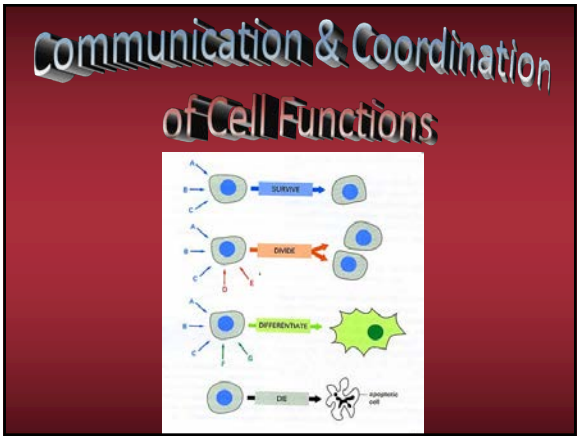
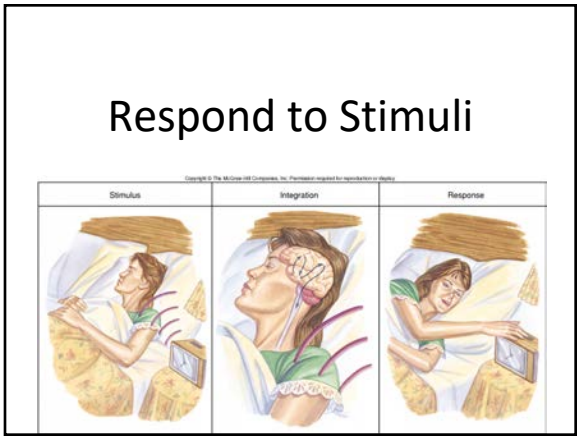
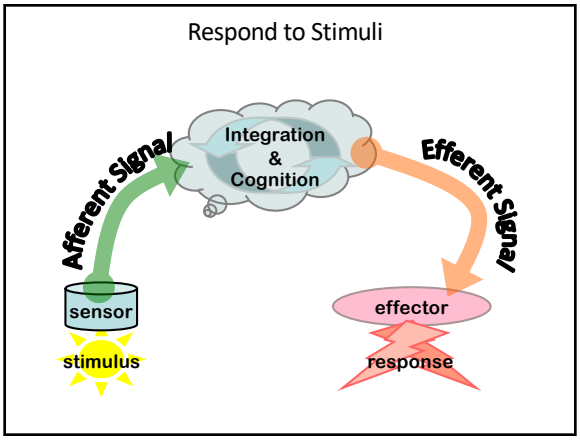
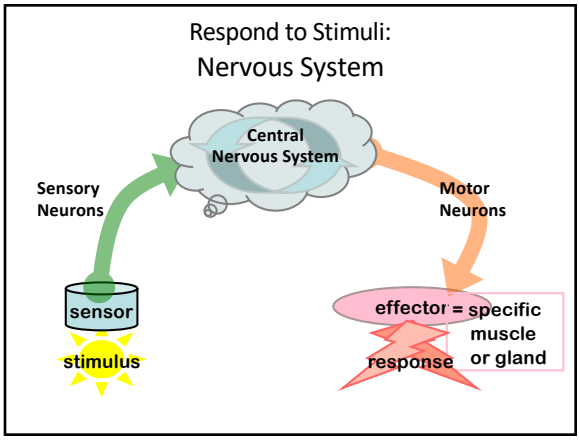
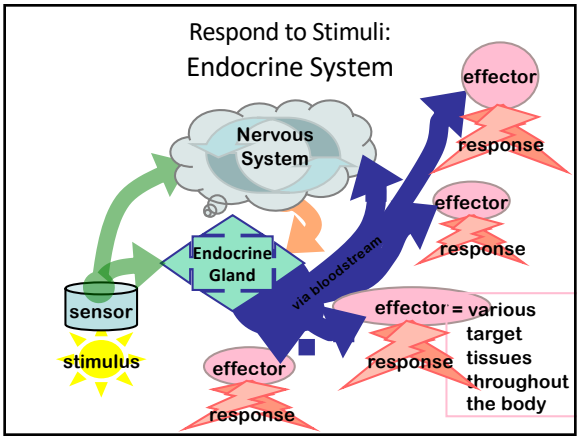
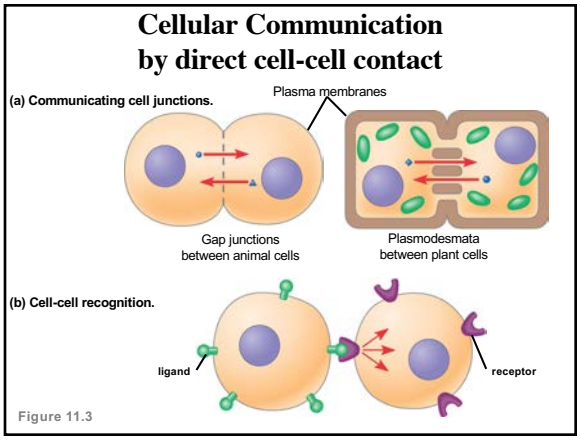

Communication & Coordination of Cell Functions
SURVIVE
DIVIDE
DIFFERENTIATE
DIE


Respond to Stimuli
Stimulus
Integration
Response


Respond to Stimuli
Afferent Signal
Integration & Cognition
Efferent Signal
sensor
stimulus
effector
response


Respond to Stimuli:
Nervous System
Central Nervous System
Sensory Neurons
Motor Neurons
sensor
stimulus
effector = specific muscle or gland
response


Respond to Stimuli:
Endocrine System
effector
response
Nervous System
effector
response
Endocrine Gland
via bloodstream
sensor
stimulus
effector = various target tissues throughout the body
effector
response
response


Cellular Communication
by direct cell-cell contact
(a) Communicating cell junctions.
Plasma membranes
Gap junctions between animal cells
Plasmodesmata between plant cells
(b) Cell-cell recognition.
ligand
receptor
Figure 11.3

Cellular Communication via chemical messengers

1. Release: initiator cell secretes (exocytosis) a chemical messenger (**signal molecules**).
2. Reception: messenger molecules bind to **receptors** (binding proteins) on target cells.
3. Transduction: binding of signal molecule to receptor causes a change in the structure and activity of the receptor protein.
4. Response: the altered receptor protein initiates a change in the enzymatic and/or transcriptional activity of the target cell.

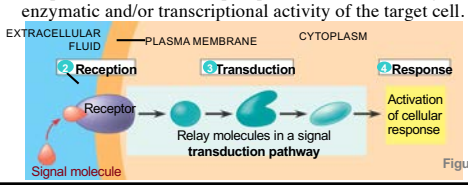
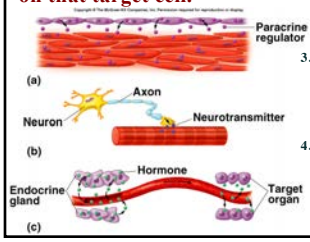


Figure 11.5

Cellular Communication — Chemical Messengers & Receptors

One cell releases a molecule (messenger) that initiates a change in another cell by binding to a protein receptor on that target cell.



1. **Synapse**: the messenger (**neurotransmitter**) diffuses across a small gap between a neuron and its target cell.
2. **Paracrine**: the messenger (local regulator, paracrine factor, growth factor, cytokine) diffuses to nearby target cells.
3. **Endocrine**: the messenger (**hormone**) diffuses into the circulatory system to travel to target cells all over the body.
4. **Exocrine**: the messenger (**pheromone**) diffuses outside of the organism's body to travel to another organism.

Major Classes of Biochemical Signal Molecules

I. Amino acid origin
   a) Amino acids
   b) Modified amino acids — bioamines
   c) Oligopeptides
   d) Proteins

II. Fatty acid origin
   a) Derived from cholesterol — steroids
   b) Derived from arachidonic acid — prostaglandins

III. Dissolved gases
   a) Nitric oxide (NO)
   b) Carbon monoxide (CO)
   c) Ethylene ($H_2C=CH_2$)

Mechanisms of Messenger Action

- Hydrophilic signal molecules — most amino acid class
  - Water soluble.
  - Short half-life: minutes
  - Do not enter target cells. Act as ligand by binding to protein receptor on cell surface.
- Lipophilic signal molecules — steroids & thyroid hormones
  - Water insoluble. Must be transported in plasma by carrier proteins.
  - Carrier proteins also protect hormone from degradation. Half-life longer: 1–2 hours.
  - Released from carrier protein to diffuse across cell membrane into target cells. Act by binding to intracellular protein receptors.

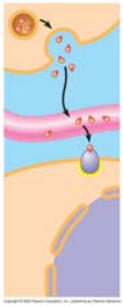
Mechanisms of **Hydrophilic** Signal Molecule Action

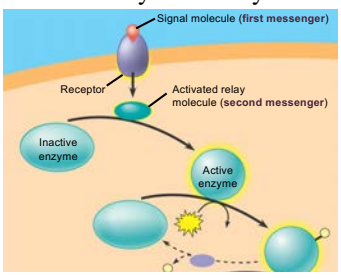
- Hydrophilic signal molecules — most amino acid class
  - Water soluble.
  - Short half-life: minutes
  - Do not enter target cells. Act as ligand by binding to protein receptor on cell surface.

1. Since the signal molecule (first messenger) does not enter the cell, the receptor/ligand complex causes a **second messenger** to be produced or released within the cell.
2. This second messenger acts as a coenzyme/cofactor to regulate cellular enzymes ⇒ change the activity of the cell.

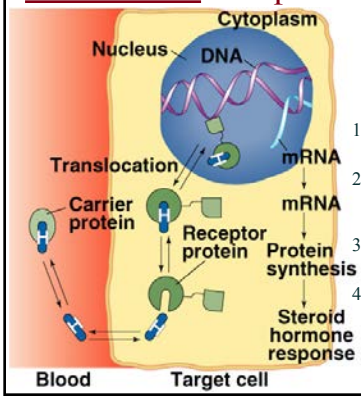
Signal transduction pathways via **second messengers**

Act as cofactors/coenzymes to modulate intracellular enzyme activity



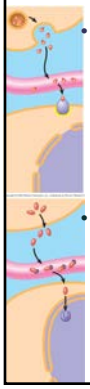


Intracellular Receptors for **Lipophilic** Signal Molecules



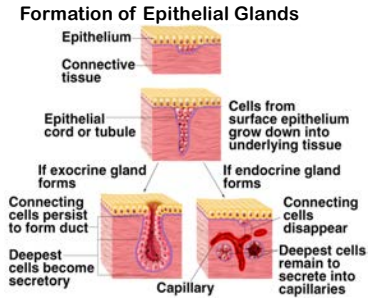
1. Steroid diffuses across membrane into cell
2. Intracellular receptor/steroid complex binds to DNA
3. Transcription factor — turns genes on/off
4. Change nature of the cell (Longer-lasting effect)

Mechanisms of Messenger Action



- Hydrophilic signal molecules — most amino acid class
  - Fast response / short half-life
  - Bind to membrane receptors on cell surface
  - Primary effect: turn enzymes on/off → Δ activity of cell.
  - Secondary effect: enzymes may produce or activate transcription factors → turn genes on/off.
- Lipophilic signal molecules — steroids & thyroid hormones
  - Slow response / long half-life
  - Bind to intracellular receptors in cytoplasm or nucleoplasm
  - Primary effect: turn genes on/off → Δ nature of cell.
  - Secondary effect: gene expression may produce or activate enzymes → turn metabolic pathways on/off.

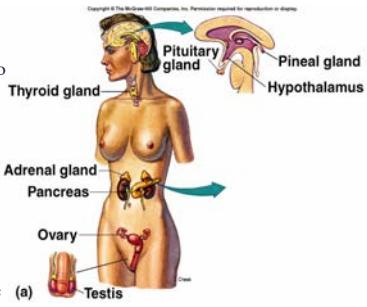
Glands: organs specialized for secretion



- **Exocrine glands: secrete via ducts "out" of body**
- **Endocrine glands: secrete into bloodstream**

Endocrine Glands and Hormones

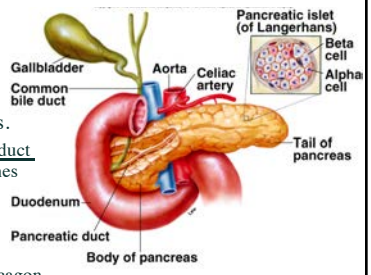
- Endocrine glands may be of epithelial or neural origin.
- Secrete biologically active molecules into the blood.
  - Lack ducts.
- Bloodstream carries hormones to target cells that contain specific receptor proteins for that hormone.
- Target cells can respond in a specific fashion.



Some glands are both exocrine *and* endocrine.

Pancreas

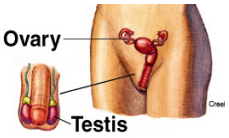
- Acinar cells produce digestive enzymes.
  - Secreted via bile duct into small intestines
- Islet cells produce hormones
  - α-cells → glucagon
  - β-cells → insulin
  - δ-cells → somatostatin
  - Secreted via capillaries into bloodstream



Some glands are both exocrine *and* endocrine.

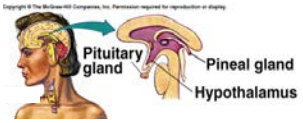
Gonads

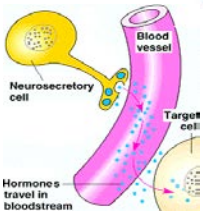
- Ovaries & testes



- Gametes secreted via sexual accessory ducts.
  - Fallopian tubes/uterus/vagina
  - Epididymus/vas deferens/urethra
- Sex steroids secreted into bloodstream.

Neuroendocrine Glands



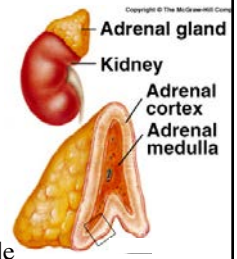


- Modified axon termini
- Secrete messenger into bloodstream (neurohormone) instead of into synaptic cleft (neurotransmitter).

Some endocrine glands have both neural *and* epithelial components.

Adrenal gland

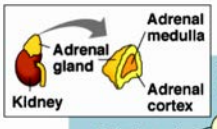
Ad-renal: "over the kidney"
Fishes have inter-renal gland



- Inner region: medulla
  - neural
- Outer region: cortex
  - epithelial
- Outermost covering: capsule
  - tough connective tissue

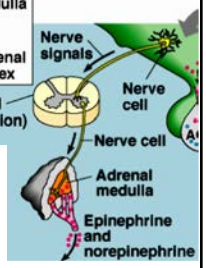
{Pituitary gland also has both neural and epithelial components.}

Adrenal Gland

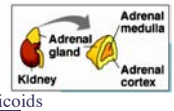


Adrenal medulla

- Modified sympathetic postsynaptic neurons
- Secrete epinephrine (adrenaline) & norepinephrine (noradrenaline) as hormones instead of as neurotransmitters.
- Extend "fight-or-flight response to whole body.

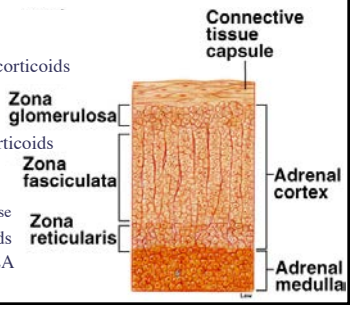


Adrenal Gland



Adrenal cortex

- Secrete steroid hormones: corticosteroids/corticoids
- Three sub-regions:
- outer layer → mineralocorticoids
  humans: aldosterone
  - regulate salt balance
- middle layer → glucocorticoids
  humans: cortisol
  - regulate sugar balance and chronic stress response
- inner layer → sex steroids
  androstenedione & DHEA
  - weak androgens



Note: not all hormones are secreted by specialized glands

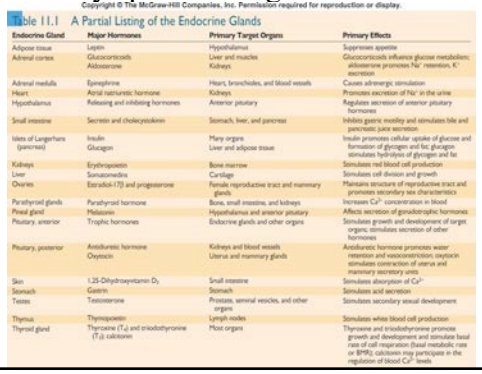


Table 11.1 A Partial Listing of the Endocrine Glands

Endocrine Gland	Major Hormones	Primary Target Organs	Primary Effects
Adipose tissue	Leptin	Hypothalamus	Suppresses appetite
Adrenal cortex	Glucocorticoids Aldosterone	Liver and muscles Kidneys	Glucocorticoids influence glucose metabolism; aldosterone promotes Na^+ retention, K^+ excretion
Adrenal medulla	Epinephrine	Heart, bronchioles, and blood vessels	Causes adrenergic stimulation
Heart	Atrial natriuretic hormone	Kidneys	Promotes excretion of Na^+ in the urine
Hypothalamus	Releasing and inhibiting hormones	Anterior pituitary	Regulates secretion of anterior pituitary hormones
Small intestine	Secretin and cholecystokinin	Stomach, liver, and pancreas	Inhibits gastric motility and stimulates bile and pancreatic juice secretion
Islets of Langerhans (pancreas)	Insulin Glucagon	Many organs Liver and adipose tissue	Insulin promotes cellular uptake of glucose and formation of glycogen and fat; glucagon stimulates hydrolysis of glycogen and fat
Kidneys	Erythropoietin	Bone marrow	Stimulates red blood cell production
Liver	Somatomedins	Cartilage	Stimulates cell division and growth
Ovaries	Estradiol-17β and progesterone	Female reproductive tract and mammary glands	Maintains structure of reproductive tract and promotes secondary sex characteristics
Parathyroid glands	Parathyroid hormone	Bone, small intestine, and kidneys	Increases Ca^{2+} concentration in blood
Pineal gland	Melatonin	Hypothalamus and anterior pituitary	Affects secretion of gonadotrophic hormones
Pituitary, anterior	Trophic hormones	Endocrine glands and other organs	Stimulates growth and development of target organs; stimulates secretion of other hormones
Pituitary, posterior	Antidiuretic hormone Oxytocin	Kidneys and blood vessels Uterus and mammary glands	Antidiuretic hormone promotes water retention and vasoconstriction; oxytocin stimulates contraction of uterus and mammary secretory units
Skin	1,25-Dihydroxyvitamin D_3	Small intestine	Stimulates absorption of Ca^{2+}
Stomach	Gastrin	Stomach	Stimulates acid secretion
Testes	Testosterone	Prostate, seminal vesicles, and other organs	Stimulates secondary sexual development
Thymus	Thymopoietin	Lymph nodes	Stimulates white blood cell production
Thyroid gland	Thyroxine (T_4) and triiodothyronine (T_3); calcitonin	Most organs	Thyroxine and triiodothyronine promote growth and development and stimulate basal rate of cell respiration (basal metabolic rate or BMR); calcitonin may participate in the regulation of blood Ca^{2+} levels

Regulation of Blood Glucose by Antagonistic Negative Feedback Loops

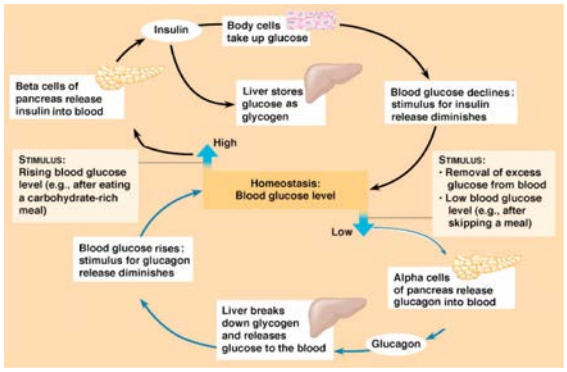
- **Pancreas** regulates blood sugar levels
- Glucose is taken up or released by liver as glycogen stores
- **Glucagon** from **alpha cells**
  - stimulate liver: glycogen → glucose
  - increase blood glucose

GAC UP

- **Insulin** from **beta cells**
  - stimulate liver: glucose → glycogen
  - decrease blood glucose

BIN DOWN

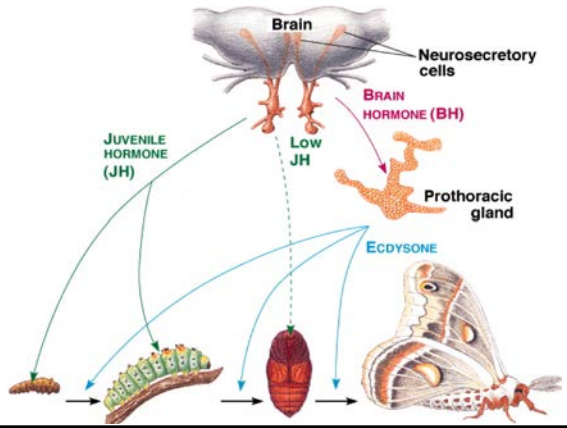
BIN DOWN



GAC UP

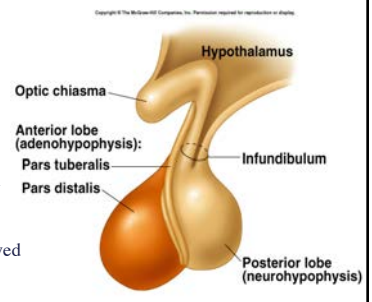
Insects and Others Also Use Antagonistic Hormones

- Ecdysone
  - induces epidermis to secrete new cuticle underneath old one
- Juvenile Hormone
  - inhibits metamorphosis of terminal molt

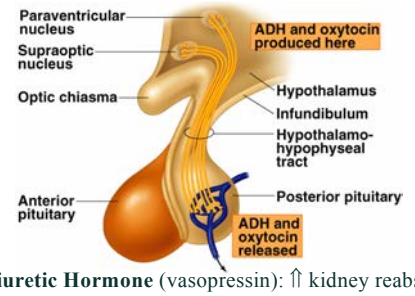


Pituitary Gland — the "Master Gland"

- Pituitary gland is located below the forebrain.
- Structurally and functionally divided into:
  - Posterior lobe — an extension of the hypothalamus neural tissue.
  - Anterior lobe — epithelial gland derived from the roof of the mouth.

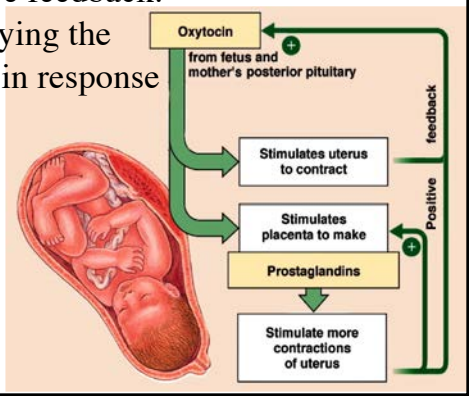


Posterior Pituitary: Neurohypophysis



- **Antidiuretic Hormone** (vasopressin): ⇑ kidney reabsorp of water ← ⇓blood Osm / ⇑ blood volume / ⇑blood pressure.
- **Oxytocin**: ⇑contractility of smooth muscle of repro. tract & mammary glands ← orgasm / birth / milk ejection reflexes.

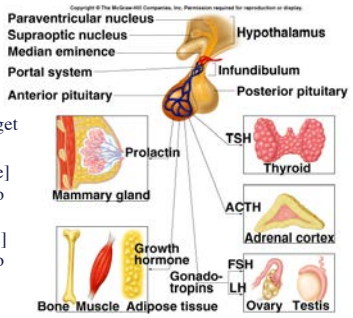
Positive feedback: amplifying the oxytocin response



Anterior Pituitary Trophic Hormones

Trophic: *"feeding"*

- Stimulate **activity** of other glands.
  "Master Gland"
- Stimulate **growth** of target tissues
  - High blood [hormone] causes target organ to hypertrophy.
  - Low blood [hormone] causes target organ to atrophy.



Regulating the Master Gland

1. Releasing (stimulating) and inhibitory hormones from the hypothalamus.

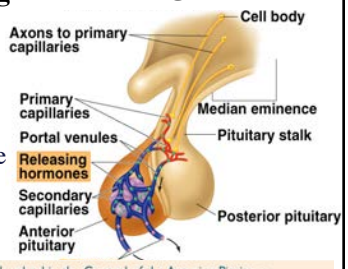
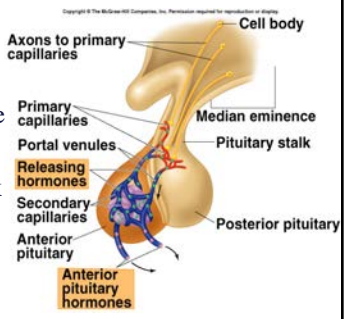


Table 11.7 Hypothalamic Hormones Involved in the Control of the Anterior Pituitary

Hypothalamic Hormone	Structure	Effect on Anterior Pituitary
Corticotropin-releasing hormone (CRH)	41 amino acids	Stimulates secretion of adrenocorticotropic hormone (ACTH)
Gonadotropin-releasing hormone (GnRH)	10 amino acids	Stimulates secretion of follicle-stimulating hormone (FHS) and luteinizing hormone (LH)
Prolactin-inhibiting hormone (PIH)	Dopamine	Inhibits prolactin secretion
Somatostatin	14 amino acids	Inhibits secretion of growth hormone
Thyrotropin-releasing hormone (TRH)	3 amino acids	Stimulates secretion of thyroid-stimulating hormone (TSH)
Growth hormone-releasing hormone (GHRH)	44 amino acids	Stimulates growth hormone secretion

Regulating the Master Gland

1. Releasing (stimulating) and inhibitory hormones from the hypothalamus.
2. Negative feedback by hormones secreted by the target glands.



Control of Pituitary Releasing Hormones

Table 11.7 Hypothalamic Hormones Involved in the Control of the Anterior Pituitary

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Thyrotropin-releasing hormone (TRH)	3 amino acids	Stimulates secretion of thyroid-stimulating hormone (TSH)
Growth hormone-releasing hormone (GHRH)	44 amino acids	Stimulates growth hormone secretion

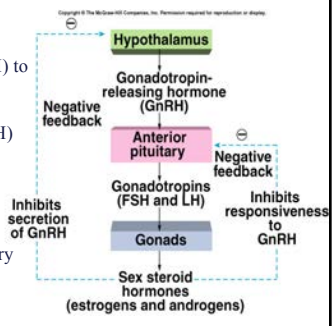
Table 11.6 Anterior Pituitary Hormones

Hormone	Target Tissue	Principal Actions	Regulation of Secretion
ACTH (adrenocorticotropic hormone)	Adrenal cortex	Stimulates secretion of glucocorticoids	Stimulated by CRH (corticotropin-releasing hormone); inhibited by glucocorticoids
TSH (thyroid-stimulating hormone)	Thyroid gland	Stimulates secretion of thyroid hormones	Stimulated by TRH (thyrotropin-releasing hormone); inhibited by thyroid hormones
GH (growth hormone)	Most tissue	Promotes protein synthesis and growth; lipolysis and increased blood glucose	Inhibited by somatostatin; stimulated by growth hormone-releasing hormone
FSH (follicle-stimulating hormone)	Gonads	Promotes gamete production and stimulates estrogen production in females	Stimulated by GnRH (gonadotropin-releasing hormone); inhibited by sex steroids and inhibin
PRL (prolactin)	Mammary glands and other sex accessory organs	Promotes milk production in lactating females; additional actions in other organs	Inhibited by PIH (prolactin-inhibiting hormone)
LH (luteinizing hormone)	Gonads	Stimulates sex hormone secretion; ovulation and corpus luteum formation in females; stimulates testosterone secretion in males	Stimulated by GnRH; inhibited by sex steroids

Feedback Control of the Anterior Pituitary

E.g., sex hormones:

1. Hypothalamus secretes releasing homone (GnRH) to stimulate Ant. Pituitary.
2. Ant. Pituitary secretes gonadotropins (LH & FSH) to stimulate gonads to:
   1. Grow & mature
   2. Secrete sex steroids
3. Sex steroids from gonads feedback to inhibit pituitary from secreting more gonadotropin.

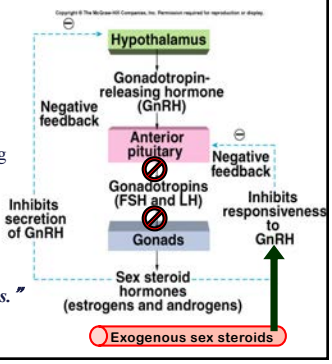


Feedback Control of the Anterior Pituitary

So, …

1. If a body builder takes anabolic steroids (synthetic androgens)…
2. The steroids act like other androgens and inhibit the pituitary from secreting gonadotropins. …
3. With supressed gonadotropin secretion, the gonads fail to grow.

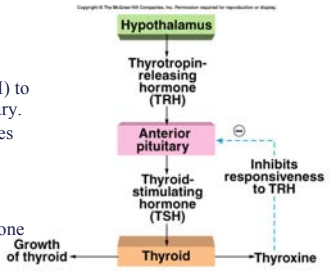
"Their grapes turn to raisins."



Feedback Control of the Anterior Pituitary

Another example: thyroid function:

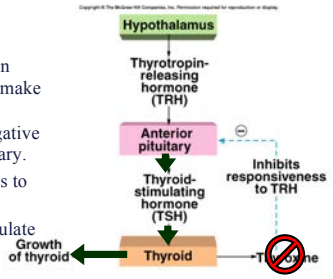
1. Hypothalamus secretes releasing homone (TRH) to stimulate anterior pituitary.
2. Anterior pituitary secretes thyrotropin (TSH) to stimulate thyroid to:
   1. Grow
   2. Secrete thyroid hormone (thyroxine)
3. Thyroxine from thyroid feedback to inhibit pituitary from secreting more TSH.



Feedback Control of the Anterior Pituitary

But, iodine is needed to synthesize thyroxine.

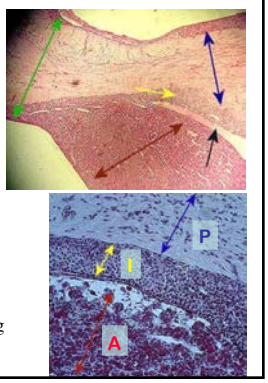
1. If the diet is deficient in iodine, thyroid cannot make thyroxine.
2. If no thyroxine, no negative feedback on ant. pituitary.
3. Ant. pituitary continues to secrete TSH
4. TSH continues to stimulate thyroid to overgrow.
5. Overgrown thyroid forms a goiter.



Pars Intermedia

In most vertebrates, a portion of the pituitary anterior lobe adjacent to the posterior lobe develops into an **intermediate lobe**.

- Principle activity is secreting melanocyte-stimulating hormone (MSH)
- MSH promotes **hyperpigmentation** from increased melanin production in melanocytes in skin and hair.
  - Cryptic coloration
  - Sexual/ territorial advertising



Pars Intermedia

Alternate processing of the same pro-hormone polypeptide:

Pro-opiomelanocortin (POMC)

[pro-opioid-melanotropin-corticotropin]

- In anterior pituitary, POMC cleaved to form endorphins (opioids) + adrenocorticotrophic hormone (ACTH)
- In intermediate lobe, ACTH fragment is further cleaved to form **α-MSH**
- In humans, intermediate lobe is greatly reduced, but present. Syndromes that cause an overproduction of ACTH (pregnancy, adrenal insufficiency [Addisons disease]) also result in elevated MSH and hyperpigmentation.
- Red-headed, poorly tanning people often have normal MSH levels, but decreased MSH-receptors.

Endocrine Pathologies

I. Abnormal hormone titer —
   - **Primary** pathology: caused the endocrine gland secreting that hormone
   - **Secondary** pathology: caused by a factor (e.g., trophic hormone) regulating that gland

   – Hypersecretion of hormone
   - Idiopathic: gland "turned on" for no obvious reason
   - Tumor hyperplasia of secretory cells
   - Secondary: hypersecretion of trophic hormone

   – Hyposecretion of hormone
   - Enzyme defect in biosynthesis of the hormone
   - Autoimmune destruction of of secretory cells
   - Receptor defect/insufficiency responding to trophic hormone
   - Secondary: hyposecretion of trophic hormone

II. Abnormal hormone response —
   - Number of receptors in target organ: desensitization
   - Mutant defective receptors in target organ
   - Defective transduction pathway step

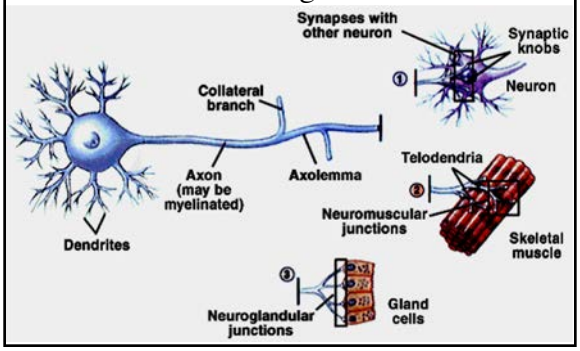
III. Exogenous hormones

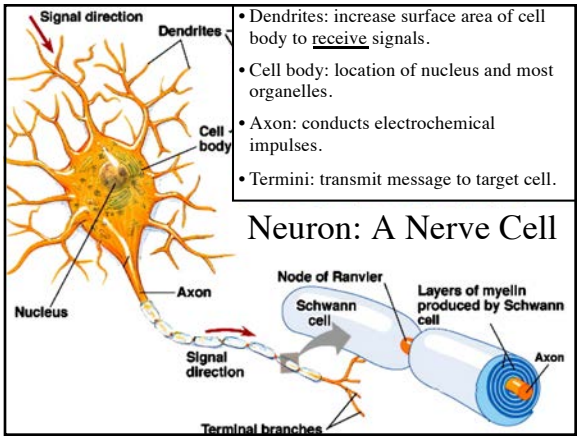
Electrochemical communication

Neurons —

1. Membrane potential
2. Excitability
3. Conduction
4. Transmission

Neurons conduct electrochemical impulses and transmit messages to other cells



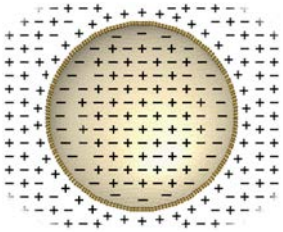


- Dendrites: increase surface area of cell body to receive signals.
- Cell body: location of nucleus and most organelles.
- Axon: conducts electrochemical impulses.
- Termini: transmit message to target cell.

Neuron: A Nerve Cell

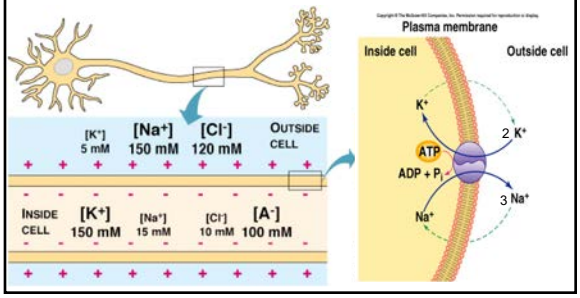
Membranes of neurons are electrically charged

- Chemical gradients of ions produce electrical gradients
- Inside of the cell is negative relative to the outside of the cell.
- Electrical gradient produces a membrane potential (voltage)



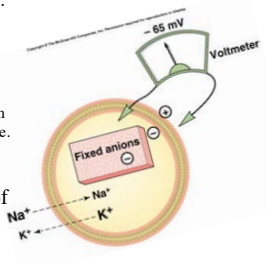
Axons are Polarized: Resting Potential

- Na is Not allowed in; K is Kontained.



Resting Membrane Potential

- At equilibrium, inside of the cell membrane would have a higher [negative charges] than the outside.
- Potential difference (voltage):
  - Magnitude of difference in charge on the 2 sides of the membrane..
- Depends upon 2 factors:
  - Ratio of the concentrations of each ion on the 2 sides of the plasma membrane.
  - Specific permeability of membrane to each different ion.
- Resting membrane potential of most cells ranges from —65 to –85 mV.

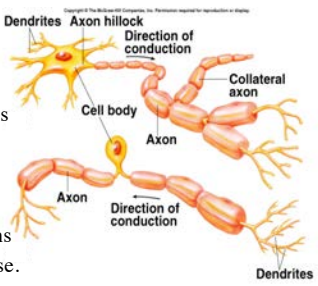


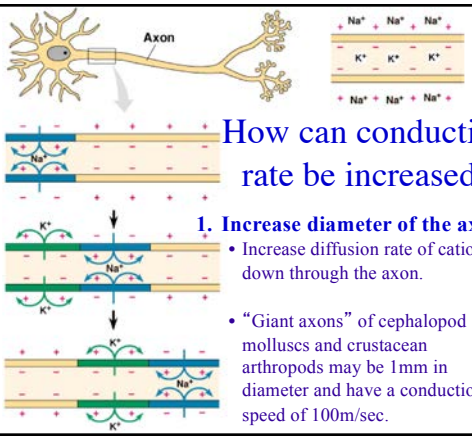
Cell Excitability (= Irritability)

- The ability to undergo rapid changes in membrane potential in response to stimuli.
  - Oocytes: rapid block to polyspermy.
  - Neurons: conduct nerve impulses
  - Muscle cells: initiate contraction

Conduction of electrochemical signals in neurons

- Nerves are **NOT** wires!
- Nerve impulses are **NOT** electricity!
- Nerve impulse are a series of action potentials propagated in sequence down the neuron.
- Only the **axon**s of neurons conduct the nerve impulse.
  - Initiated at the hillock,
  - Propagate toward the axon terminus





How can conduction rate be increased?

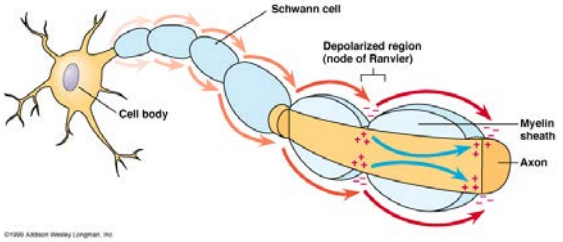
1. Increase diameter of the axon.

- Increase diffusion rate of cations down through the axon.
- "Giant axons" of cephalopod molluscs and crustacean arthropods may be 1mm in diameter and have a conduction speed of 100m/sec.

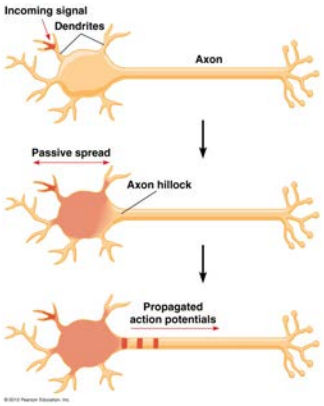
How can conduction rate be increased?

2. Myelinated axons

— vertebrates only!



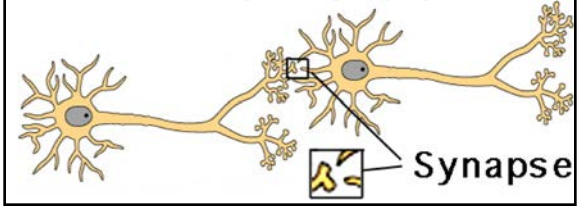
- Saltatory conduction: 25µm myelinated vertebrate neuron may have conduction rate of 120 m/sec.



Transmission:

Synapses & Local Signaling

- **Synaptic terminals** release a neurotransmitter.
  - e.g. acetylcholine
- NT binds to receptors on postsynaptic cell.



Transmission of the signals: the Synapse

- Synapse: functional connection between a neuron and another neuron or an effector cell (muscle or gland).
- Synaptic cleft: a slight gap between the pre-synaptic cell (axon terminus) and the post-synaptic cell.
- Series of action potentials conducted to axon terminus ⇒ causes exocytosis of vesicles containing a chemical messenger (neurotransmitter) into the synaptic cleft..
- Neurotransmitter binds to a receptor protein on the surface of the effector cell ⇒ turns on the receptor.
- The intracellular portion of the activated receptor causes a response in the post-synaptic cell.