volume during expiration. This form of pulse, first noticed by Griesinger, and named *pulsus paradoxus* by Kussmaul, occurs in various diseases, and is an index of the presence of one of two conditions: the existence during inspiration of a direct mechanical obstacle to the emptying of the left ventricle into the aorta, or increase of the negative inspiratory pressure from changes which prevent the free entrance of air into the lungs. The most striking examples of the first condition are found in *fibrous mediastinitis* and *fibrous pericarditis;* the firm cords of connective tissue developed in these affections, passing from the sternum and pericardium upwards and backwards towards the great vessels, enclosing the latter and to some extent dragging them from their normal position and attaching them more or less intimately to the sternum, are put on the stretch when the thorax is dilated in inspiration, and grasp and constrict the aorta, innominate artery, &c. Only a portion of the contents of the left ventricle, therefore, finds its way into the aorta during inspiration, the arterial pulse is rendered feebler, or even disappears if the chest be expanded to its utmost; in expiration, on the contrary, the aorta regains its natural calibre and the pulse its normal volume. It is plain also that the pulse will be full enough which responds to those contractions of the heart which do not happen to coincide with an inspiration.—But the *pulsus paradoxus* is also observed in certain cases of pericarditis in which the aorta is free from the embrace of such adhesions. Its occurrence in these circumstances is ascribed to various causes: to occasional embarrassment of the left ventricle during inspiration, from thickening of the pericardium associated with atrophy of the muscular structure of the heart (Traube, Stricker); or to the pressure of pericardial effusion, which retards the flow of blood from the venæ cavæ into the heart, particularly during expiration (when the intrathoracic tension is augmented), so that the heart contains less blood at the beginning of inspiration than at the commencement of expiration (Bäumler).—The second condition described as favourable to the production of the *pulsus paradoxus* is found in *stenosis of the air-passages*. Even in health the pulse may be slightly of this character, as each inspiration lessens the pressure within the thorax and within the aortic system of vessels generally, while expiration, on the contrary, adds to this pressure; the arterial pulsations therefore, which correspond to such contractions of the heart as are coincident with inspiration are smaller than those felt during expiration. These differences, though usually so trifling as to be inappreciable by the finger, are readily demonstrable on a sphygmographic tracing, the primary wave of the inspiratory pulsations being considerably lower than that of the expiratory pulse (Riegel). If, however, the inspiratory negative pressure within the thorax be abnormally low, as in cases of stenosis of the larger air-passages, and if to this be added as a second factor diminution of the contractile power of the heart, the inequalities just mentioned are much exaggerated, and are easily detected by the unaided sense of touch, pulsation being sometimes completely abolished during inspiration.

Inequality of the pulse in one radial artery as compared with that in the other (*pulsus differens*) may be of physiological or pathological origin. Of the former nature are those instances in which the vessel divides into its two branches at a higher point in its course on one side of the body than on the other, and so comes to be of comparatively small calibre at the part at which the pulse is usually taken; and as this anomaly is not on the whole very rare, it should always be looked for when marked difference in the radial pulses presents itself. Pathological inequalities of this kind are most commonly due to pressure on the arteries of one side, as by intrathoracic tumours implicating the aorta between the left common carotid and the left subclavian, occasionally also by tumours (carcinomatous lymphatic glands) which press upon the axillary artery; partial obliteration of one of the brachial arteries, and other local and generally easily recognised causes, often give rise to the same phenomena.

5. Tension of the Artery.

By this term is meant the pressure exercised by the blood on the inner surface of the vessels. It reaches its maximum when the expansion of the artery is at its height, and sinks to its minimum at the end of the contraction of the arterial wall. The greater the distension of the vessel by the blood-wave the greater is its tension. An artery in a state of extreme tension is less compressible than one whose walls are more relaxed; the former is hard to the touch, the latter soft, a tense artery thus making what is technically known as a *hard pulse*, a relaxed

artery a *soft* pulse. Other things being alike the intra-arterial pressure is increased by hypertrophy of the left ventricle, and diminished when the action of the heart is weakened, or when its cavities contain less than the normal amount of blood.—The degree of tension of the arterial wall during expansion determines also the extent to which the artery springs into prominence with each stroke of the heart; the harder and stronger the pulse the greater will be the elevation of the artery, provided that the capacity of the vessel is not in any way lessened, (as, for instance, in cases of stenosis of the aortic orifice).

Constrictions of the left venous and arterial orifices offer good examples of affections in which the differences in tension shown by the pulse are well-marked. In the former the left ventricle receives less than the normal volume of blood on which to expend its energy and consequently begins to atrophy at a comparatively early stage of the disease, when the pulse becomes smaller and of low tension; in stenosis of the aortic orifice, on the other hand, though the blood-wave is indeed small, as in the preceding case, and the radial arteries also contracted, the blood is forced onwards by all the power of a hypertrophied left ventricle and the tension of the pulse is accordingly considerably raised.

6. Celerity (activity) of the Pulse.

This term is used to express the relation which exists between the duration of the expansion and that of the contraction of the artery.

In the normal condition the expansion of the vessel by the wave propagated from the heart lasts almost exactly as long as its contraction; this, at least, is the impression given to the finger, but the sphygmographic tracing shows that the lines formed by the dilatation of the artery are really shorter than those corresponding to its elastic recoil. The relation of these different parts of the tracing to each other, however, is subject to great variation. If from pathological causes the artery attain at once its maximum of expansion, and return equally rapidly to a state of quiescence, a pulse is produced which is designated the *pulsus celer*,—a brisk, active pulse. The slighter manifestations of this peculiarity are scarcely appreciable by the finger, but in well-marked cases such a pulse is exceedingly characteristic, and is usually spoken of as a *bounding* pulse. This nimbleness in movement displayed by the arterial wall is the more readily recognised the larger the vessel in which it is observed; it is therefore more distinct in

the brachial and femoral arteries than in the radials. The most exquisite examples of this symptom are found in aortic insufficiency: the arteries are quickly and forcibly dilated by the pressure of the blood driven into them by the enlarged and powerful left ventricle, but their recoil follows as speedily, the systolic wave being exhausted in two directions,—centrifugally (into the capillaries) and centripetally (by regurgitation into the ventricle). A sharply-defined pulse, therefore, is regarded as pathognomonic of insufficiency of the aortic valves.

A pulse distinguished by the opposite qualities is termed a *sluggish* pulse (*pulsus tardus*). It is noticed particularly when the arteries lose their elasticity, as from sclerosis. Vessels so affected present unusual resistance to expansion by the pulse-wave and subside equally slowly in the intervals; they feel firmer to the touch than in health, and in exaggerated cases may become so hard as to be absolutely incompressible.

7. Dicrotism of the Pulse.

Though the finger applied to the radial artery in the healthy subject is sensible of but one impulse, occurring during the period of expansion of the vessel, it may be demonstrated by means of the sphygmograph (see p. 248) that in the period of contraction also a slight elevation of the artery takes place,—usually indeed two such elevations are observable in the tracing. These are caused by recoil-waves, that is, by blood-waves which, during the contraction of the arteries, flow backwards towards the heart, where they encounter the closed aortic valves, rebound from these and again travel outwards towards the periphery. But if the tension of the arteries is lessened, as in high fever, and if, further, the primary impulse produced by the systole of the heart be short and vigorous, the reflected wave may effect such a considerable degree of diastolic elevation of the artery as will render the use of the sphygmograph superfluous, the unaided finger being sufficient for the detection of the feebler *after-stroke*. This is designated the *double*, or *dicrotic* pulse. It is fully developed only when the temperature becomes decidedly febrile, 39°—40° C. (102·2°—104° F.), particularly when it remains for some time at this point, as in typhus and other affections characterised by continued fever. In individuals already exhausted and emaciated

by chronic disease very slight fever and a comparatively low temperature suffice to give rise to distinct dicrotism of the pulse, as the arterial tension in such patients gives way more rapidly than in cases of acute disease in previously healthy persons. In febrile attacks of short duration, also, as in intermittent fever, dicrotism is observed, occasionally even when the pulse is not at all increased in frequency; this fact is direct proof that the high temperature, apart from the other phenomena of fever, is of itself to be regarded as the cause of dicrotism (Riegel).

In those who are much emaciated, in whom the radials pulsate prominently, a double pulse may be recognised, without applying the finger to the wrist or having recourse to the sphygmograph, by examining the artery in powerful sunlight, when it will be seen that each primary pulsation casts a shadow, which is followed by a second shorter shadow, on the adjacent part of the surface. Dicrotism sometimes also manifests itself in the double jerking movement occasioned by the pulsation of the popliteal artery and communicated to the dependent leg and foot when the patient sits with one knee crossed over the other. In large animals this reduplication of the pulse may be demonstrated by puncturing the femoral artery and causing the stream of blood issuing from it to impinge on a strip of paper moving slowly past it, on which it forms a tracing; this process, described by Landois, is termed *Hæmautography*.

The *hyper-dicrotous* pulse is observed in very high fever, in which the temperature ranges from 40°—41° C. (104°—105·8° F.); in it the second beat is somewhat later than in the ordinary dicrotous pulse, appearing immediately before the renewed expansion of the artery, so that it closely resembles a preliminary systolic stroke. It is, however, really a dicrotic pulse, the peculiar character of which is due solely to its rapidity, each primary pulsation following so hard upon the preceding secondary stroke that the latter is shortened and to a certain extent rendered abortive. If the pulse become still more rapid even this shortened after-beat (or preliminary pulsation) disappears, and the dicrotic pulse merges into one which is strictly monocrotic.—A pulse which is obscurely dicrotic is named *sub-dicrotic;* it is noticed in moderate fever, when the temperature is only slightly elevated.

Sphygmography.

(The graphic representation of the arterial pulse.)

The undulations of the pulse in all the superficial arteries may be measured instrumentally and represented graphically in tracings. The apparatus which is almost universally employed for this purpose is that invented by Marey, subsequently modified and improved by other in-

vestigators. It consists essentially of a delicate lever, firmly attached to which is a small button or cushion; the latter, being placed so as to rest exactly on the artery, rises and falls with the expansion and contraction of the vessel and communicates these movements to the lever, which inscribes them on a slip of smoked paper fixed on a plate and carried forwards by clockwork. The more recently constructed instruments of Landois and Sommerbrodt have this advantage over Marey's, that they indicate the precise amount of pressure exerted on the artery. —Only the most important of the vast array of facts brought to light by the use of the sphygmograph, can be mentioned here. It has been ascertained that the *normal pulse* is not monocrotic, but always *dicrotic* (Marey), usually even *tricrotic* (O. Wolff). Thus, whilst the *line of ascent* of *all* arteries, that which corresponds to the expansion or diastole of the arteries, is nearly vertical (varying in height according to the size of the vessel under examination) and *perfectly unbroken*, that which answers to the contraction or systole of the arteries is interrupted by slight secondary *elevations*, of which *two* are more distinctly marked than the others. The first of these owes its existence to the circumstance that the blood-wave, when compressed by the elastic contraction of the artery, is not wholly propagated towards the periphery, a portion of it being sent backwards towards the heart, where it strikes against the already closed aortic valves; the second is produced by the new wave which, generated by this shock, sweeps outwards again in the direction of the peripheral arteries (Buisson, Marey, &c.). These elevations, known as the *recoil-waves*, are the more clearly defined and appear the earlier (that is, the nearer the upper end of the down-stroke of the tracing) the closer to the heart the artery under examination, the less its tension, and the shorter the primary wave (that due to the primary expansion of the artery); the converse of these propositions also holds good (Landois). If both secondary waves occur in the period of contraction of the artery, which is usually the case, the pulse is tricrotic, if one be wanting the pulse is dicrotic. —Besides these recoil-waves several other less marked undulations present themselves in the descending line of the tracing, caused by the oscillations of the arterial wall as it returns to a state of rest after having been expanded by the primary (cardiac systolic) wave, and designated by Landois *elasticity-waves*. They vary in number in different arteries, and are the higher the further removed the vessel in question is from the heart and the greater its tension.

Pathological deviations from the normal form of the pulse tracing are seen sometimes in the ascending, sometimes in the descending line. The up-stroke, which in the healthy pulse is perfectly unbroken and nearly vertical, is occasionally interrupted by a number of small pointed elevations. These are observed when a large volume of blood is projected into the arteries by each systole of the heart, and when the expansion of the vessels is not effected in one movement but in several successive oscillations. Such interruptions of the line of ascent are noticed in the following conditions: in hypertrophy and dilatation of

the left ventricle, especially when consequent on nephritis ; in those in whom the elasticity of the arteries is diminished,—in old persons, therefore, and in cases of atheromatous degeneration ; in aortic stenosis, and in aggravated aortic insufficiency (Landois). The tracing given by the arteries of paralysed parts of the body, where there is vasomotor paralysis combined with a slow circulation, is also of this character.

The pathological modifications of the descending line of the pulse-tracing consist either of an exaggeration or a diminution of the elevations normally present. Should these elevations, particularly the second of those described as recoil-waves, be considerably increased in height, this change becomes *appreciable to the finger* as dicrotism, a sign the special causes of which have already been stated (p. 247). The recoil-waves, on the other hand, are enfeebled when the aortic valves become incompetent, as the regurgitation of blood which takes place into the left ventricle during the cardiac diastole almost always effectually counteracts any tendency to the propagation of such a secondary impulse towards the periphery. In stenosis of the aortic orifice also they are faint and imperfectly developed, on account of the partially filled condition of the arteries ; here, however, the slow expansion of the vessels (that is, the slow passage of the current of blood through the contracted orifice) is evidenced by the less upright sloping up-stroke and by the rounding of the apex of the tracing, which normally is distinctly pointed.—The tracings of mitral and other lesions of the heart show little that is characteristic ; that given by the small pulse associated with stenosis of the left auriculo-ventricular orifice is certainly throughout less elevated than usual, nevertheless it may be affirmed that on the whole only an approximative diagnosis as to the nature of the heart affection is possible if it be founded solely on the data furnished by sphygmographic examination.

Another instrument, named the "Pulsuhr," which promises to be of great service in the investigation of the properties of the pulse, has recently been introduced by Waldenburg. This is an ingeniously constructed apparatus which enables us to measure with precision, and state definitely in figures, not simply to estimate, as heretofore, the tension, fulness, and volume of the pulse. It is fitted with a mechanism by means of which the position of the plate which rests on the artery and follows its pulsations, may be exactly regulated. The movements of the plate are communicated to a two-armed lever, from the extremity of the longer limb of which passes a thread ; the latter winds round an axle and so turns an index, which shows on a dial the distance, magnified about a hundred times, through which the plate is carried ; the diameter of the artery, that is, its fulness, is in that way obtained. The same indicator rises and falls with all the movements of the artery ; this gives the height of the pulsation, that is, the volume of the pulse, amplified to a similar degree.—To the end of the shorter arm of the lever is attached a spring, the case enclosing which is connected by wheel-work with another index, smaller than that just mentioned, showing on the dial the weight which at any given time presses on the spring. (The construction of the instrument is such that to

ascertain this weight the distance travelled by the larger indicator has first to be deducted from that through which the smaller one moves). On turning the screw, the plate having been accurately adjusted on the artery, the spring-case, and with it the lever and the arterial plate, are pushed downwards and both indicators caused to move, the oscillations of the larger of the two corresponding with the height of the pulse-wave. The length of the greatest of these oscillations expresses the *volume of the pulse*. On screwing down the spring-case still further the movements of the indicators become gradually smaller and are finally abolished when the artery is completely flattened and its calibre obliterated : the extent to which the position of the larger index has been altered may now be read on the dial ; this gives the diameter of the vessel, that is, its *fulness* at the time of examination ; the distance travelled by the smaller index, after subtracting from it the excursion of the larger one, shows the weight which was required to compress the artery, that is, the *tension of the pulse*.

Palpation of the Veins.

Almost the only veins ever examined by the hand are the jugulars, very rarely the superficial brachial veins ; the others yield no diagnostic signs to palpation. The pulsation perceptible in the jugular veins in cases of insufficiency of the tricuspid valves and other affections giving rise to overloading of the right auricle and incompetency of the jugular valves, and the more exceptional forms of pulsation observed in other superficial veins belonging to the domain of the vena cava superior, have already been under discussion ; the vibration of the walls of the jugular veins (frémissement or thrill), associated with chlorosis, is reserved for consideration in the section on Auscultation (see "Venous murmurs").