Normal values for each of these volumes and capacities have been calculated. They have been found to vary with sex, height and age. All pulmonary volumes and capacities are about 20 to 25 % less in females than in males.

A particular pattern of abnormal lung volume may occur in a particular form of lung disease and such a pattern is useful confirmatory evidence of a diagnosis made on clinical grounds. Further, serial lung function testing is of use in demonstrating progressive deterioration in function or in confirming a satisfactory response to therapy. For example, if the ratio (FEV_1)/(FVC) of the volume of gas that can be exhaled forcibly in one second from maximum inspiration (FEV_1) to the forced vital capacity (FVC) is less than 70%, airway obstruction as in chronic bronchitis is likely to be present. If the FEV_1/FVC is greater than 85%, a so called 'restrictive' defect may be present. This is seen in cases of diffuse pulmonary fibrosis.

Pulmonary function tests are performed for the assessment of the lung's ability to act as a mechanical pump for air and the ability of the air to flow with minimum impedance through the conducting airways. These tests are classified into two groups: single-breath tests and multiple-breath tests.

There are three types of tests under the *single-breath* category. These are

- Tests that measure expired volume only.
- Tests that measure expired volume in a unit time.
- Tests that measure expired volume/time.

In the class of *multiple-breath* test measurements is the Maximal Voluntary Ventilation (MVV) which is defined as the maximum amount of air that can be moved in a given time period. Here, the patient breathes in and out for 15 s as hard and as fast as he or she can do. The total volume of the gas moved by the lungs is recorded. The value is mulitiplied by 4 to produce the maximum volume that the patient breathed per minute by voluntary effort.

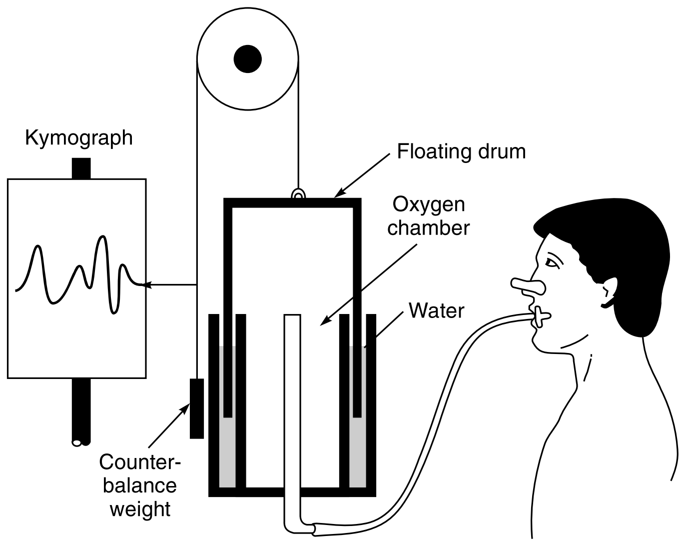
A resting person inspires about 0.5 litre of air with each breath, with the normal breathing rate of 12 to 20 breaths per minute. With exercise, the volume may increase 8 to 10 times and the breathing rate may reach 40 to 45 breaths per minute. A respiratory disease may be suspected if these volumes, capacities or rates are not in the normal range.

13.2 SPIROMETRY

The instrument used to measure lung capacity and volume is called a spirometer. Basically, the record obtained from this device is called a spirogram. Spirometers are calibrated containers that collect gas and make measurements of lung volume or capacity that can be expired. By adding a time base, flow–dependent quantities can be measured. The addition of gas analzsers makes the spirometer a complete pulmonary function testing laboratory.

13.2.1 Basic Spirometer

Most of the respiratory measurements can be adequately carried out by the classic water-sealed spirometer (Fig. 13.3). This consists of an upright, water filled cylinder containing an inverted counter weighted bell. Breathing into the bell changes the volume of gases trapped inside, and the



➤ **Fig. 13.3** ***Basic water sealed spirometer***

change in volume is translated into vertical motion, which is recorded on the moving drum of a Kymograph. The excursion of the bell will be proportional to the tidal volume. For most purposes, the bell has a capacity of the order of 6–8 l. Unless a special light weight bell is provided, the normal spirometer is only capable of responding fully to slow respiratory rates and not to rapid breathing, sometimes encountered after anaesthesia. Also, the frequency response of a spirometer must be adequate for the measurement of the forced expiratory volume. The instrument should have no hysteresis, i.e. the same volume should be reached whether the spirometer is being filled or being emptied to that volume.

As the water-sealed spirometer includes moving masses in the form of the bell and counter-weights, this leads to the usual problems of inertia and possible oscillation of the bell. This can lead to an over-estimation of the expiratory volume. A suggested compensation is by the use of a spirometer bell having a large diameter and which fits closely over the central core of the spirometer, so that the area of water covered by the bell is small in relation to that of the water tank. If the spirometer is used for time-dependent parameters, then it must also have a fast response time, with a flat frequency response up to 12 Hz. This requirement applies not only to the spirometer, but also to the recorder used in conjunction with the recording device.

The spirometer is a mechanical integrator, since the input is air flow and the output is volume displacement. An electrical signal proportional to volume displacement can be obtained by using a linear potentiometer connected to the pulley portion of the spirometer. The spirometer is a heavily damped device so that small changes in inspired and expired air volumes are not recorded. The spirometers can be fitted with a linear motion potentiometer, which directly converts spirometer volume changes into an electrical signal. The signal may be used to feed a flow-volume differentiator for the evaluation and recording of data. The response usually is ± 1% to 2 Hz and ± 10% to 10 Hz.

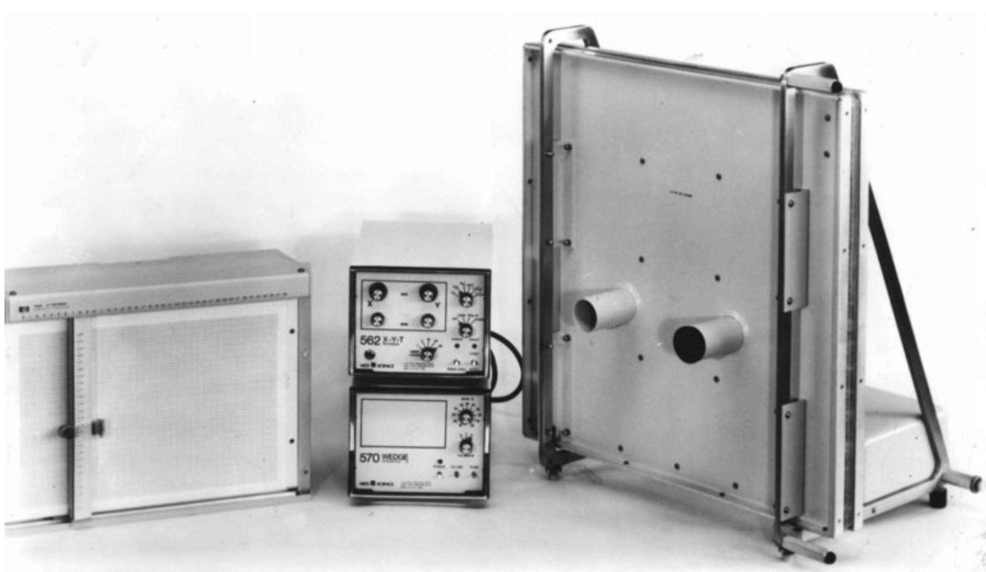
Tests made using the spirometer are not analytical. Also, they are not completely objective because the results are dependent on the cooperation of the patient and the coaching efforts of a good respiratory technician.

There have been efforts to develop electronic spirometers which could provide greater information-delivering and time-saving capabilities. Also, there have been efforts to obtain more definitive diagnostic information than spirometry alone can provide.

Calculating results manually from the graph of the mechanical volume spirometer requires considerable time. Transducers have been designed to transform the movement of the bell, bellows or piston of volume spirometers into electrical signals. These are then used to compute the numerical results electronically. The popularity and low cost of personal computers have made them an attractive method of automating both volume and flow spirometers. An accurate spirometer connected to a personal computer with a good software programme has the potential of allowing untrained personnel to obtain accurate result.

13.2.2 Wedge Spirometer

A wedge spirometer (Fig. 13.4) consists of two square pans, parallel to each other and hinged along one edge. The first pan is permanently attached to the wedge casting stand and contains a pair of 5 cm inlet tubes. The other pan swings freely along its hinge with respect to the fixed pan. A space existing between the two pans is sealed airtight with vinyl bellows. The bellows is extremely flexible in the direction of pan motion but it offers high resistance to 'ballooning' or inward and outward expansion from the spirometer. As a result, when a pressure gradient exists between the interior of the wedge and the atmosphere, there will only be a negligible distortion of the bellows.



➤ **Fig. 13.4** *Wedge spirometer (Courtesy: Med. Science, USA)*