF MEDIUM SIZES (at least hundreds of grams)

SEASONAL SLEEP (big animals)

they have more reserves and a higher S/Vol

Specie	T_b normale (°C)	T_b nel torpore (°C)	Rapporto tra MR nel torpore e MR normale
Monotremi			
Echidna	32,2	5,7	0,44
Marsupiali			
Opossum nano	33,7	10,1	0,22
Insettivori			
Toporagno	34,7	14,0	0,10
Roditori			
Topo	37,4	19,0	0,44
Ghiro	37,7	7,0	0,35
Citello	37,1	5,0	0,15
Carnivori			
Tasso	37,0	28,0	0,50
Uccelli			
Succiacapre	37,0	10,0	0,17
Colibrì	40,0	21,0	0,13

Tabella 8.13. Variazione della temperatura corporea (T_b) e del tasso metabolico (MR) di alcuni mammiferi e uccelli in cui si manifesta il torpore. Il tasso metabolico basale è simile a quello dei mammiferi non torpidi. Viene anche mostrato il rapporto tra il tasso metabolico nel torpore e quello basale. (Dati da GEISER, 1988).

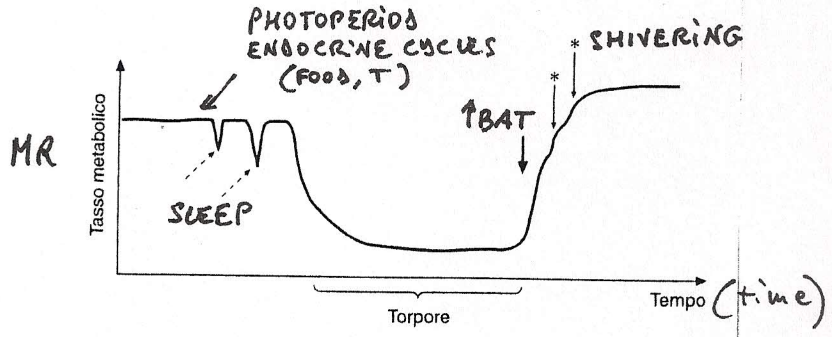


Figura 8.46. Andamento della variazione del tasso metabolico all'inizio e alla fine del torpore in un piccolo mammifero. Le frecce tratteggiate indicano le «prove» preliminari, quando il tasso metabolico si abbassa transitoriamente; l'entrata nello stato di torpore avviene poi gradatamente e con relativa lentezza. Il torpore cessa bruscamente (frecce continue) quando si attiva il tessuto adiposo bruno (BAT) e il tasso metabolico può in seguito aumentare ancora per brevi periodi a causa del brivido (*).

BAT= BROWN ADIPOSE TISSUE

AROUSAL FROM TORPOR

ANTEROPOSTERIOR T GRADIENT

↓

BLOOD TO BROWN FAT AND IMPORTANT ORGANS

↓

↑ T

↓

CORTICOSTEROIDS + INSULIN

↓

↑ T IN THE ENTIRE BODY

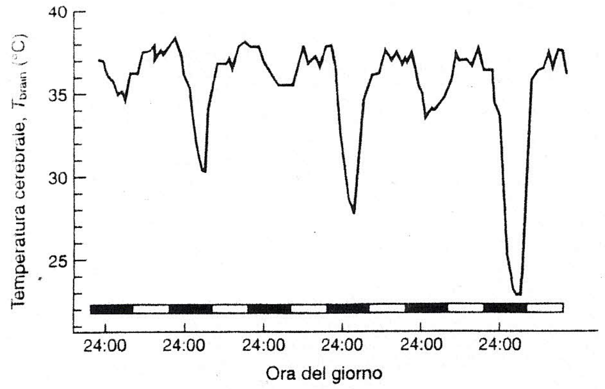


Figura 14.44. L'inizio del torpore in un citello, con il progressivo abbassamento della temperatura cerebrale una notte dopo l'altra. (Adattata da STRUMWASSER, 1960).

Specie	Massa corporea	Tempo di entrata	Tempo di risveglio
Toporagno	2 g	35 min	13 min
Colibrì	4 g	59 min	17 min
Opossum del miele	10 g	80 min	24 min
Succiacapre	40 g	224 min	41 min
Succiacapre di Nuttall	86 g	350 min	55 min
Avvoltoio	230 g	39 h	3,2 h
Echidna	3,5 kg	27 h	3,8 h
Marmotta	4,0 kg	29 h	4,0 h
Tasso	9,0 kg	45 h	5,4 h
Orso	80 kg	138 h	12,3 h

Tabella 14.5. Tempo necessario per entrare o uscire dal torpore in animali con massa corporea differente. I valori sono stati calcolati dalle equazioni allometriche, con il raffreddamento e il risveglio a 15 °C e con la temperatura corporea compresa tra 17 e 37 °C.

ESTIVATION (not simple quiescence
typical of many desert invertebrates,
e.g. arthropodes)

DESERT OR SEMI-ARID ENVIRONMENTS

↓ MR, ↓ GROWTH, REPRODUCTION, RESPONSE TO STIMULI

↑ TOLERANCE TO T

- E.g. DESERT SNAILS (up to 98% of lifetime)
  - ↓ MR (even > 90%), water conservation
  - EPIPHRAGM (calcareous or mucous lid)
  - SPECIFIC PROTEINS FOR METABOLIC CONTROL
  - PROTECTED SHELTERS

- Amphibia, reptiles: ↓ MR (50-70%)
  e.g. Scaphiopus (frog): DISIDRATATION + UREA
  ANTIOXIDANTS on AROUSAL
  LIPIDIC RESERVES, even 10 months

- PULMONATES, fishes of drying regions.

- DESERT ENDOTHERMS
  - ~~DEEP~~ SLEEP OR CIRCADIAN TORPOR
  - ↓ T ~ 25-30 °C
  - PHYSIOLOGY SIMILAR TO HIBERNATION

DIAPAUSE

ARREST OF DEVELOPMENT OR LIFE CYCLE
USUALLY IN INSECTS

- SUMMER OR WINTER, but can last for years
  (reserves + nest)

- It's a DORMANT STATE TRIGGERED ENDOGENOUSLY
  by EXTERNAL STIMULI (PHOTOPERIOD, etc.)

- It's PART of the LIFE CYCLE, ARISES BEFORE
  THE DIFFICULT CONDITIONS.

- In the desert, CLIMATE and FOOD AVAILABILITY
  often more important than PHOTOPERIOD.

- Synchronizes the life cycle with the
  environment.

- low RESPIRATORY FREQUENCY
  VERY VISCOUS BODY FLUIDS
  (ANTI-FREEZING COMPOUNDS in WINTER)

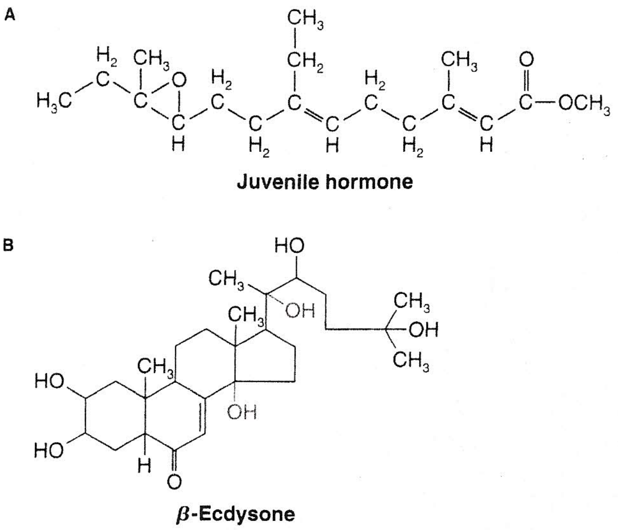


Figure 9-35 Juvenile hormone and β-ecdysone play key roles in regulating insect development. **(A)** The structure of juvenile hormone from the cecropia moth *Hyalophora cecropia.* This hormone promotes the retention of juvenile characteristics in larvae and induces reproductive maturation in adults. Several homologs of juvenile hormone occur naturally in insects. **(B)** The structure of β-ecdysone, the physiologically active molt-inducing hormone. The prohormone α-ecdysone, which lacks the hydroxyl group on C-20 (red), is synthesized from cholesterol in the prothoracic glands of insects. After its release, α-ecdysone is converted in certain target tissues into the active hormone β-ecdysone.

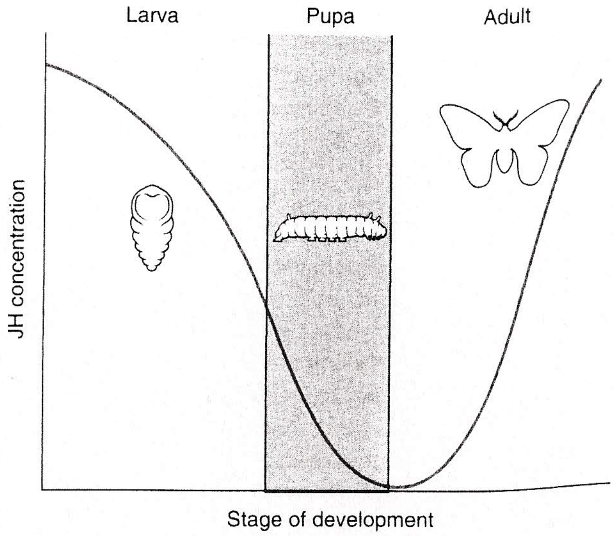
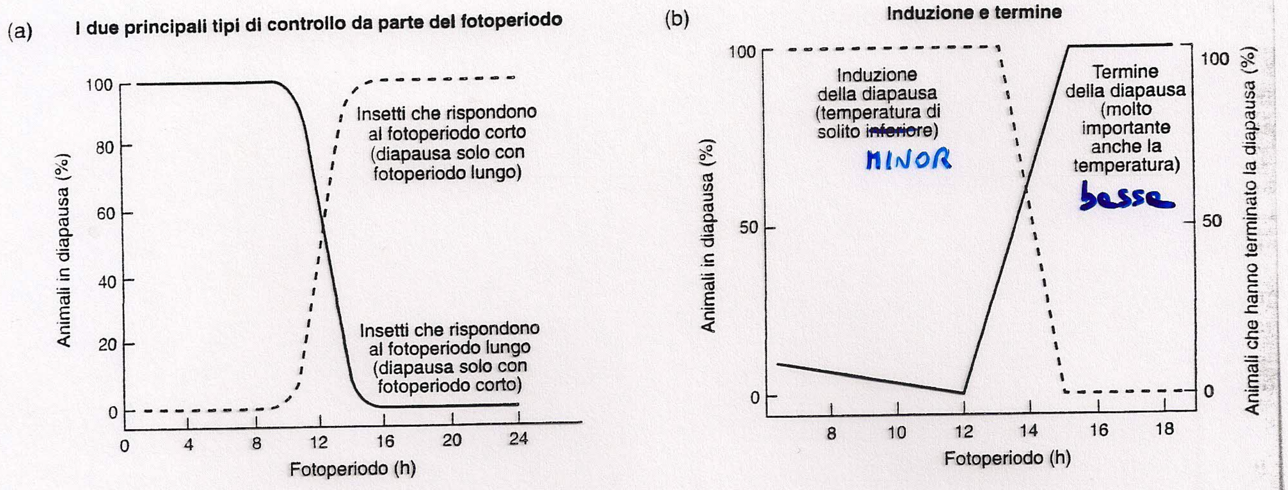
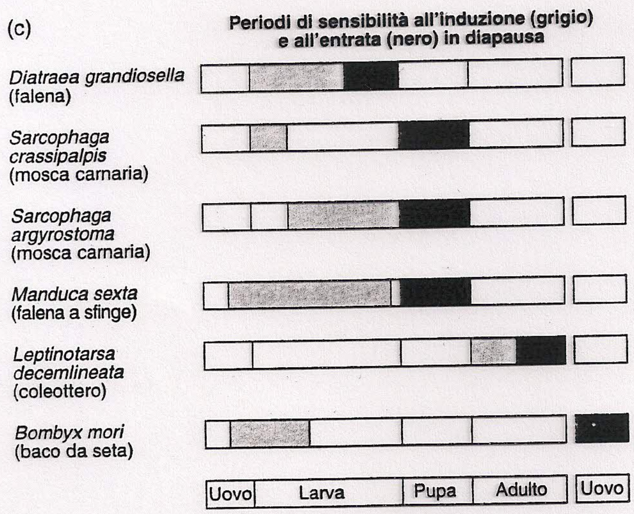


Figure 9-36 Normal progression through the insect life cycle depends on changes in the level of juvenile hormone. Metamorphosis of the juvenile larval form to the pupa occurs when the concentration of juvenile hormone falls below a certain threshold level. After the adult insect emerges and feeds, secretion of juvenile hormone begins again, regulating ovarian activity and stimulating development of male accessory organs. [Adapted from Spratt, 1971.]





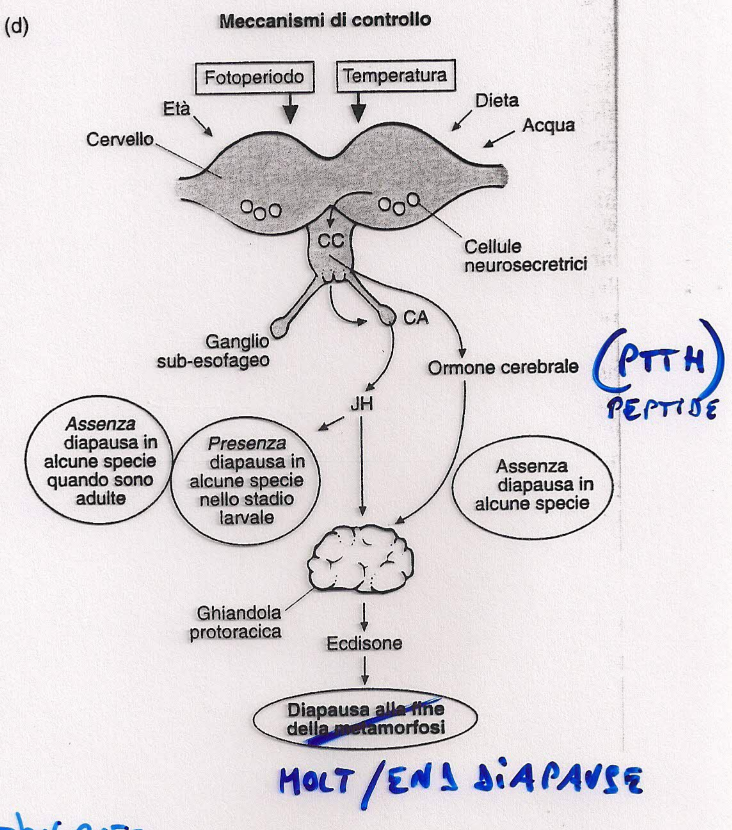


Figura 8.45. Controllo della diapausa negli insetti: CA, corpo allato; CC, corpo cardiaco; JH, ormone giovanile. (c, Ristampa da KERKUT, G.A. & GILBERT, L.I., *Comprehensive Insect Physiology, Biochemistry and Pharmacology*, Vol. 8. *Endocrinology II*, copyright 1985 col permesso di Elsevier Science).

↓ RESPIRATION RATE
VERY VISCOUS BODY FLUIDS
(because of antifreezing agent during winter diapause)

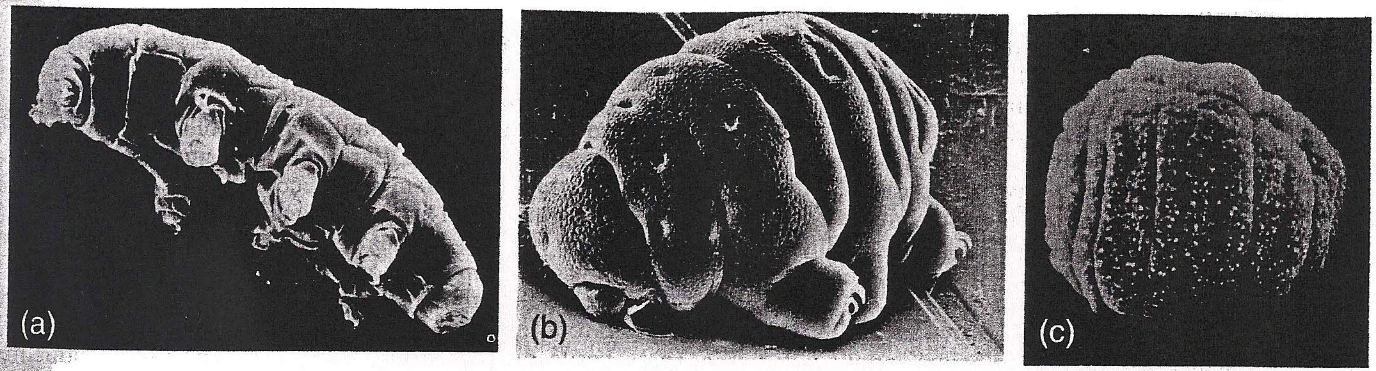


Figura 12.3. ↑ Fotografia al microscopio elettronico a scansione di un tardigrado (a) nel suo normale stato idratato, (b) poco dopo l'inizio della criptobiosi, (c) nello stadio finale della criptobiosi (botte). (Cortesia di J.C. WRIGHT).

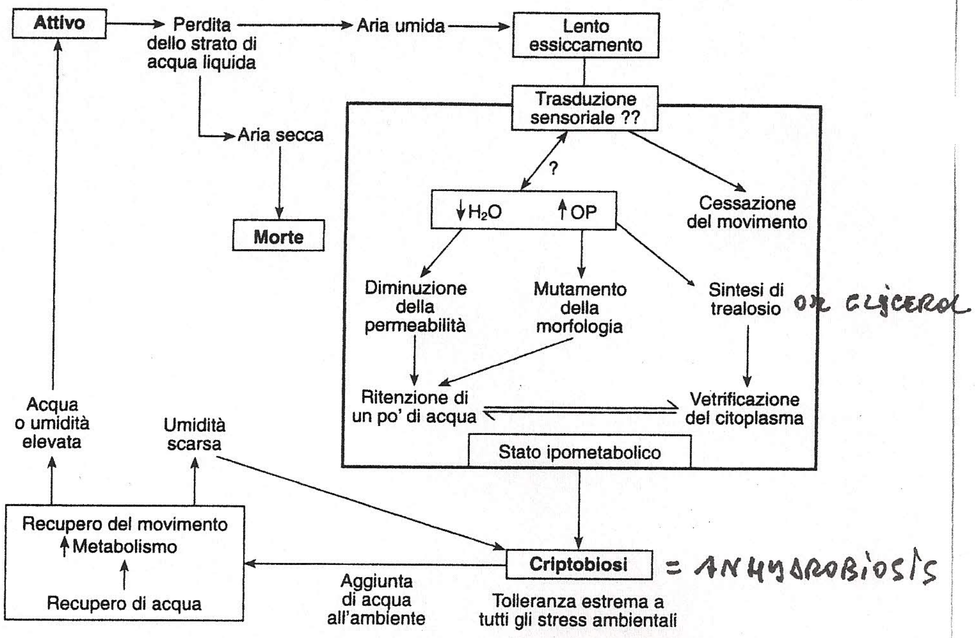


Figura 12.4. → Il controllo della criptobiosi: l'effetto della presenza di acqua, di aria umida o secca e dei meccanismi endogeni di controllo. OP, pressione osmotica.

MOSS LAYERS
FISSURES

TARDIGRADES
NEMATODES
ROTIFERS