(Purkynje fibres) which operate at 70, 40-60 & 30-40 beats per minute respectively; without the effect of the parasympathetic nervous system SA node acts at 100bpm.

Action potentials occur at fairly regular intervals and once a heartbeat is initiated all healthy cells in the myocardium normally contract; an increase of heart rate shortens diastole only, the length of systole is constant.

The sinoatrial node generates an action potential that spreads over the atria and causes atrial systole, this reaches the atroventricular node where the signal is delayed for ~120ms. Impulse then travels down the purkynje fibres in the ventricular septum and through the ventricular myocardium from the endo to epicardial surface. The ventricles then contract in a twisting motion from the apex up to cause a forceful ejection of blood; this is followed by myocyte relaxation from the epi to endocardial surface lasting for ~700ms.

**Cardiac Output** — Volume output per minute by the left heart; at rest ~5L/min or 80ml per beat

\[
\text{Cardiac Output (L/min) = Stroke Volume (L) x Heart Rate (min}^{-1})
\]

**Myocardial Cells** — Spread of electrical activity from from pacemaker cells depolarises myocytes to a threshold, once this is reached fast gated Na⁺ channels are opened to make the membrane potential ~+50mV. Na⁺ channels then close but at the same time Ca²⁺ channels open and the influx of Ca²⁺ ions keeps the membrane polarised. In addition Ca²⁺ entry stimulates Ca²⁺ release from intracellular stores, causing the cell to remain contracted (tension generated is proportional to \([\text{Ca}^{2+}]_o\)); this process lasts ~250ms (systole). At the end of systole Ca²⁺ channels close and K⁺ efflux (in addition to intracellular Ca²⁺ sequestration) causes repolarisation & subsequent relaxation of the cell (diastole).

**Pacemaker Cells** — Once an action potential has ended these cells depolarise slowly via Na⁺ influx through Iₚ channels; once the threshold is reached voltage gated Ca²⁺ channels open causing action potentials to begin spontaneously (no fast Na⁺ channels in a pacemaker cell of action potential is slow). The interval between beats depends on how fast the pacemaker potential depolarises (NA speeds up, ACh slows down). Ca²⁺ channels close via Ca²⁺ efflux through voltage gated channels causes repolarisation.

- **Funny Current** — Iₚ – Na⁺ channels which are activated by hyperpolarisation meaning the more negative the potential is, the more of these channels that open, allowing slow Na⁺ influx to reach threshold potentials. Prevents spontaneous activity of myocytes

**Autonomic Nervous System**

The autonomic nervous system controls heart rate, force of contraction & peripheral resistance of blood vessels in all of the cardiovascular system except for the cerebral circulation.

- **Sympathetic** —NA acts on β₁ receptors causing an increase in Ca³⁺ entry during the action potential which speeds up pacemaker potential
- **Parasympathetic** — Vagus nerve synapses at the SA & AV nodes where post-ganglionic cells release ACh that acts on M₂ receptors to decrease heart rate & AV node conduction velocity. At rest this is the autonomic input most active. Parasympathetic input to the heart can increase when cold ice is placed on the face, the carotid sinus is massaged or in a valsalva manoeuvre
- **Afferent** — Sensory neurones from baroreceptors in the carotid sinus & arch of aorta communicate with cardiovascular centre in medulla oblongata

Most arteries & veins have α₁ adrenoceptors and coronary, liver & skeletal muscles also have β₂ receptors. Vasomotor tone is the tonic contraction of smooth muscle that can constrict or dilate blood vessels to alter flow resistance.

Circulating adrenaline has a higher affinity for β₂ receptors which dilate blood vessels by opening K⁺ channels, counteracting the effect of noradrenaline which acts on α₁ receptors to increase Ca²⁺ release from stores to cause vasoconstriction. α₁ receptors are less sensitive, but when activated (high adrenaline) override effect of β₂.