B.SC. ZOOLOGY (H)

SEMESTER- 4

NAME OF TEACHER: TAPAN KUMAR ROY

CORE COURSE: COMPARATIVE ANATOMY OF VERTEBRATES LAB: ZOOA- CC4-8-P

TOPIC: COMPARATIVE STUDY OF HEART AND BRAIN, WITH THE HELP OF MODEL/PICTURE

Everyone is instructed to draw first eight pictures provided for comparative anatomy and do necessary pointings/ marking of structures.

For your convenience book diagrams are also provided as reference for your convenience.

Necessary write up of the pictures will be supplied within a short.

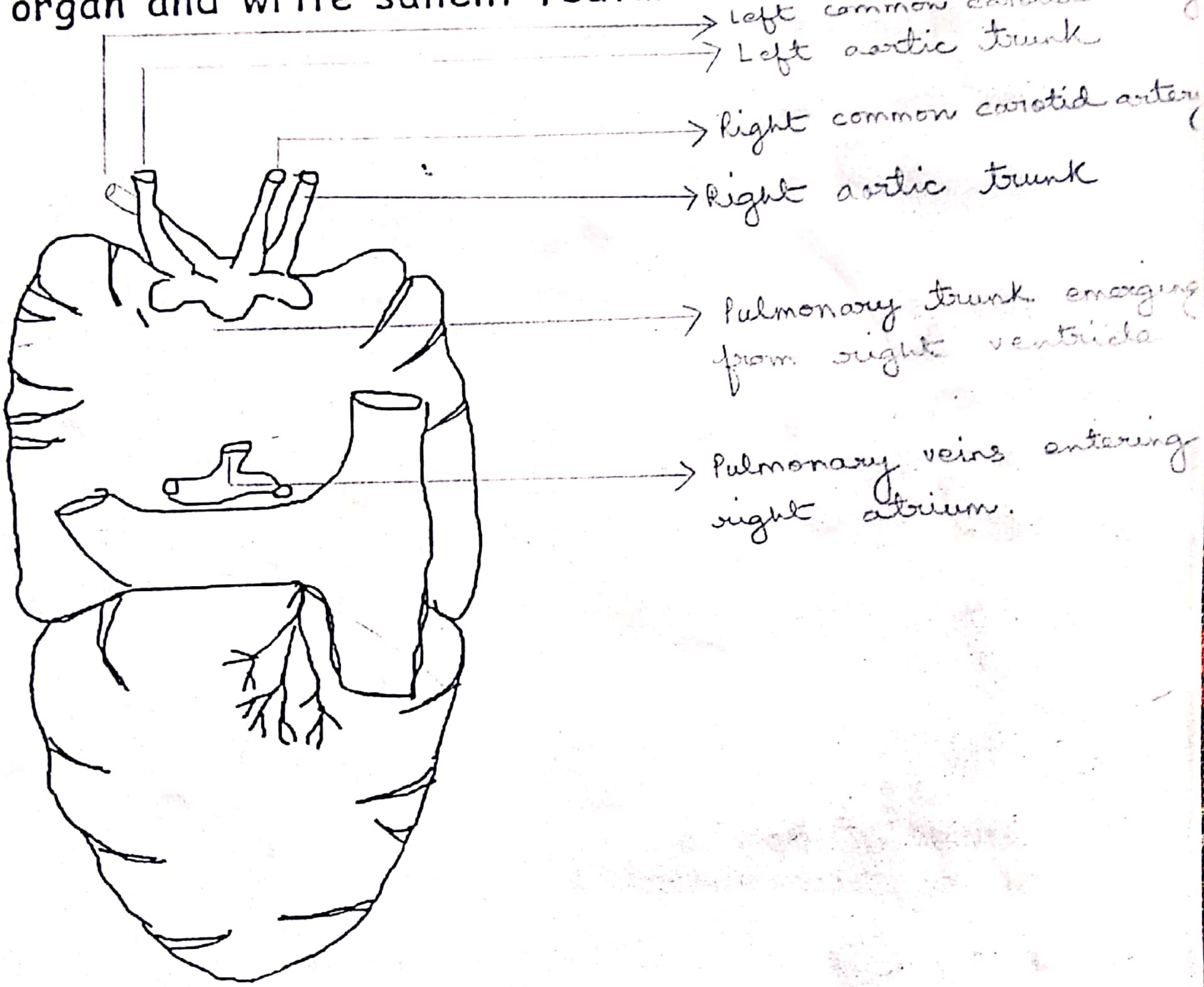
③

Heart and associated vessels of sphenodon (Dorsal view)

Roll No.

Registration No.

Q. 2. Identify the organ. Label the parts of the organ and write salient features.



⑥

Roll No.

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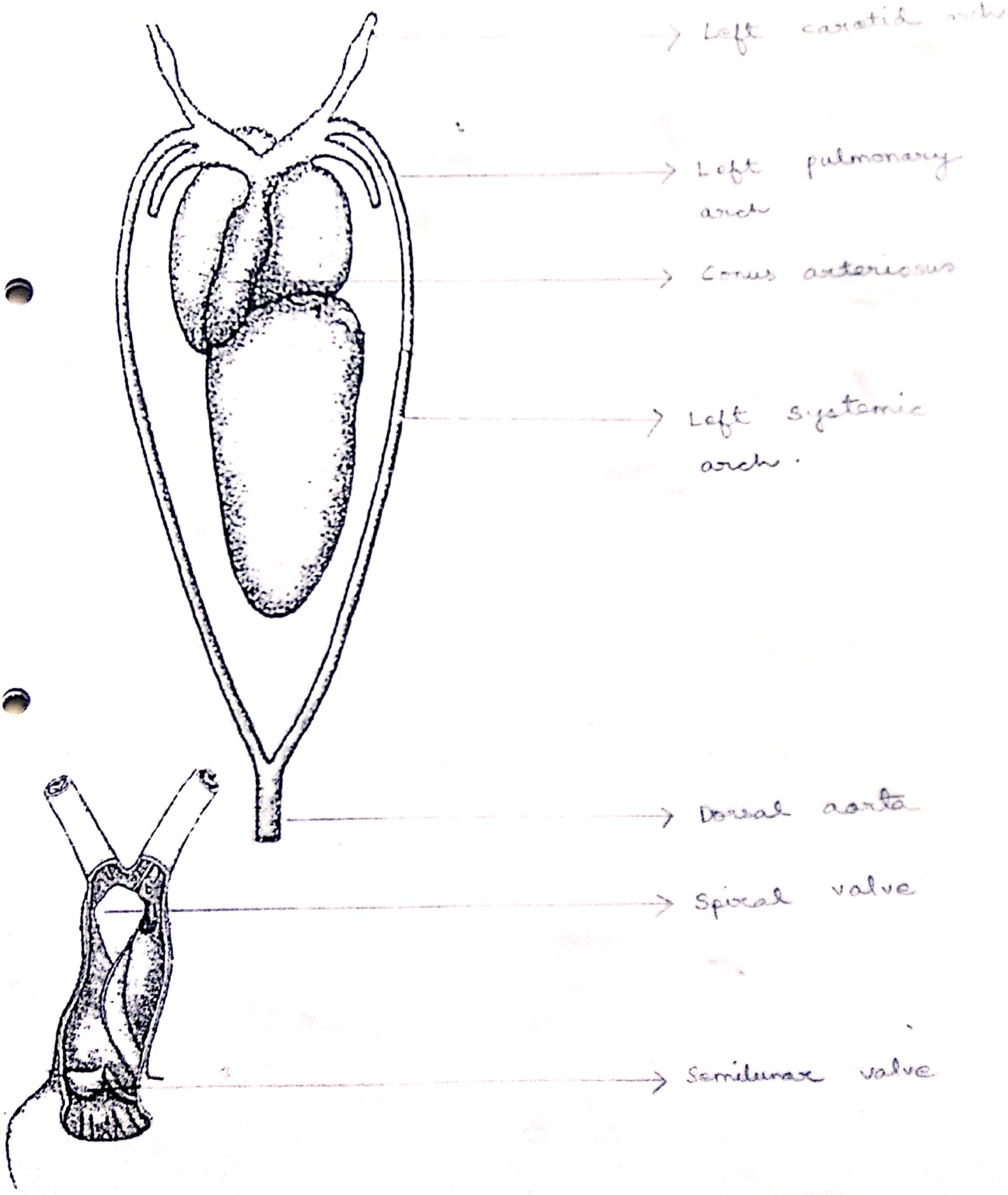
Heart and aortic arches of frog (Ventral view)

Q. 2. Identify the organ. Label the parts of the organ and write salient features.



①

Heart & associated arches of a bird (Ventral view)

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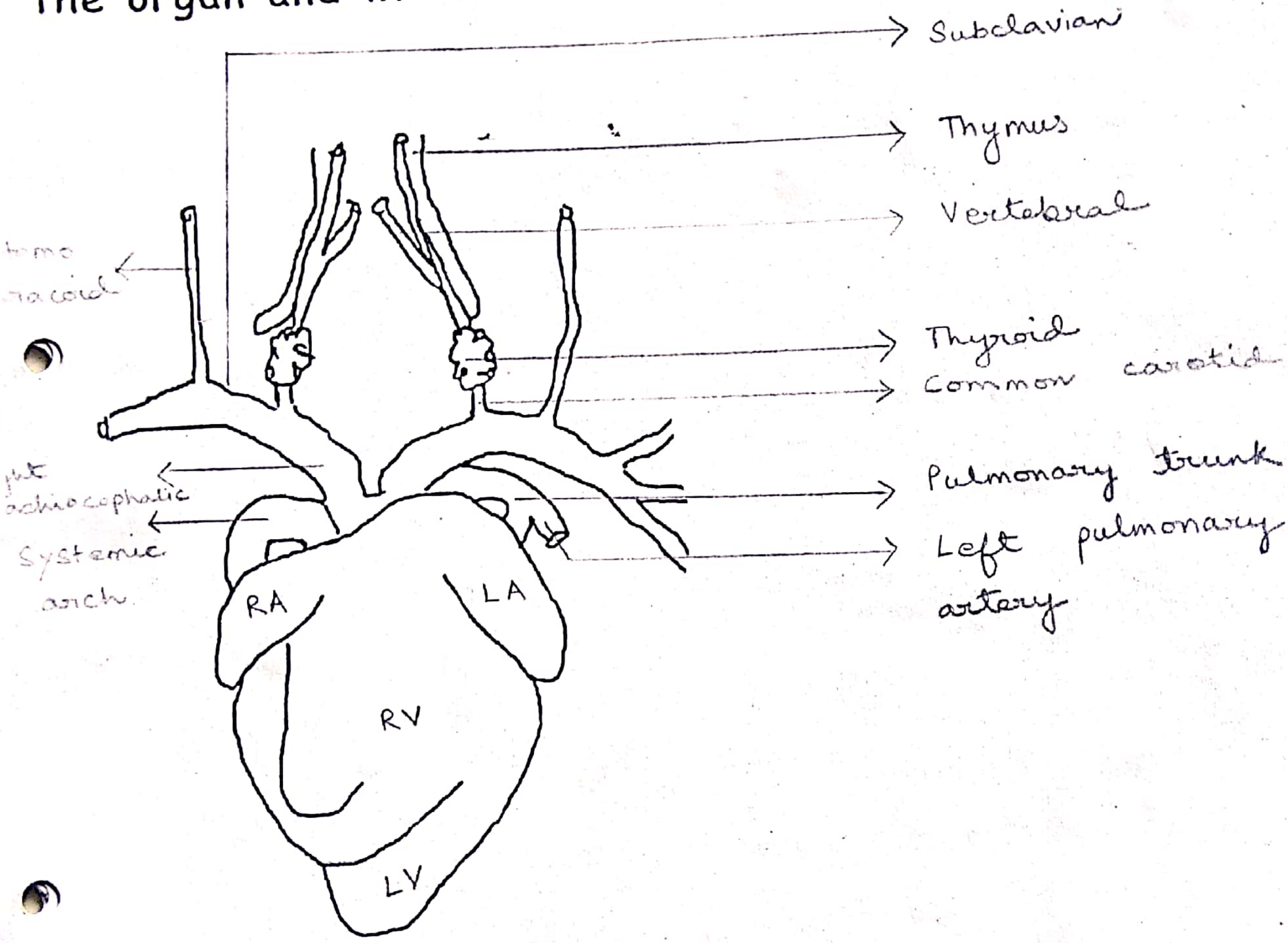
Q. 2. Identify the organ. Label the parts of the organ and write salient features.



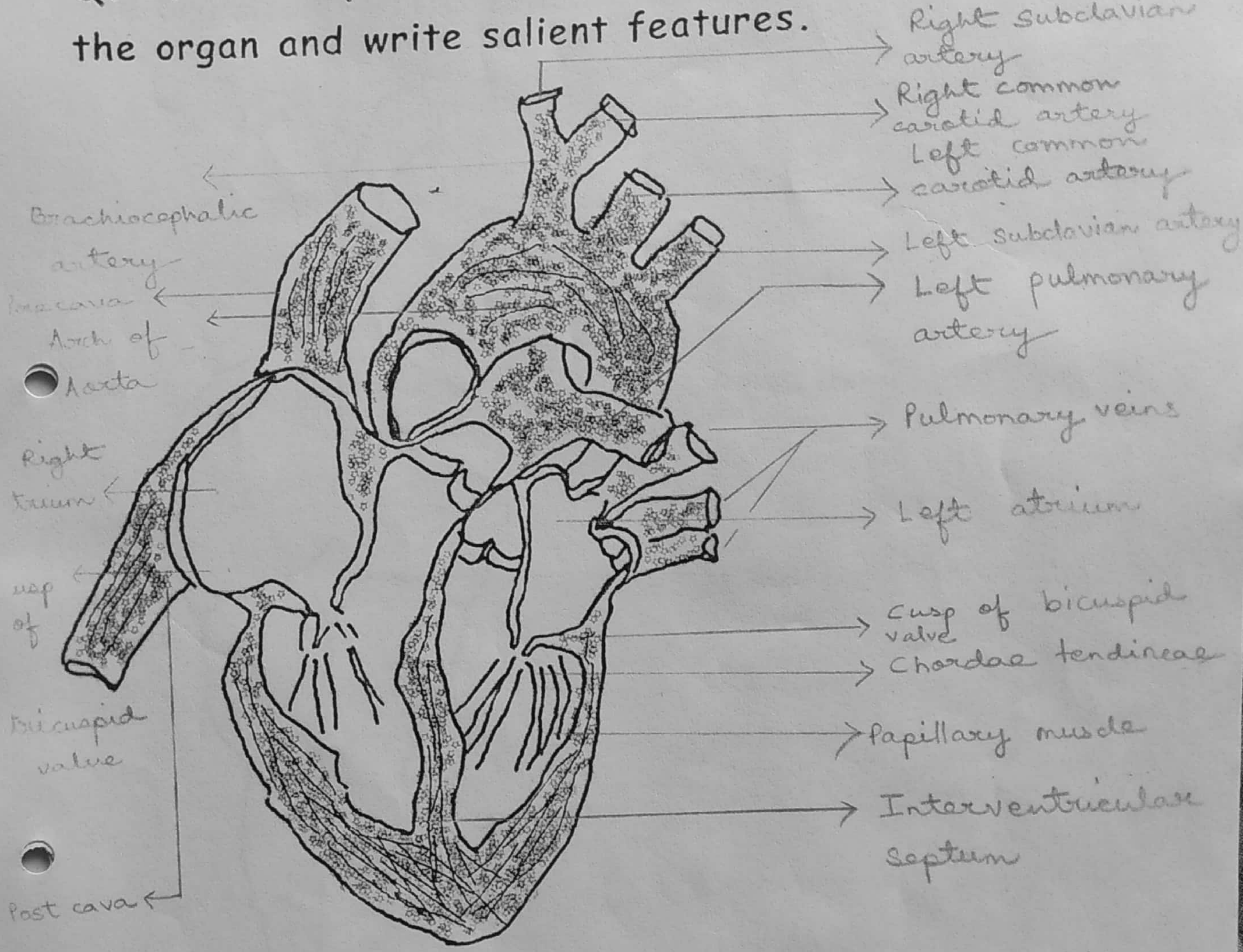
8.

Human heart

Roll No.

Registration No.

Q. 2. Identify the organ. Label the parts of the organ and write salient features.



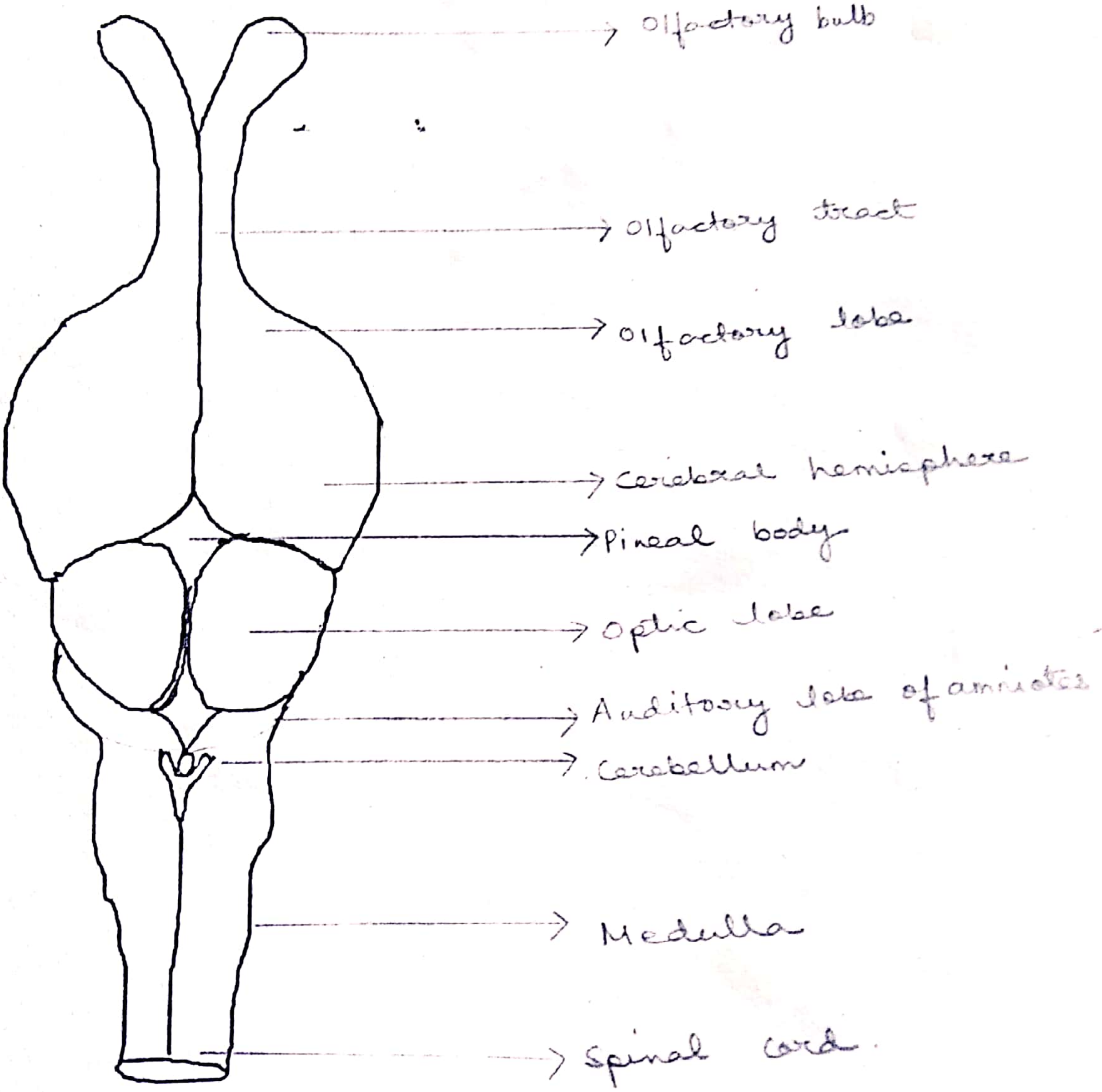
12

Brain of Snake (Dorsal view)

Roll No.

Registration No.

Q. 2. Identify the organ. Label the parts of the organ and write salient features.

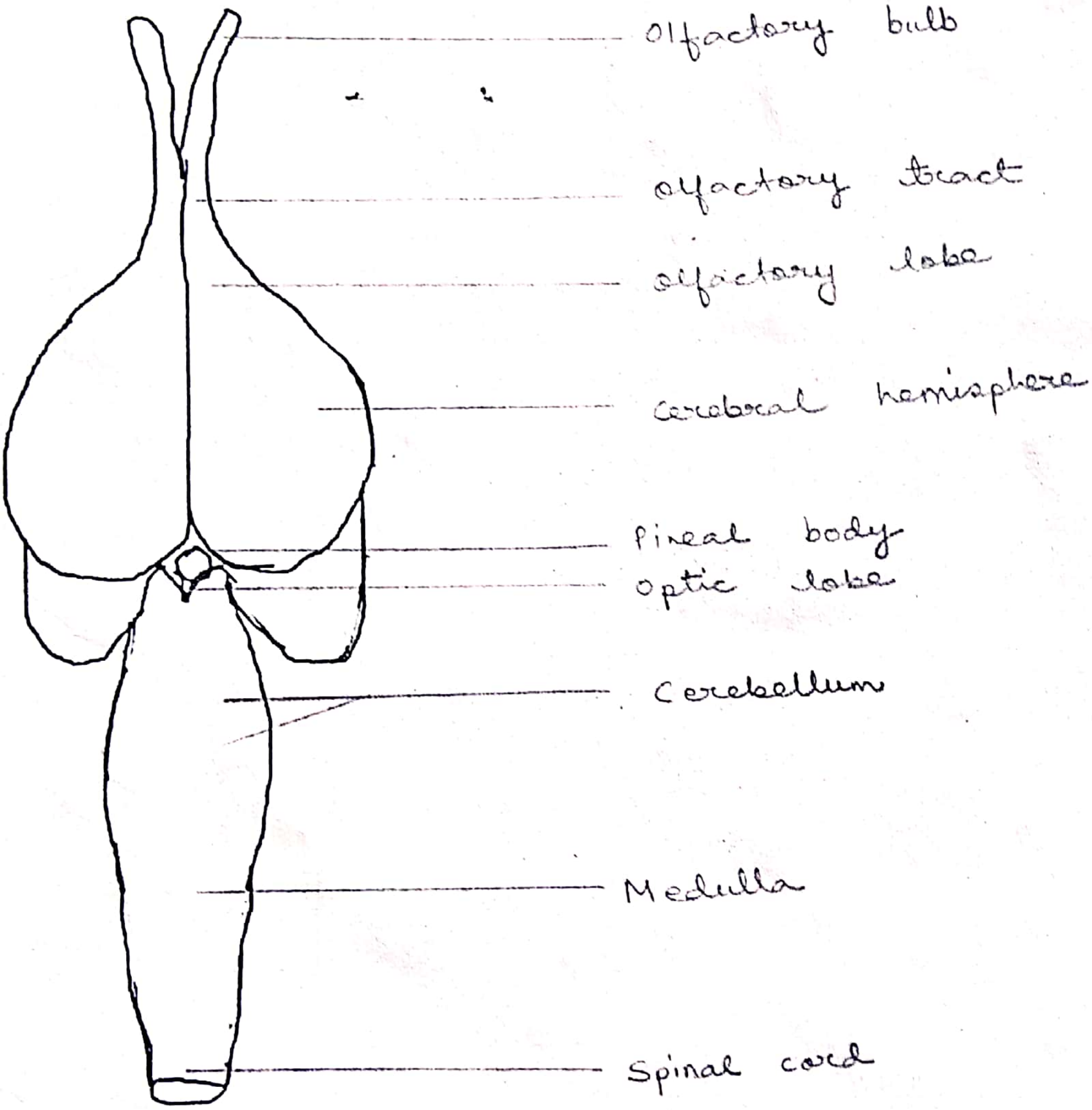


Brain of chicken (Dorsal view)

Roll No.

Registration No.

Q. 2. Identify the organ. Label the parts of the organ and write salient features.

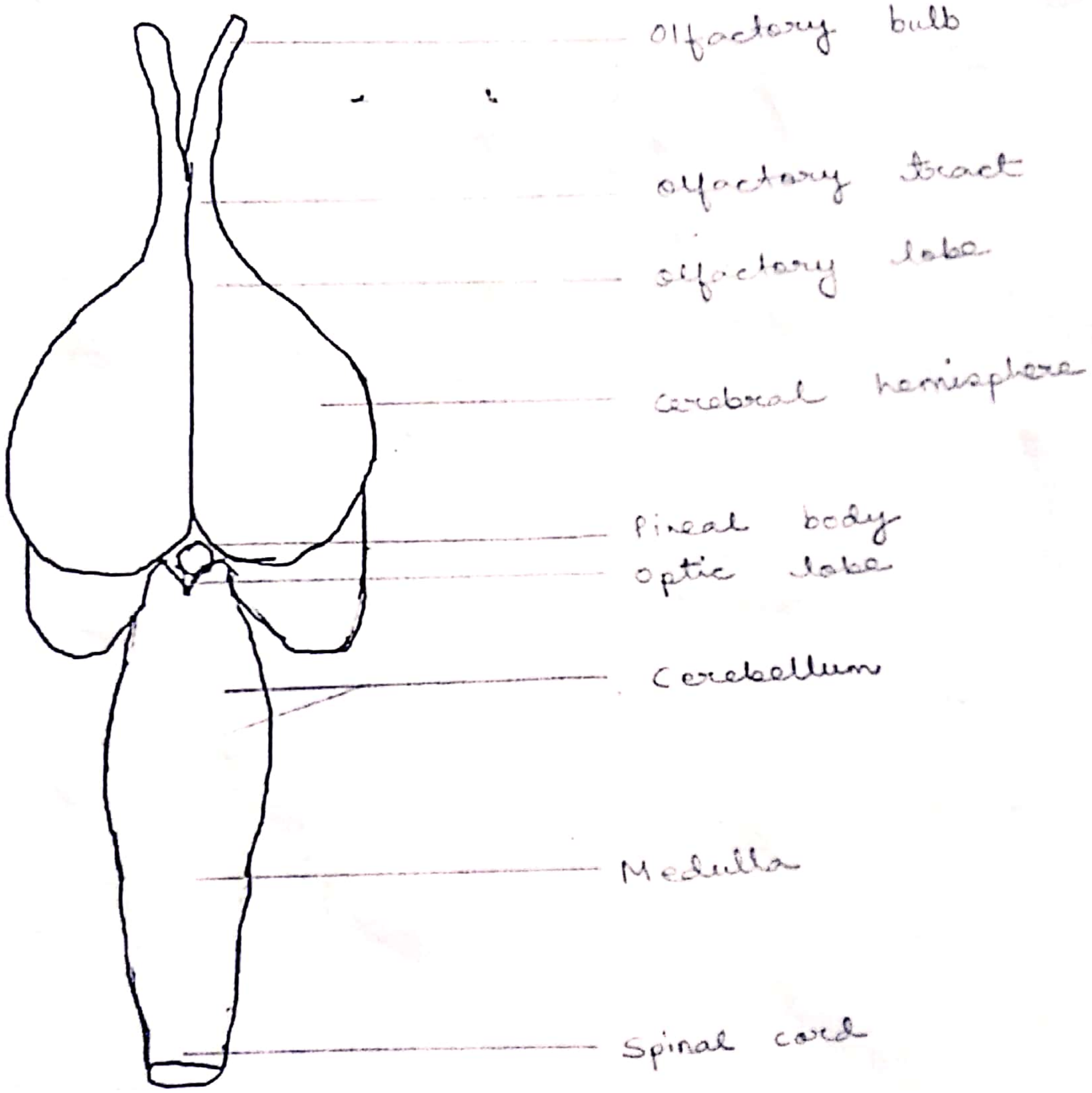


Brain of chicken (Dorsal view)

Roll No.

Registration No.

Q. 2. Identify the organ. Label the parts of the organ and write salient features.



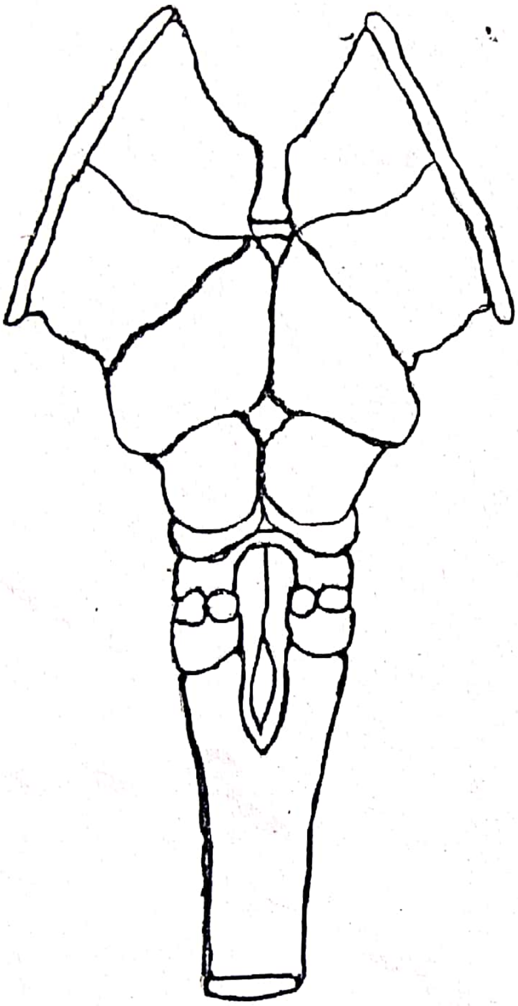
T. ⑭

Brain stem of a sheep (Mammals)

Roll No.

Registration No.

Q. 2. Identify the organ. Label the parts of the organ and write salient features.



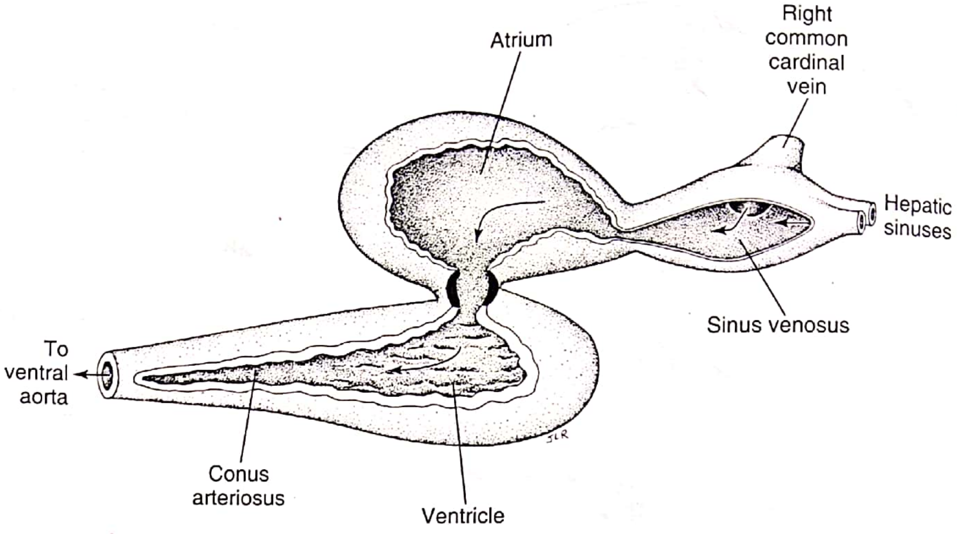


**FIGURE 14.7**
Heart of *Squalus acanthias* opened to show chambers and blood flow. Left lateral view.

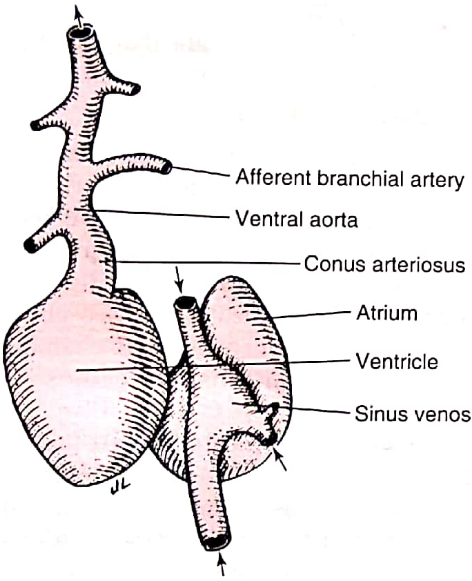


**FIGURE 14.8**
Heart and associated vessels of an agnathan. *Myxine glutinosa,* ventral view. *Arrows* indicate direction of blood flow.

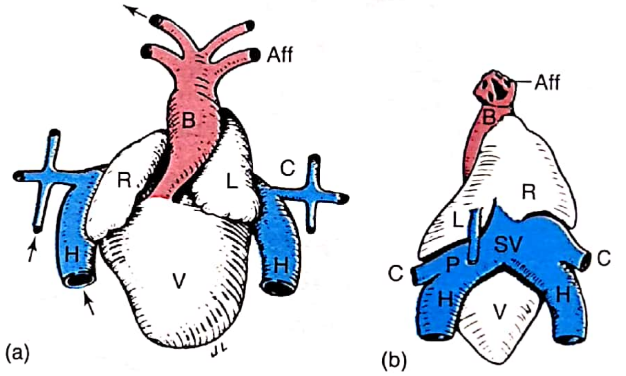


**FIGURE 14.9**
Heart and associated vessels of *Necturus.* (*a*) Ventral view. (*b*) Dorsal view. **Aff,** common channel leading to fourth and fifth afferent branchial arteries (see fig. 14.18*d*); **B,** bulbus arteriosus of ventral aorta; **C,** common cardinal vein; **H,** hepatic sinus; **L,** left atrium receiving, in (*b*) the pulmonary vein; **P,** pulmonary vein; **R,** right atrium; **SV,** sinus venosus; **V,** ventricle. In (*a*), a short conus arteriosus connects the ventricle with the bulbus. *Arrows* show direction of blood flow. Colors represent arteries (*red*) and veins (*blue*) but not necessarily oxygen content.

continuous with the ventral aorta. The conus is composed chiefly of cardiac muscle and elastic connective tissue. A series of semilunar valves facing forward within the conus prevents backflow of blood into the ventricle. Because of its elasticity, it balloons with each delivery of ventricular blood and then slowly constricts, thereby maintaining a steady arterial pressure in the ventral aorta so that the flow of blood through the gill capillaries, like the flow of countercurrent respiratory water over the gill filaments, is steady despite the rhythmicity of the ventricular beat.

The conus arteriosus of teleosts is shorter than that of sharks, but a muscular swelling at the base of the teleost ventral aorta, the **bulbus arteriosus**, performs the same role. It maintains a steady flow of blood over the gills. A bulbus arteriosus is present also in *Necturus* and some other perennibranchiate amphibians (fig. 14.9*a*).

## Hearts of Dipnoans and Amphibians

Modifications in the heart and associated arteries in dipnoans and tetrapods are correlated with aerial respiration. The modifications enable oxygenated blood returning from the swim bladders or lungs to be separated in the heart from deoxygenated blood returning from other organs. Air-breathing ray-finned fishes differ in

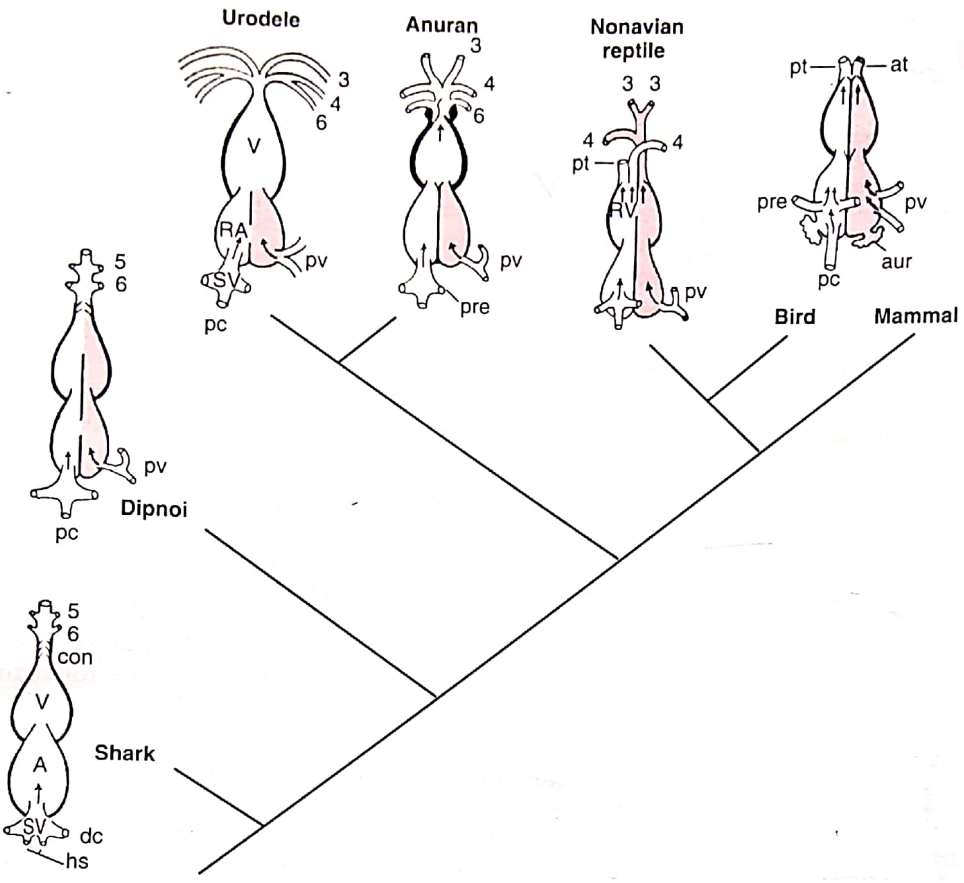


**FIGURE 14.10**
Heart chambers and oxygenated blood flow (*red*) in some generalized craniates. Distribution of oxygenated blood beyond the ventricle in dipnoan, urodele, and reptile depends on the species and the physiological needs of the organism. The parts of the heart shown are **A**, atrium; **RA**, right atrium; **V**, ventricle; **RV**, right ventricle; **SV**, sinus venosus; **con**, conus arteriosus; **aur**, auricle of mammalian heart. **3** to **6**, third to sixth aortic arches. Other vessels are **at**, aortic trunk; **dc**, common cardinal vein; **hs**, hepatic sinus; **pc**, postcava; **pre**, precava (common cardinal vein); **pt**, pulmonary trunk; **pv**, pulmonary veins.

that oxygenated blood returns to the systemic veins, resulting in mixing prior to arrival at the heart. It should be remembered that aerial respiration in these taxa represents a secondary mechanism that augments gill respiration in times of depleted environmental oxygen. On the other hand, the extant dipnoans (South American and African lungfishes) and tetrapods are obligate air breathers.

One modification in dipnoans and amphibians was the establishment of a partial or complete **interatrial septum** so that there are partial or complete **right and left atrial chambers** (figs. 14.9*a*, and 14.10, Dipnoi, urodele, anuran). The septum is complete in anurans and in some urodeles. Except in *Neoceratodus* (Dipnoi), the veins from the swim bladder or lungs empty directly into the *left* atrium; therefore, the blood in this chamber is oxygen rich. The sinus venosus empties into the *right* atrium (see fig. 14.9*b*); hence, the blood in this chamber is low in oxygen. In lungless urodeles, the atrium remains totally undivided.

A second modification is the formation of a partial **interventricular septum** (chiefly in dipnoans but also in *Siren*, a urodele) or of **ventricular trabeculae** (in amphibians). Trabeculae are shelves or ridges projecting from the ventricular wall into the chamber and running mostly cephalocaudad. Interventricular septa and ventricular trabeculae perform identical functions: They maintain separation of oxygenated and unoxygenated blood that began in the left and right atria.

A third modification is formation of a **spiral valve** in the conus arteriosus in dipnoans and anurans. The valve in dipnoans (fig. 14.11) consists of a pair of longitudinal typhlosolelike folds of the lining of the conus. In anurans, it is a single flap (fig. 14.12). The valves direct oxygen-poor blood into aortic arches that lead to gills or lungs (see figs. 14.11 and 14.18*b*, *blue*; and fig. 14.12), and they channelize oxygenated blood into arches that supply other organs (see figs. 14.11 and 14.18*b*, *red*; and fig. 14.12).

A fourth modification shortened the ventral aorta so that it becomes practically nonexistent as embryonic development progresses (figs. 14.11 and 14.12). As a result, blood moves from the conus arteriosus directly into appropriate vessels. Urodeles, however, retain a prominent ventral aorta (see fig. 14.9).

Many of the adaptations enabling aerial respiration in dipnoans and postlarval amphibians are seen also in amniotes.

## Hearts of Amniotes

Amniote hearts have two atria, two ventricles (a unique third ventricular chamber in turtles and squamates), and, except in adult birds and mammals, a

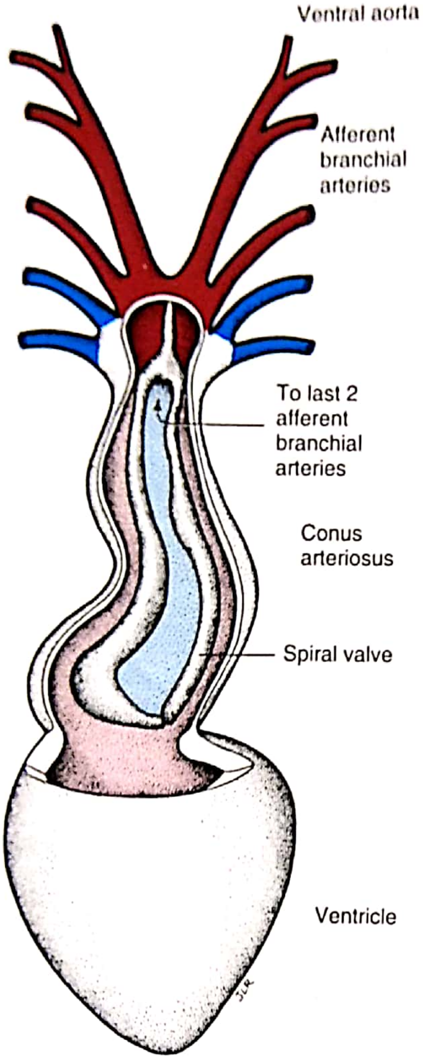


**FIGURE 14.11**
Conus arteriosus and afferent branchial arteries of the lungfish *Protopterus.* The spiral valve distributes oxygen-rich blood (*red*) to the first three afferent branchial arteries and oxygen-poor blood (*blue*) to the last two, which supply the respiratory swim bladder and internal gills, as shown in figure 14.18*b*.

sinus venosus (figs. 14.13*b* and 14.24). The sinus venosus in crocodilians, unlike in other reptiles, is partially incorporated into the wall of the right atrium. Birds and mammals have a sinus venosus during early development, but it fails to keep pace with the growth of the right atrium into which it empties and is finally indistinguishable as a separate chamber. Thereafter, the vessels that emptied into the sinus venosus empty directly into the right atrium. The embryonic location of the sinus venosus is marked in adults by a **sinoatrial (SA) node** of neuromuscular tissue. The node plays a key role in innervation of the heart, to be discussed shortly.

The right and left atria of amniotes are completely separated by an interatrial septum. Nevertheless, they are confluent during embryonic development via an **interatrial foramen,** or **foramen ovale,** which closes near the time of hatching or at birth. The site of the obliterated foramen is marked in adult mammalian hearts by a depression, the **fossa ovalis,** in the medial wall of the right atrium.

The *right* atrium of nonavian reptiles (see fig. 14.24) receives blood from the sinus venosus; that of birds and mammals receives, directly, blood that earlier in phylogeny and during embryonic development emptied first into the sinus venosus (see fig. 14.26). The *left* atrium receives blood from the pulmonary veins. In mammals only, each atrium has an earlike flap, or **auricle,** within which is a blind chamber (see fig. 14.39). The functional advantage of the mammalian auricle has yet to be demonstrated.

The two ventricles are completely separated in crocodilians, birds, and mammals (see fig. 14.26). In turtles and squamates, however, a unique third chamber, the **cavum venosum,** has developed at the upper limit of the interventricular septum (see fig. 14.24). It functions to shunt oxygen-rich and oxygen-poor blood into or away from specific arteries that leave the heart. Its role can best be understood after we have studied those arteries, which we will do shortly.

The muscular walls that line the ventricular chambers of mammals exhibit sturdy interanastomosing muscular ridges and columns, the **trabeculae carneae.** They strengthen the walls of these powerful pumps and increase the force exerted by them.

One-way valves guard the passageways from the atria into the ventricles of craniates. In amniotes, each valve consists of one or more fibrous flaps, or **cusps** (muscular on the right side of the heart in crocodilians and birds), connected, chiefly in mammals, by tendonous cords (**chordae tendineae**) to **papillary muscles** that project from the ventricular walls (see fig. 14.26). During relaxation of the ventricles (**diastole**), blood from the atria flows freely past the cusps and into the ventricles. During ventricular contraction (**systole**), the cusps are forced forward or upward into the atrioventricular passageway, preventing reflux of blood into the atria. Each valve has one or two cusps in reptiles. In most mammals, the left valve has two cusps (**bicuspid,** or **mitral valve**), and the right has three (**tricuspid valve**). **Semilunar valves** at the exits of the ventricles into the pulmonary and aortic trunks prevent backflow into the ventricles as the latter relax (see fig. 14.26).

## Innervation of the Heart

The hagfish heart lacks any external innervation. There are modified intrinsic cells that may respond to circulatory signals. The embryonic vertebrate heart begins to pulsate before any nerve fibers have reached it, and adult heart tissue, infused with an appropriate physiological solution, will continue to pulsate after its extrinsic innervation has been severed. Tissue from the heart

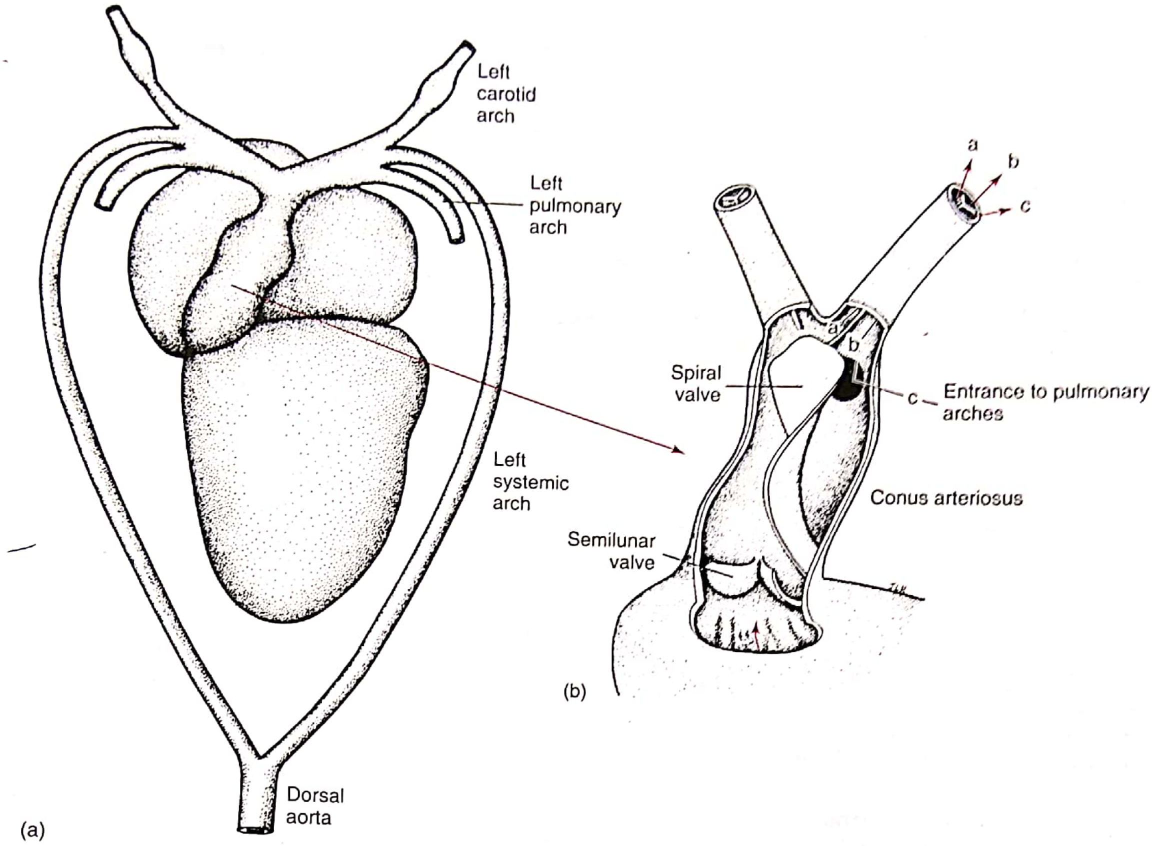


**FIGURE 14.12**
Heart and aortic arches of frog, ventral view. (*b*) Conus arteriosus opened to show passageways to left carotid arch (arrow **a-a**), and left systemic arch (arrow **b-b**). **c,** arrow enters common passageway to left and right pulmonary arches, then turns to enter passageway to left pulmonary arch.

of an embryonic chick, and its descendant cells, was kept alive and pulsating in a French laboratory for many years early in the twentieth century. The contraction of heart muscle is, therefore, autogenic, requiring no extrinsic neural stimulus for its initiation. Pulsation depends on the appropriate concentrations of certain electrolytes, especially Na, K, and Ca ions, in the tissue fluids that bathe cardiac muscle. The rate of autogenic pulsation of a denervated sinus venosus is imposed on the atria and ventricles via an intrinsic conduction system composed of atypical cardiac muscle fibers (**Purkinje fibers**) that constitute a conduction network with high conductile competence.

An extrinsic neural stimulus is necessary, however, to produce a regular beat that can be increased or slowed reflexly by the central nervous system in response to the physiological needs of the animal. Consequently, once nerve fibers have reached the sinus venosus during embryonic development, these fibers impose a rate of contraction on the cardiac muscle of that chamber. Thereafter, in fishes, amphibians, and nonavian reptiles, this beat is transmitted by the intrinsic conduction system to the atrium (or atria), then to the ventricle (or ventricles), and finally, to the conus arteriosus, if there is one. Thus, the sinus venosus is the *pacemaker* of the heart of these cold-blooded vertebrates. The sinus venosus of fishes is innervated by the vagus nerve (tenth cranial nerve) only. In anurans and amniotes, the heart is innervated also by fibers from the sympathetic trunk, the two sets of fibers having opposite effects on the heart rate (inhibitory fibers via the vagal nerve, accelerator fibers via cardiac nerves from the sympathetic trunk, see fig. 16.35).

In birds and mammals, the embryonic sinus venosus eventually becomes incorporated into the wall of the right atrium, where it remains as a nodular mass of modified cardiac muscle and connective tissue known as the sinoatrial (SA) node. This node continues to receive the incoming fibers of the autonomic nervous system, and it is the SA node that serves as the pacemaker for the heart of birds and mammals. Impulses from the SA node are conducted via Purkinje fibers to the

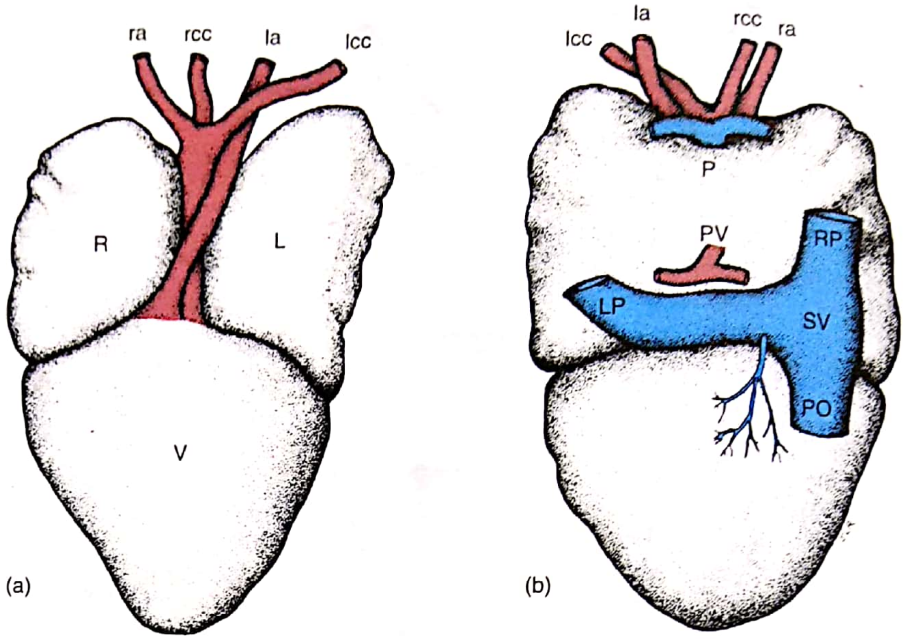


**FIGURE 14.13**
Heart and associated vessels of *Sphenodon*. (*a*) Ventral view. The ventricle, **V**, is divided internally into two chambers. (*b*) Dorsal view. **L**, left atrium; **R**, right atrium. *Red* vessels contain oxygenated blood. They are **la**, left aortic trunk; **lcc**, left common carotid artery; **PV**, pulmonary veins entering right atrium; **ra**, right aortic trunk; **rcc**, right common carotid artery. *Blue* vessels carry blood low in oxygen. They are **LP**, left precava; **P**, pulmonary trunk emerging from right ventricle; **PO**, postcava; **RP**, right precava; **SV**, sinus venosus.

myocardia of both of the atria, causing them to contract. The stimuli also spread to an **atrioventricular (AV) node** embedded in the heart near the cusps of the right atrioventricular valve. The AV node is unique to birds and mammals. From the AV node, an **atrioventricular bundle** of Purkinje fibers extends into the interventricular septum and splits into two parallel bundles that extend the length of the septum. From these, small bundles of Purkinje fibers ramify throughout the myocardium of both ventricles, providing stimuli that cause the ventricles to contract fractions of a second after the atria have done so. The Purkinje fibers are also innervated directly by autonomic nerve fibers, as is the myocardium in general.

During the short interval between contraction of the atria and that of the ventricles, blood in the atria empties into the dilated ventricles. Contraction of the latter then propels ventricular blood into the outgoing arteries.

## Morphogenesis of the Heart

When the heart is first recognizable in craniate embryos, it is an almost straight, pulsating tube in fishes and amphibians (fig. 14.14*a*) or a pair of tubes in amniotes (fig. 14.14*d*). The tubes receive incoming blood at their caudal ends and are continuous with the embryonic ventral aortas at their cephalic ends. The unpaired tube of sharks, basal bony fishes, and amphibians organizes from an unpaired aggregation of mesenchyme beneath the pharynx derived from lateral-plate mesoderm (fig. 14.15*a*). The paired tubes of amniotes organize from the same precursor tissues, differing only in that the tubes organize before the paired lateral plates have met in the midventral line (fig. 14.15, chick and rabbit). The paired tubes of amniotes eventually unite to form one (see fig. 14.14*e*). Mesenchyme cells trapped within the tubes become hemocytoblasts (stem blood cells).

As development progresses, the tube bends to the animal's right and then twists, so that the atrial region, previously at the caudal end, is carried dorsad and cephalad until it reaches its adult location. The location of the atrium in sharks is shown in figure 14.7. The twisting and bending is correlated with the confinement of the rapidly growing heart in a less expansive pericardial cavity.

In amphibians and amniotes, the twisting is carried further than in fishes, so that the atrial region finally lies cephalad to the ventricular region (see fig. 14.14*a* to *c*, frog, and *d* to *i*, chick). Following this, the atrial chamber expands to form bilateral pouches, and a median dorsal fold within the atrial chamber grows ventrad, separating the pouches into left and right atria. As a final major step in amniotes, an interventricular septum commences the separation of the ventricular chamber into right and left sides. The site of the septum is marked externally by a longitudinal **interventricular groove** that creases the surface of the ventricle (fig. 14.14*i*).

As hatching approaches in birds, the sinus venosus becomes almost completely incorporated into the wall of the right atrium. This takes place much earlier in mammals. Because it is imperative that oxygen and nutrients be circulated as early in development as possible, the heart is the first organ to function. It does so even before any nerves have reached it to impose a rhythm.

The initial straight tube that will become the heart of sharks and amphibians organizes from *paired mesenchymal masses* of lateral-plate somatic and splanchnic mesenchyme that aggregate in the midline beneath the pharynx to form a single endothelial tube (fig. 14.15*a*). In amniotes, a *pair of already organized endothelial tubes* comes together beneath the pharynx, fuses, and forms a single tube (fig. 14.15*b* and *c*). In either case, the heart is a bilateral contribution of lateral-plate mesoderm.

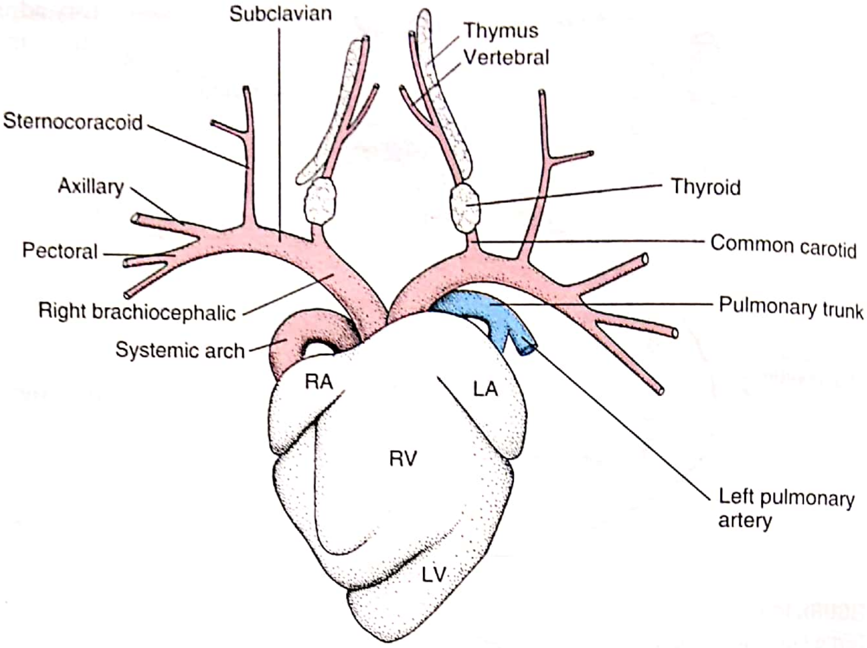


**FIGURE 14.25**

Heart and associated arches of a bird, ventral view. **LA, RA,** left and right atria; **LV, RV,** left and right ventricles. The systemic arch is the right fourth aortic arch. The paired brachiocephalic arteries are the embryonic ventral aortas distal to the base of the fourth arch. In adults, they arise by a common stump from the aortic trunk that gives rise also to the systemic arch (see fig. 14.19*g*).

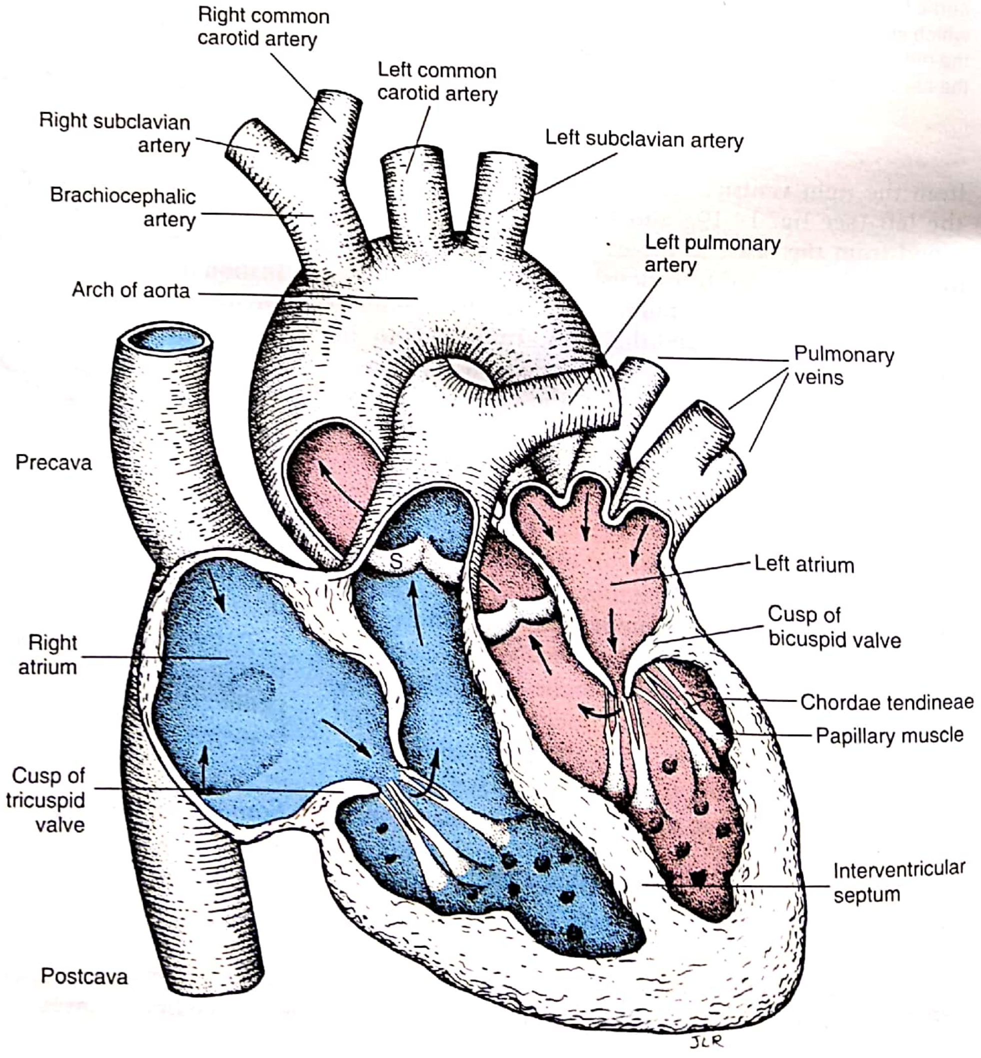


**FIGURE 14.26**

Human heart, auricles removed. **S,** semilunar valve at entrance to pulmonary trunk. A similar valve is seen at entrance to arch of the aorta. The third cusp of the tricuspid valve has been removed. The sinus venosus has been incorporated into the wall of the right atrium.

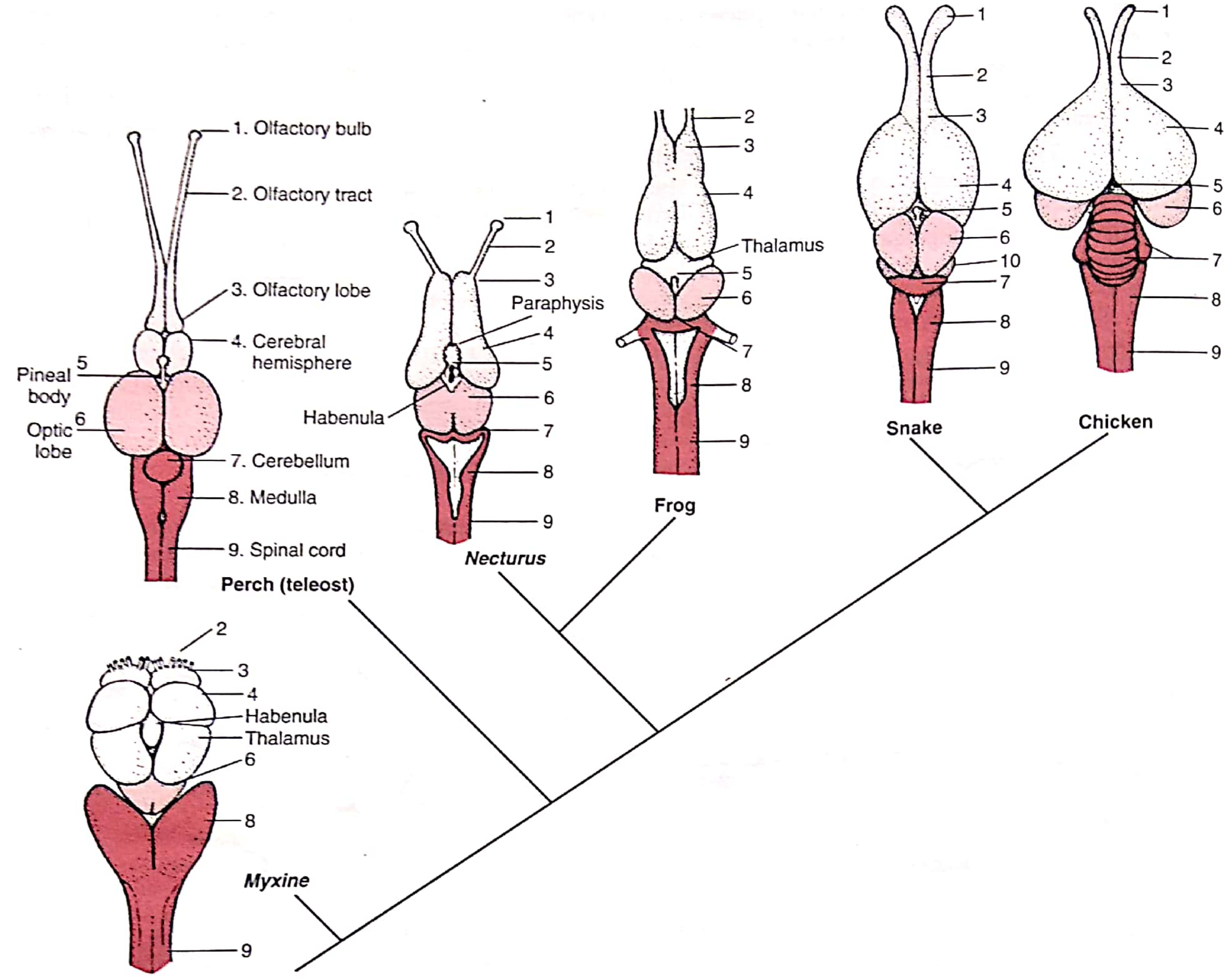


**FIGURE 16.14**

Craniate brains, dorsal view. The roof of the fourth ventricle has been removed in *Necturus*, frog, and snake. The forebrain, midbrain, and hindbrain are differentially colored. The habenuli, thalami, and pineal bodies are part of the diencephalon. **1** to **9**, see perch for key; **10**, auditory lobe of amniotes. Mammalian brains are shown in figure 16.23.

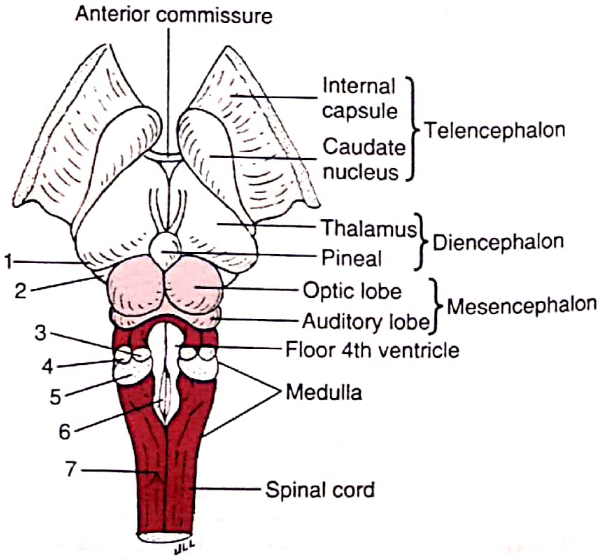


**FIGURE 16.15**

Brain stem of a sheep. The cerebral hemispheres and cerebellum have been cut away to reveal the underlying structures. **1,** location of lateral geniculate body of thalamus; **2,** medial geniculate body; **3** to **5,** anterior, middle, and posterior cerebellar peduncles. The peduncles had to be cut to remove the cerebellum. **6,** hypoglossal trigone in floor of the fourth ventricle (location of the hypoglossal nuclei); **7,** posterior funiculus (ascending fibers for proprioception). Optic and auditory lobes constitute the corpora quadrigemina. The habenulae lie under cover of the pineal. A paired fiber tract, the stria medullaris, is seen passing toward the habenulae on the surface of the thalamus. Three shades of *red* indicate forebrain, midbrain, and hindbrain.