Carlson (7e)

PowerPoint Lecture Outline

Chapter 9: Sleep and Biological Rhythms

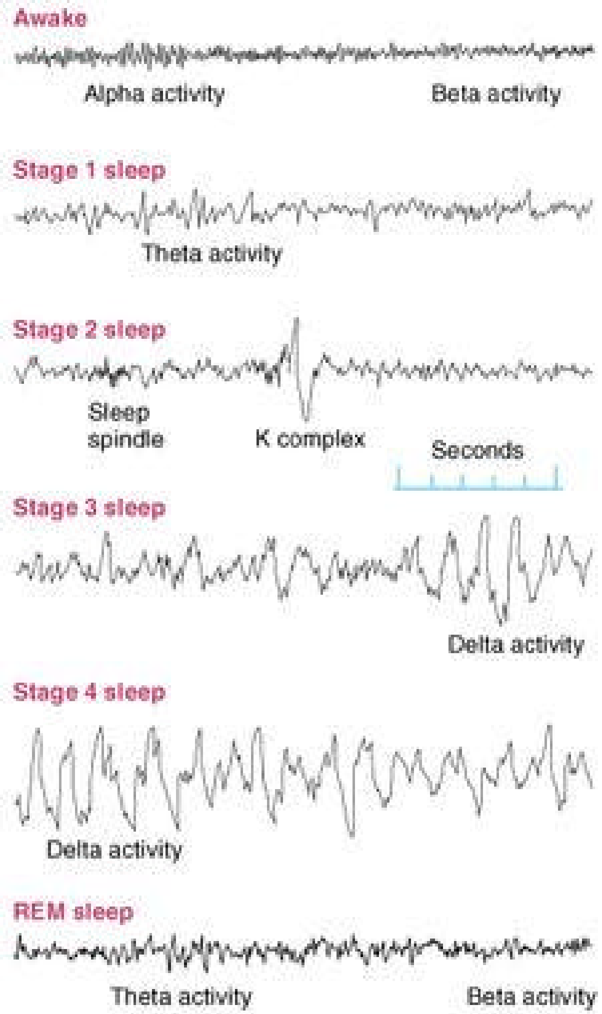
Sleep

- Sleep is a behavior and an altered state of consciousness
  - Sleep is associated with an urge to lie down for several hours in a quiet environment
    - Few movement occur during sleep (eye movements)
  - The nature of consciousness is changed during sleep
    - We experience some dreaming during sleep
    - We may recall very little of the mental activity that occurred during sleep
- We spend about a third of our lives in sleep
  - A basic issue is to understand the function of sleep

Measures of Sleep

- Electrophysiological instruments can be used in the sleep laboratory to assess the physiological changes that occur during an episode of sleep
  - Muscle tone (EMG)
  - Summated brain wave activity (EEG)
    - Wakefulness: beta activity (13-30 Hz) is present in the EEG record (desynchrony: low amplitude, high frequency waveforms)
    - Eyes closed: alpha activity (8-12 Hz) appears in the EEG record (synchrony: high amplitude, low frequency waveforms)
  - Eye movements
  - Blood flow to the genitals

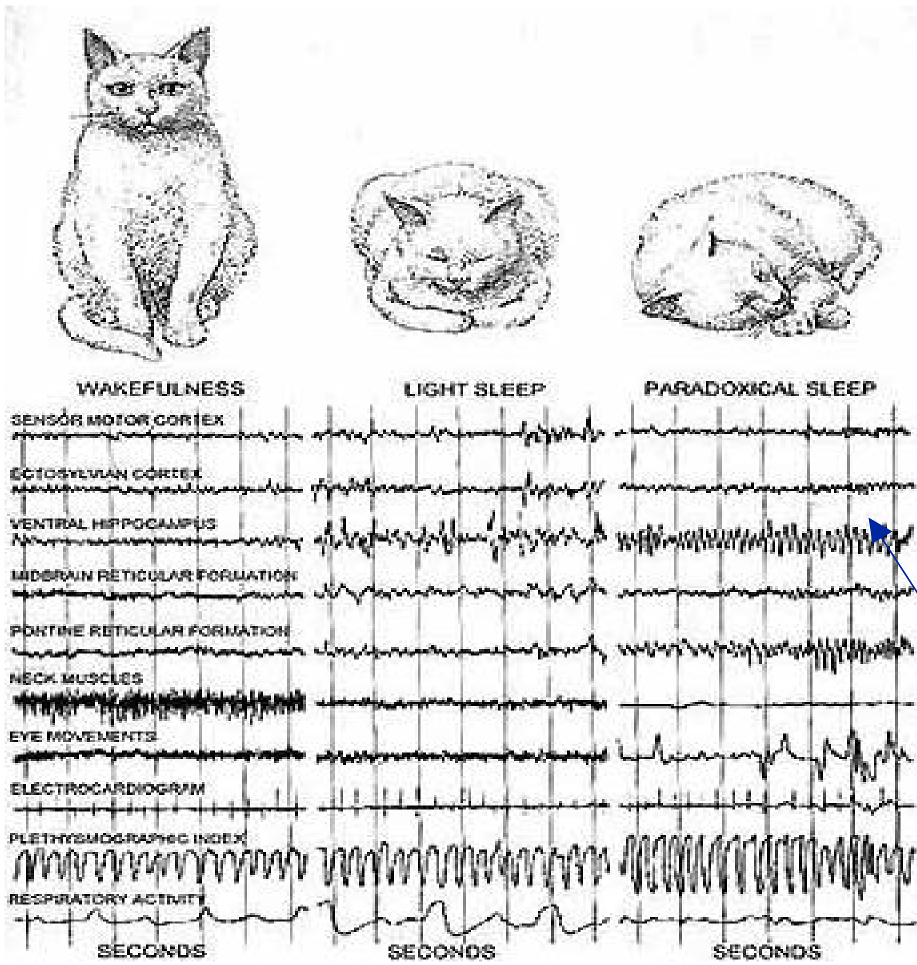
► **An EEG Recording of the Stages of Sleep**



Source: From Horne, J.A. *Why We Sleep: The Functions of Sleep in Humans and Other Animals*. Oxford, England: Oxford University Press, 1988.

EEG Waveforms During Sleep

Synchrony



Source: http://ura1195-6.univ-lyon1.fr/home.html

Desynchrony

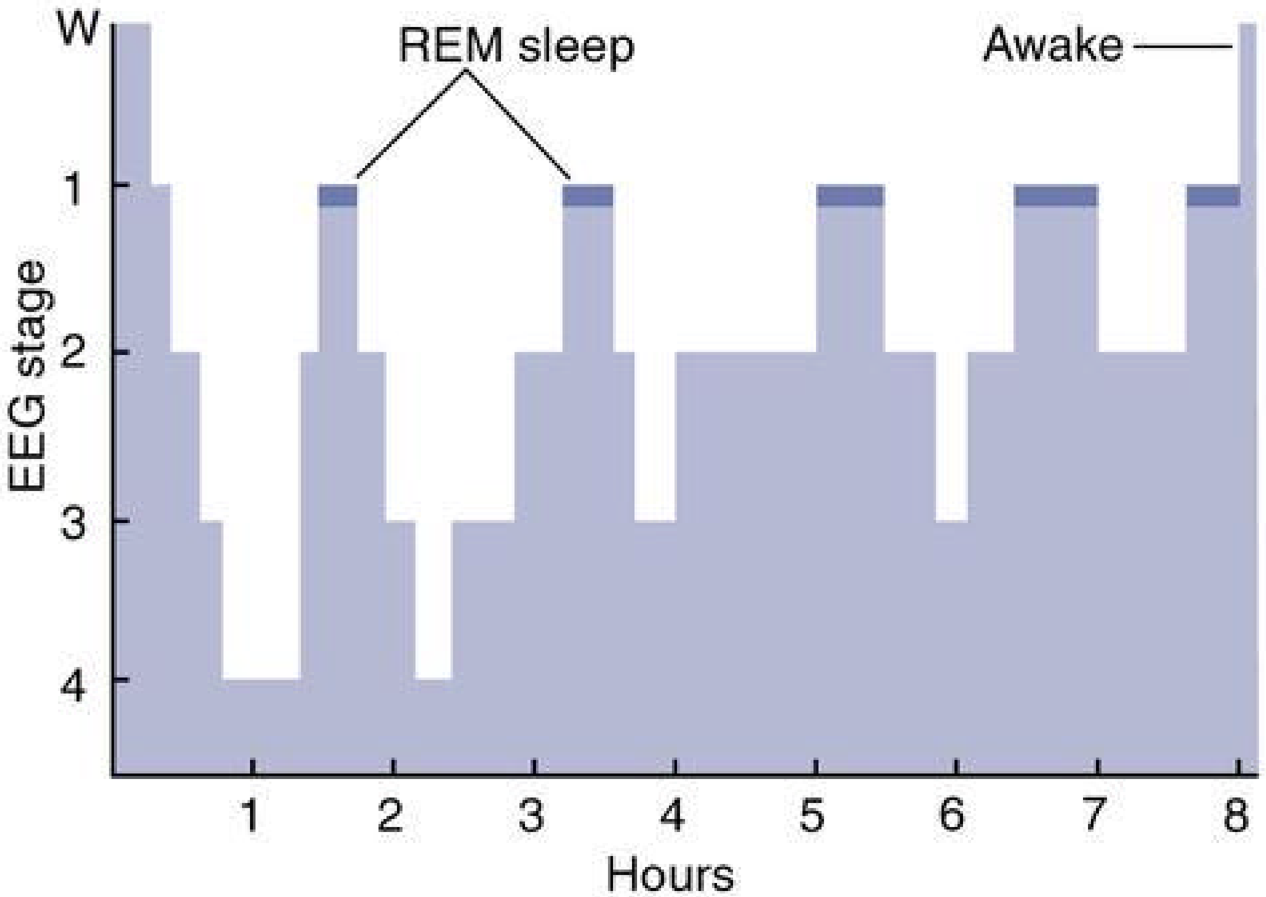
Non-REM Sleep

- Alpha, delta, theta activity are present in the EEG record
  - Stages 1 and 2
  - Stages 3 and 4: delta activity (synchronized)
    - Termed slow-wave sleep (SWS)
- Light, even respiration
- Muscle control is present (toss and turn)
- Dreaming (cold, rational)
  - Difficult to rouse from stage 4 SWS (resting brain?)

REM Sleep

- Presence of beta activity (desynchronized EEG pattern)
- Enhanced respiration and blood pressure
- Rapid eye movements (REM)
- Pontine-Geniculate-Occipital (PGO) waves
- Loss of muscle tone (paralysis)
- Vivid, emotional dreams
- Signs of sexual arousal
  - Assess impotence: postage stamps versus the sleep lab

► **Typical Pattern of the Stages of Sleep During a Single Night**



Sleep Stage Cycles

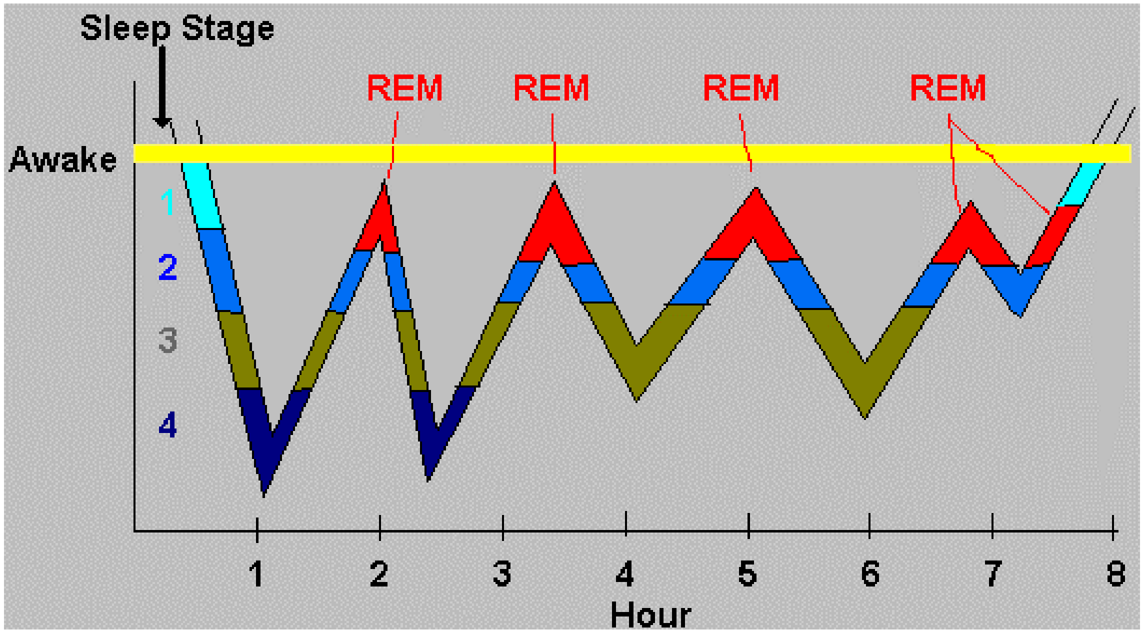


Figure courtesy of Dr. Eric Chudler

1. SWS precedes REM sleep
2. REM sleep lengthens over the night
3. Basic sleep cycle = 90 minutes

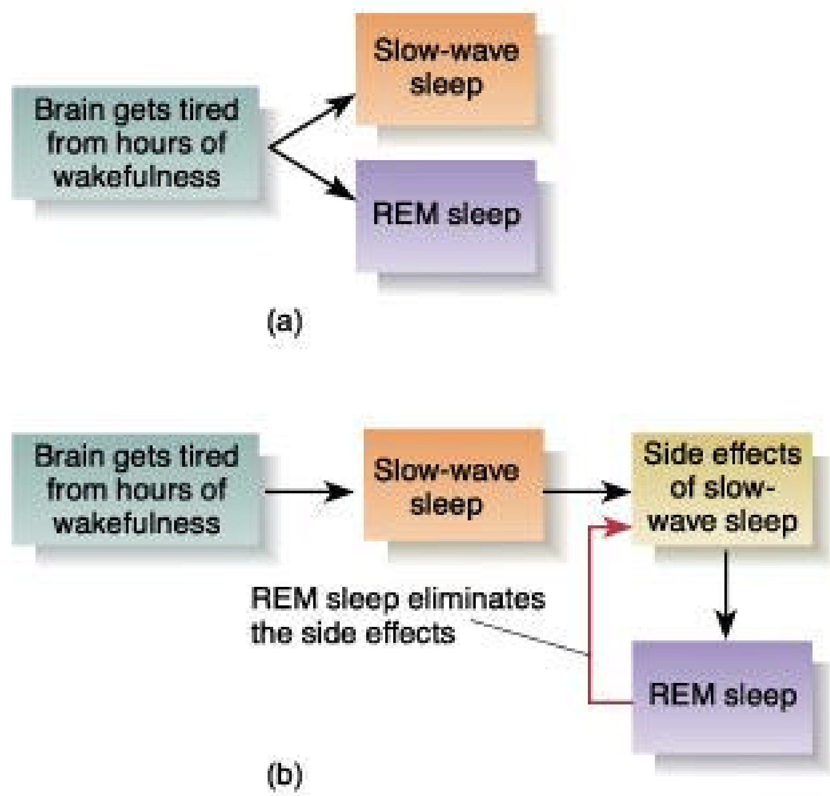
Mental Activity in Sleep

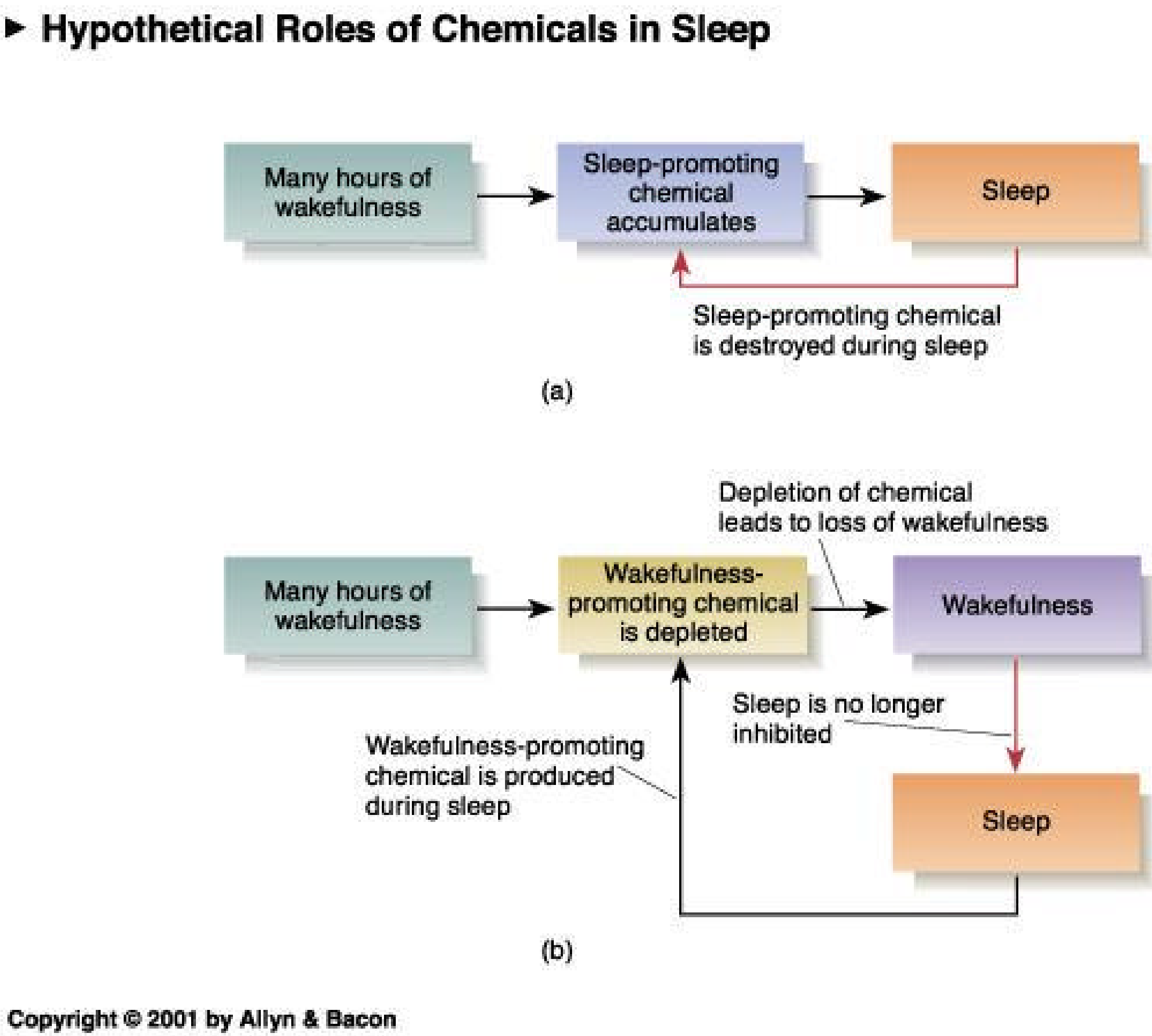
- Mental activity continues during sleep
  - Dreams occur during SWS and REM sleep
  - REM sleep is accompanied by high levels of blood flow in the visual association cortex but low levels in the inferior frontal cortex
  - REM eye movements resemble those made when a person scans a visual image
  - Nightmares can occur during stage 4 of SWS

What is the Function of Sleep?

- Sleep as an <u>adaptive</u> response?
  - Sleep is noted in all vertebrates
  - The signs of REM sleep (muscle paralysis, EEG desynchrony, eye movements) occur in mammals
  - Did sleep evolve to keep our ancestors away from predators?
  - Indus dolphins sleep even though doing so is dangerous
    - These dolphins exist in muddy water and through natural selection have become blind
- <u>Restoration and repair</u>?
  - Brain activity is reduced during SWS (delta activity)
  - Persons awakened from SWS appear groggy and confused
  - Yet, exercise and forced bed rest have little effect on sleep

► Two Possible Explanations for the Relation between Waking, Slow-wave Sleep, and REM Sleep




Hypothetical Roles of Chemicals in Sleep
Many hours of wakefulness
Sleep-promoting chemical accumulates
Sleep
Sleep-promoting chemical is destroyed during sleep
(a)
Depletion of chemical leads to loss of wakefulness
Many hours of wakefulness
Wakefulness-promoting chemical is depleted
Wakefulness
Sleep is no longer inhibited
Wakefulness-promoting chemical is produced during sleep
Sleep
(b)
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Sleep Deprivation Studies

- Human sleep deprivation studies indicate that sleep deprivation can impair cognitive function
  - Perceptual distortions and hallucinations as well as impaired ability to concentrate have been reported during sleep deprivation
  - But sleep deprivation does not result in a physiological stress response nor does it interfere with normal bodily function
- Animal studies indicate drastic health consequences of sleep deprivation
  - Rats that are forced to walk on rotating platform lose sleep
  - Sleep deprived rats exhibited increased eating and activity and eventually became ill and died

Sleep Stage Functions

- SWS may reflect restoration
  - Assessment of SWS after:
    - Prolonged bed rest (no real changes in SWS)
    - Exercise (temperature inc. => inc. SWS)
    - Mental activity increases SWS
- REM sleep may reflect:
  - Vigilance: alertness to the environment
  - Consolidation of learning/memory
  - Species-typical reprogramming
  - Facilitation of brain development: Infants spend more time in REM sleep
  - An antidote for the deleterious effects of SWS

Chemical Control of Sleep/Waking

- Sleep is regulated: loss of SWS or REM sleep is made up somewhat on following nights
  - Does the body produce a <u>sleep-promoting chemical</u> during wakefulness or a <u>wakefulness-promoting chemical</u> during sleep?
- Unlikely that sleep is controlled by blood-borne chemicals in the general circulation given:
  - Siamese twins share the same circulatory system, but sleep independently
  - Bottle-nose dolphins: the two hemispheres sleep independently

Neural Regulation of Arousal

- Electrical stimulation of the brain stem induces arousal
  - Dorsal path: RF--> to medial thalamus --> cortex
  - Ventral path: RF --> to lateral hypothalamus, basal ganglia, and the forebrain
- Neurotransmitters involved in arousal:
  - NE neurons in rat locus coeruleus (LC) show high activity during wakefulness, low activity during sleep (zero during REM sleep)
    - LC neurons may play a role in vigilance
  - Activation of ACh neurons produces behavioral activation and cortical desynchrony
    - ACh agonists increase arousal, ACh antagonists decrease arousal
  - 5-HT: stimulation of the raphe nuclei induces arousal whereas 5-HT antagonists reduce cortical arousal

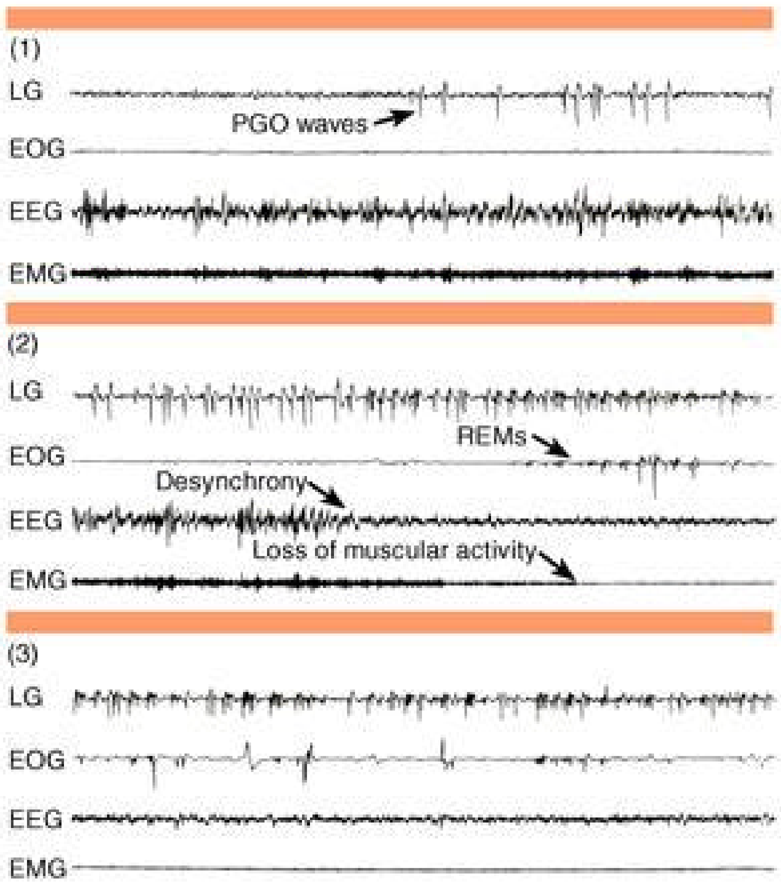
Neural Control of SWS

- The ventrolateral preoptic area (VLPA) is important for the control of sleep
  - Lesions of the preoptic area produce total insomnia, leading to death
  - Electrical stimulation of the preoptic area induces signs of drowsiness in cats
  - VLPA neurons promote sleep

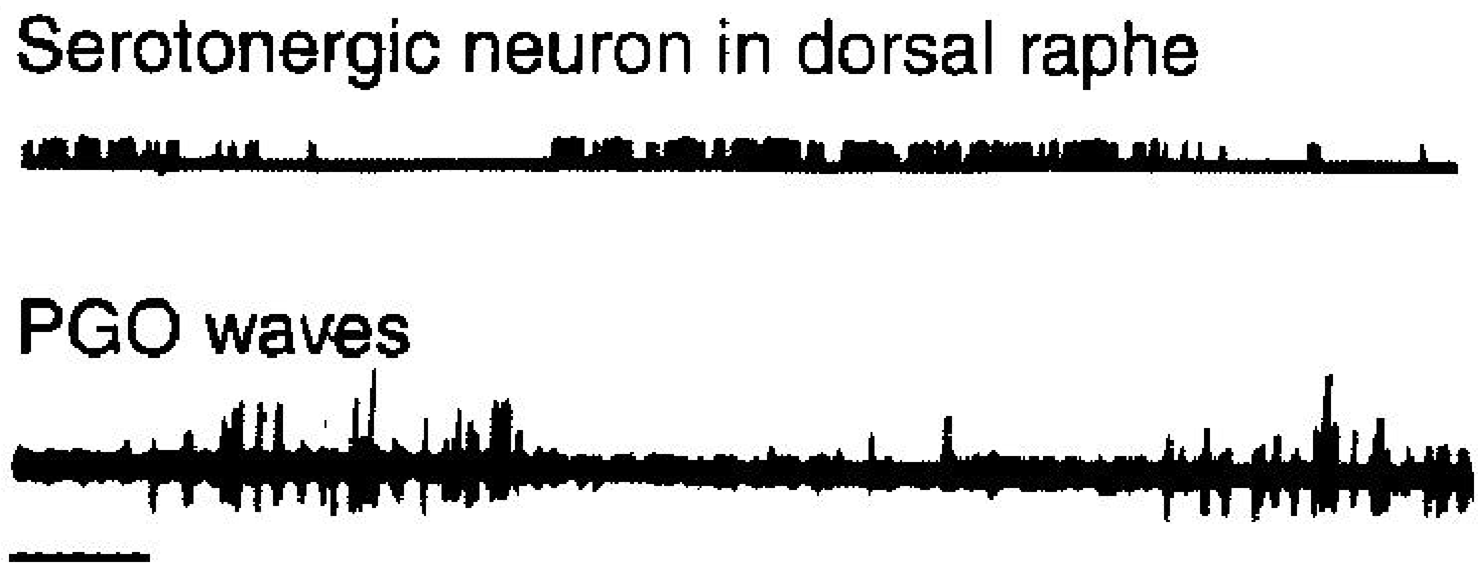
Neural Control of REM Sleep

- The pons is important for the control of REM sleep
  - PGO waves are the first predictor of REM sleep
  - ACh neurons in the peribrachial pons modulate REM sleep
    - Increased ACh increases REM sleep
    - Peribrachial neurons fire at a high rate during REM sleep
    - Peribrachial lesions reduce REM sleep
  - Pontine ACh neurons project to the thalamus (control of cortical arousal), to the basal forebrain (arousal and desynchrony), and to the tectum (rapid eye movements)
  - Pontine cells project via magnocellular cells within medulla to the spinal cord: release glycine to inhibit alpha-motoneurons (induce REM motor paralysis or atonia)

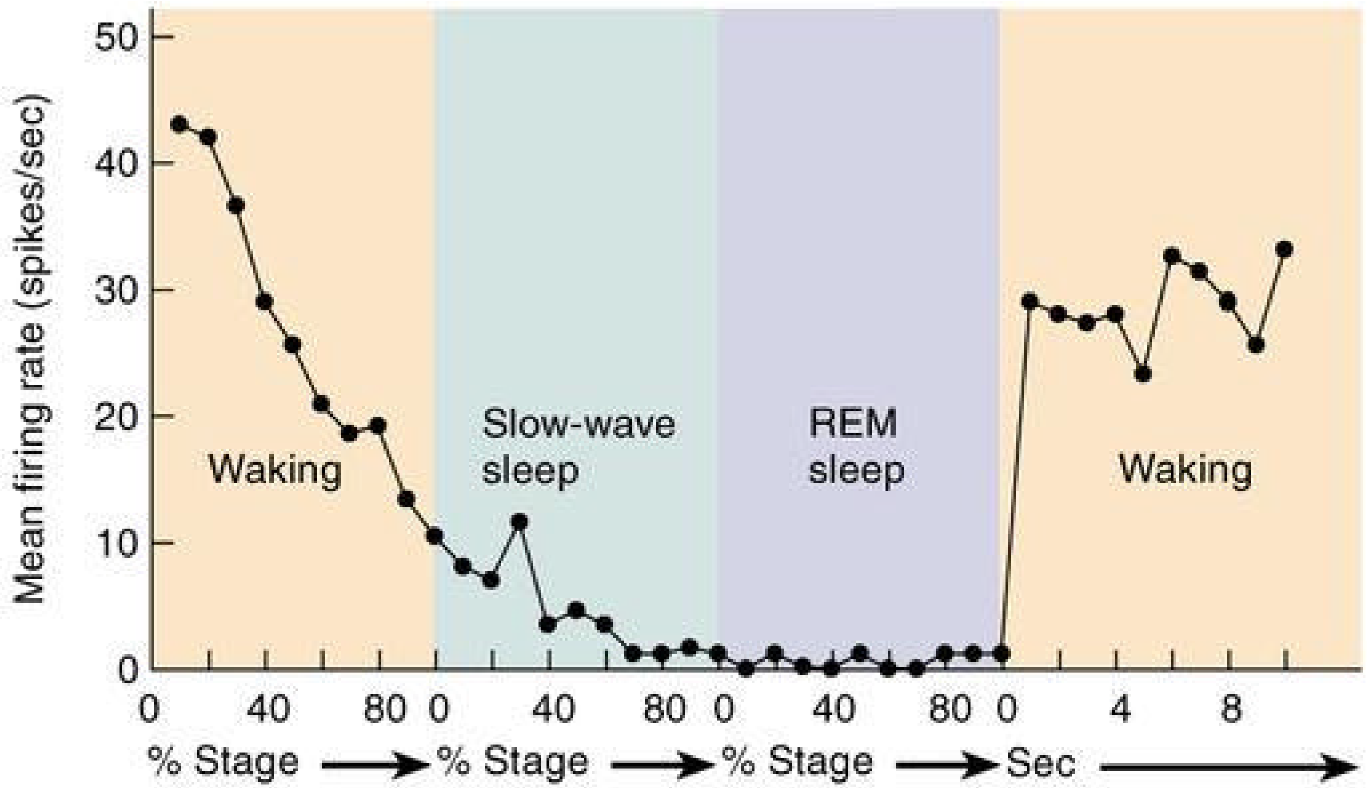
▸ Onset of REM Sleep in a Cat



Source: Adapted from Steriade, M., Paré, D., Bouhassira, D., Deschênes, M., and Oakson, G. *Journal of Neuroscience*, 1989, *9*, 2215–2229.

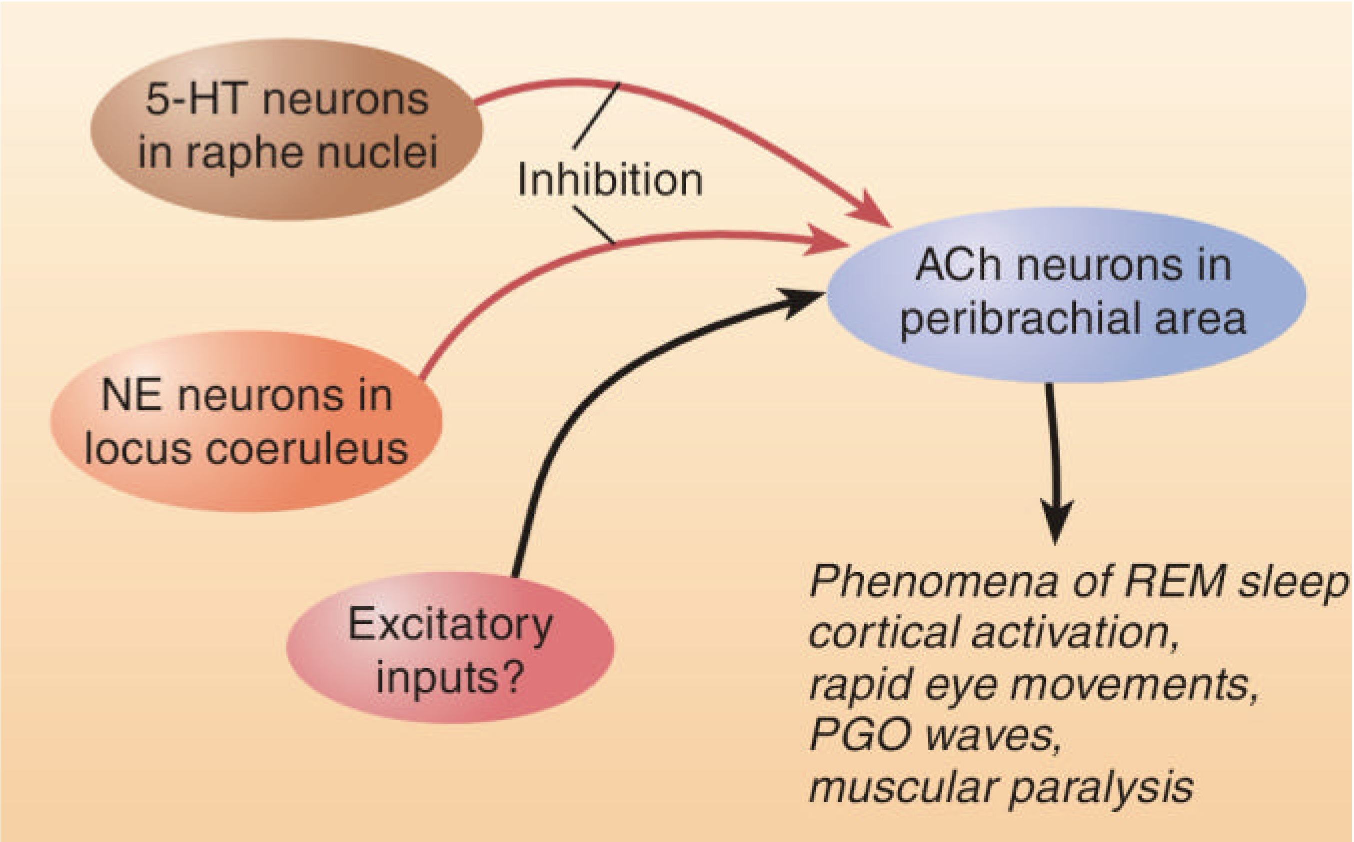

Serotonergic neuron in dorsal raphe
PGO waves

▸ **Activity of Noradrenergic Neurons in the Locus Coeruleus of Freely Moving Cats During Various Stages of Sleep and Waking**

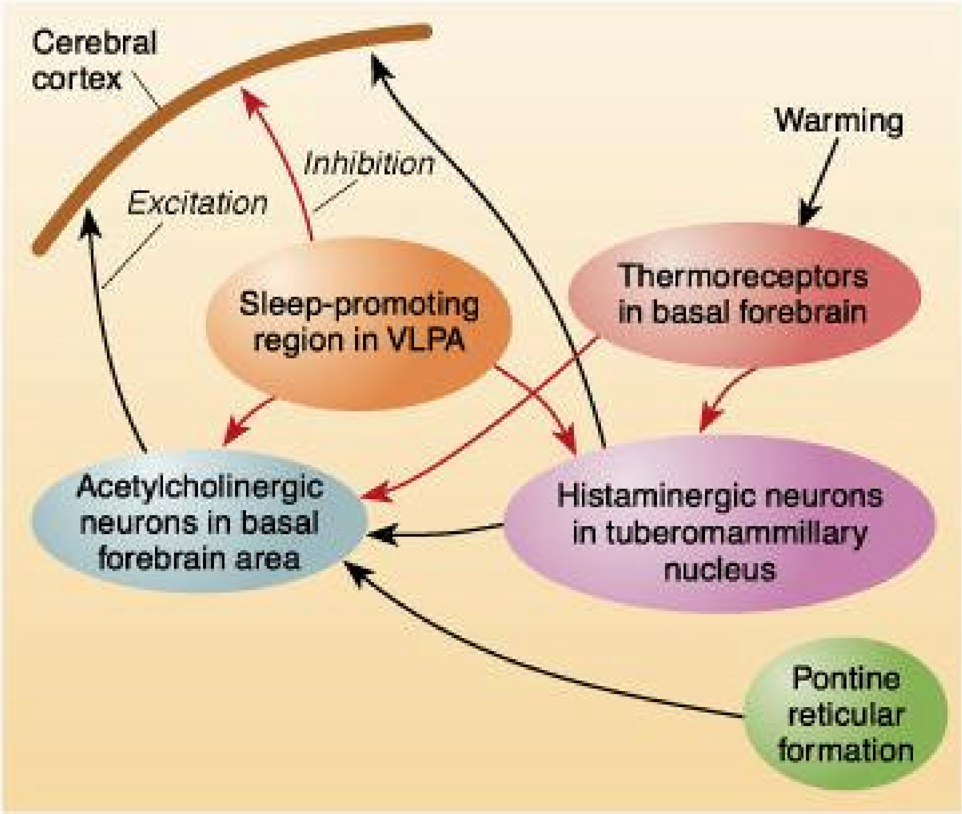


Source: From Aston-Jones, G., and Bloom, F.E. *The Journal of Neuroscience*, 1981, *1*, 876–886. Copyright 1981, The Society for Neuroscience.

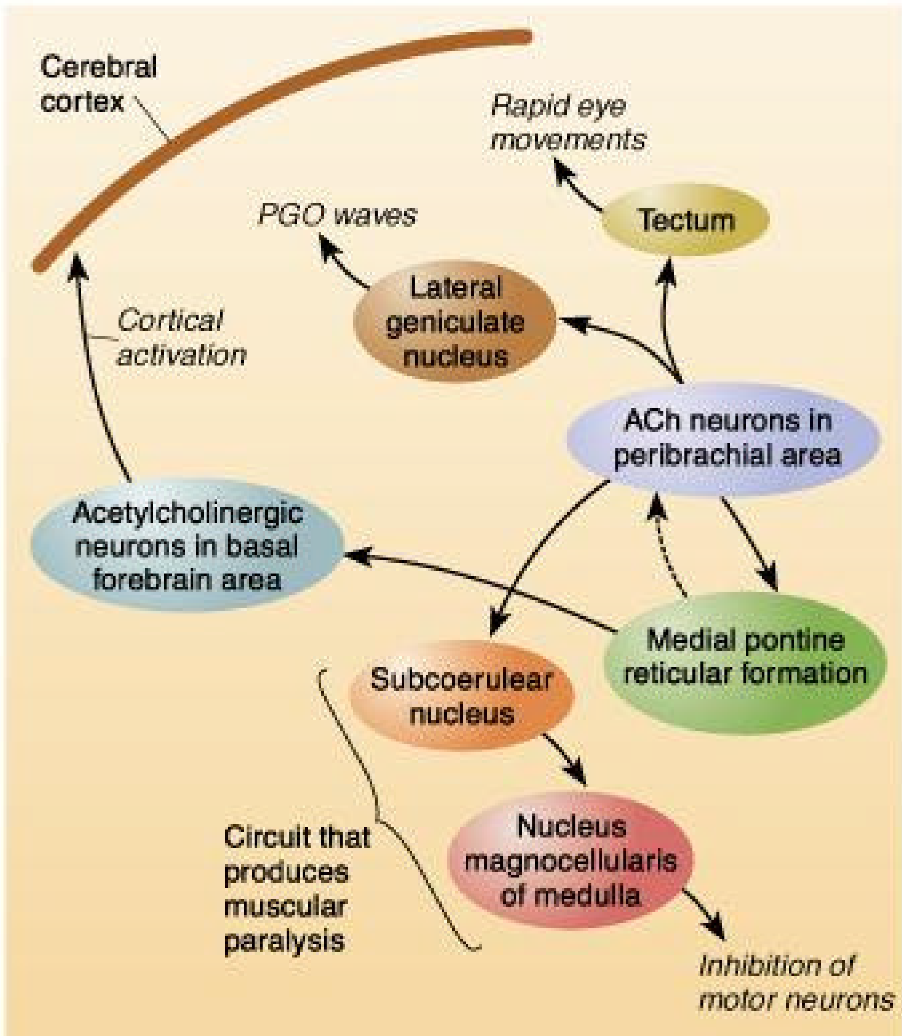
NT Interactions: REM Sleep



► **Schematic Diagram of the Role of the VLPA**



► **A Summary of the Neural Circuitry thought to be Responsible for REM Sleep**



Sleep Disorders

- Insomnia refers to a difficulty in getting to sleep or remaining asleep and has many causes
  - Situational
  - Drug-induced: Use of sleeping pills can result in insomnia
  - Sleep apnea: person stops breathing and is awakened when blood levels of carbon dioxide stimulate breathing
- Narcolepsy: Sleep appears at odd times
  - Sleep attack: urge to sleep during the day
  - Cataplexy: REM paralysis occurs, person is still conscious
    - Sleep paralysis: REM paralysis that occurs just before or just after sleep
  - Narcoleptics have reduced CSF levels of the neuropeptide orexin or altered activity of the orexin-B receptor

Biological Rhythms

- Many of our behaviors display rhythmic variation
  - SWS/REM cycles last about 90 minutes
    - Daily rest-activity cycle is about 90 minutes
  - Circadian rhythms ("about a day")
    - One cycle lasts about 24 hours (e.g. sleep-waking cycle)
    - Light is an external cue that can set the circadian rhythm
    - Some circadian rhythms are endogenous (do not require light) suggesting the existence of an internal (biological) clock
  - Monthly rhythms
    - Menstrual cycle
  - Seasonal rhythms
    - Aggression, sexual activity in male deer

Suprachiasmatic Nucleus

- The suprachiasmatic nucleus (SCN) contains a biological clock that governs some circadian rhythms
  - SCN receives input from
    - amacrine/ganglion cells in the retina, a pathway that may account for the ability of light to reset the biological clock (zeitgeber function)
    - the intergeniculate leaflet of the lateral geniculate thalamic nucleus
      - This pathway may mediate the ability of other environmental stimuli to reset circadian rhythms (e.g. animals own activity)
  - SCN lesions disrupt circadian rhythms
  - SCN cells may not require direct neural connections to control circadian rhythms, but may do using chemical signals

SCN Clock Cells

- SCN cells exhibit circadian rhythms in activity
  - SCN glucose metabolism (2-DG method) is higher during the day than during the night
  - Each SCN cell appears to have its own clock (separate daily peaks in activity)
    - Yet SCN clock cells act in a synchronized fashion (a chemical rather than a neural effect)
- Nature of clock cells
  - Hypothesis was that clock cells produced a protein that upon reaching a critical level, inhibited its own production
    - Fruit fly: two genes *per* and *tim* control the production of two proteins: PER and TIM, eventually high levels of these proteins turn off the *per* and *tim* genes, resulting in declining levels of PER and TIM proteins, which in turn activates the two genes

Seasonal Rhythms

- SCN plays a role in governing seasonal rhythms
  - Testosterone secretion in male hampsters shows an annual rhythm with increased secretion as length of day increases
    - This annual rhythm is abolished by SCN lesions; lesioned hampsters secrete testosterone all year long
- Pineal gland interacts with the SCN to control seasonal rhythms
  - The SCN projects to the PVN, which connects with the pineal gland which secretes melatonin
    - During long nights, the pineal gland secretes high amounts of melatonin
  - Lesions of the SCN, of the PVN, or of the neural connection between the SCN and PVN disrupt seasonal rhythms controlled by day length