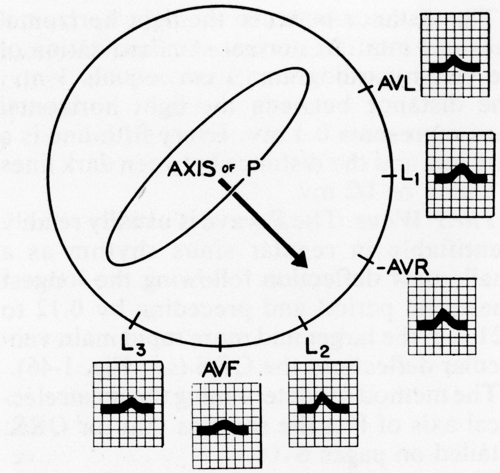

Fig. 1-48. The configuration of the P wave in the various frontal lead positions when the mean electrical axis of P is at 45 degrees. The P wave is upright in all frontal leads. Note that −AVR is the mirror image of AVR. Therefore, the upright P wave presented here in −AVR corresponds to an inverted P in the conventional AVR lead.

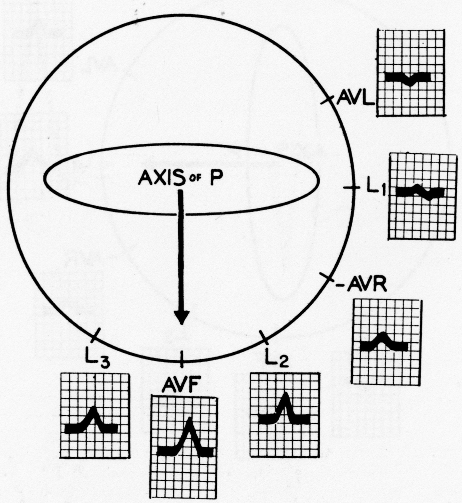

Fig. 1-49. The mean electrical axis of the P wave is at 90 degrees and a tall P wave is recorded in AVF. The P wave is transitional in lead I and is inverted in AVL.

The P usually assumes the following forms in the various leads:

L1	—Upright.
L2	—Upright, usually of greatest amplitude in this lead. (The P is usually most easily identified and measured in this lead.)
L3	—May be upright, isoelectric, diphasic, or even inverted.
AVR	—Always inverted.
AVL	—Usually upright. May be diphasic or inverted.
AVF	—Usually upright.
Precordial leads:	
V1	—Usually inverted.
V2 and V3	—May be inverted, diphasic, upright, or isoelectric.
V4 to V6	—Usually upright, but may be of very low amplitude and difficult to identify in these leads.

In identifying the P wave and determining its normalcy, all the leads should be examined. At times the P wave may not be readily identified in the 12 lead standard electrocardiogram because of one or more of the following factors:

1. The P wave may be of very low voltage or isoelectric, especially in electrocardiograms of low voltage.

2. If the cardiac rate increases, the P wave may be superimposed on the preceding T wave and may not be readily identified as a separate entity.

3. In prolongation of the P-R interval, the P wave may be superimposed on the preceding T wave, even at normal heart rates.

4. In arrhythmias, the P wave may be replaced by waves of other atrial electrical activity, such as atrial flutter waves or atrial fibrillation waves.

5. In premature beats and ectopic rhythms, difficulties may be encountered in identifying the P wave. Chapter 2 should be consulted for more detailed instructions and descriptions of these abnormal forms.

6. The U wave, usually a small, slow wave that follows the T wave, may sometimes be mistaken for a P wave, particularly when the P wave is of very low voltage and not readily evident. Examination of other leads will usually aid in differentiating the P wave from the U wave; readily identifiable P waves may be present in other portions of the electrocardiogram.

The various methods for identifying an obscure P wave are detailed on page 25. Further description of the P wave will be found in the "Abnormal P Wave" section. The method for calculating the heart rate from the P-P interval is presented on page 24.

The P-R Interval (P-Q). The P-R interval extends from the beginning of the P wave to the initial deflection of the QRS. If the first QRS deflection is downward, the interval is really a P-Q interval, but by common custom is called the P-R. The P-R interval varies with the age, size, and weight of the patient as well as with the heart rate, being shorter at rapid heart rates. It normally equals 0.12 to 0.21 sec., but this interval may be shorter in tachycardia and in children. The full range of normal values is given in Table 1-1 (p. 24). The P-R interval consists of the P wave proper and the P-R segment (the interval between the end of the P and the beginning of the Q). The P-R segment is usually isoelectric (Fig. 1-50).

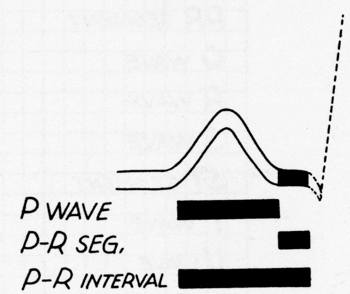

Fig. 1-50. Diagram of the P wave, the P-R segment, and the P-R interval.

The P-R interval is usually measured in lead 2. Several difficulties may be encountered in the attempt to determine the exact value for the P-R interval. In any given lead, part of the P wave may be isoelectric. If, in that lead, the initial phase of the P wave is isoelectric, the P-R interval will measure less than it actually is. If the P wave is measured in that lead in which the initial portion of the QRS is isoelectric, the P-R interval will measure longer than it actually is (Fig. 1-51). Both of these errors would be avoided if all of the frontal plane leads were recorded simultaneously. However, this procedure is usually not clinically feasible. The best method for determining the P-R interval is to measure it in that lead with both a well formed P and a QRS which either is initiated with a Q wave or is the widest QRS in routine leads.

Because of the above difficulties in measuring the P-R interval, minor deviations from the normal or minor deviations from tracing to tracing in the same patient should be interpreted with caution.

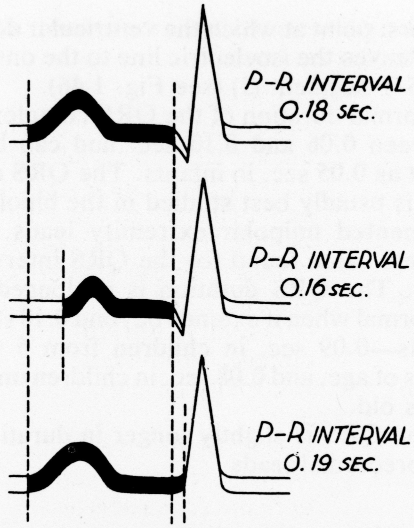

Fig. 1-51. Diagram illustrating variations of the P-R interval due to isoelectric periods in the P wave or the QRS. In the top line the true P-R interval is 0.18 sec. and neither the P wave nor the QRS complex is isoelectric in its initial phase. In the second line the apparent P-R interval is 0.16 sec. because the initial 0.02 sec. of the P wave is isoelectric. In the third line the P-R interval appears to be 0.19 sec. because the initial 0.01 sec. of the QRS complex is isoelectric.

The QRS (the Main Ventricular Deflection). The QRS is a record of the electrical activity of the ventricular depolarization (Fig. 1-52). It is usually the largest and sharpest deflection on the electrocardiogram. It may consist of the following waves:

1. The first downward deflection is the Q wave.
2. The first upward deflection is the R wave.
3. The first downward deflection after the first upward deflection is the S wave.
4. If the first upward deflection has returned to cross below the baseline, the second upward deflection is called the R′ wave.
5. A downward wave after the R′ wave is S′ wave, etc.
6. If there is a downward deflection on the R wave, which does not reach the baseline, the entire wave is called a notched R wave.
7. A ventricular complex which consists of an entirely negative deflection is called a QS complex.

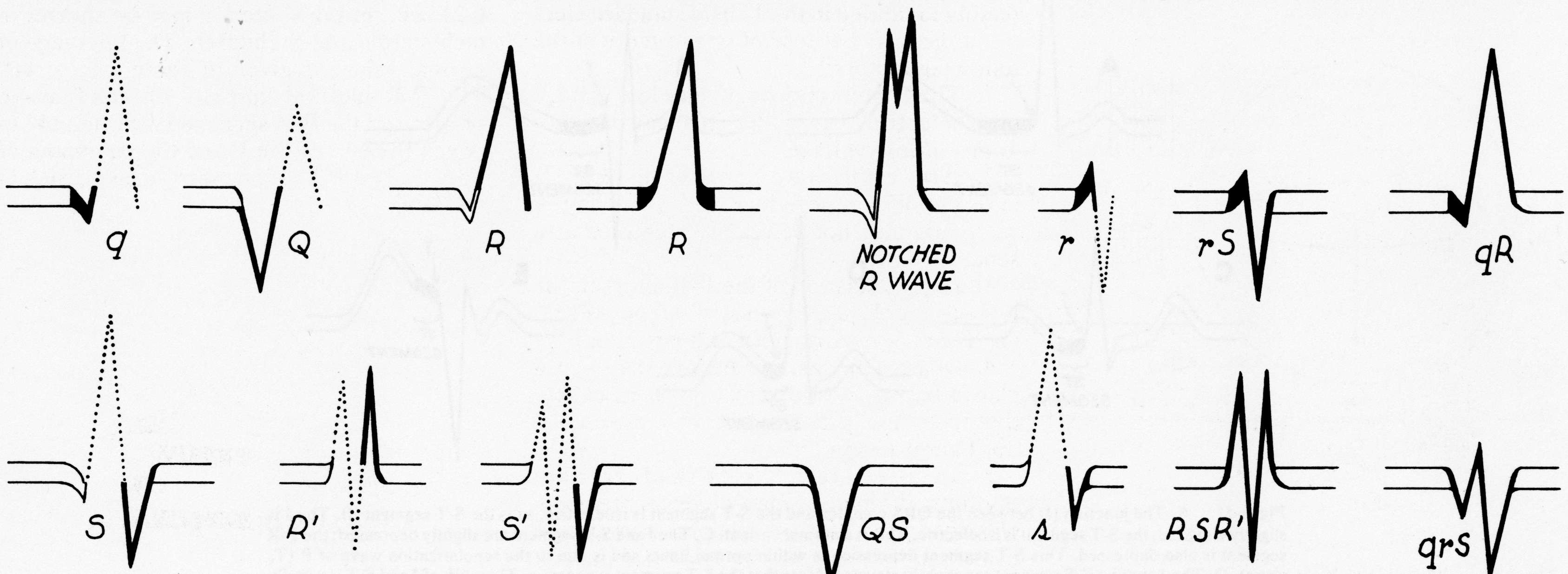

Fig. 1-52. Schematic representation of the various forms of the component parts of the QRS and their nomenclature.

The amplitude, duration, configuration, and electrical axis of the QRS must all be analyzed. The amplitude of the QRS varies over a wide range. It is usually higher in the precordial leads than in the standard leads. It is commonly more than 4 or 5 mm. in at least one of the standard leads and less than 22 mm. in any of these same leads. It is usually more than 10 mm. in at least one of the precordial leads and less than 25 mm. in any of these leads, except in children and young adults. When the amplitude of the QRS is increased, *high voltage* is present. When the amplitude of the QRS is decreased, *low voltage* is present.

The duration of the QRS is measured from the first point at which the ventricular deflection leaves the isoelectric line to the onset of the S-T segment (J) (see Fig. 1-46).

Normal duration of the QRS complex lies between 0.06 and 0.10 sec. and can be as short as 0.05 sec. in infants. The QRS duration is usually best studied in the bipolar or augmented unipolar extremity leads. The highest value found for the QRS interval is used. The QRS duration is prolonged and abnormal when it extends beyond 0.10 sec. in adults—0.09 sec. in children from 5 to 14 years of age, and 0.08 sec. in children under 5 years old.

The QRS is slightly longer in duration in the precordial leads.

In the presence of tachycardia, the QRS is usually narrower.

The initial negative deflection of the QRS, the Q wave, may be present normally in any lead. The upper limits of normal of both amplitude and duration of the Q wave also vary for each of the leads. The detailed criteria for the normalcy of the Q will be presented in Chapter 4. Normally, when the QRS has a large positive deflection, an R wave, the preceding Q is less than 0.03 sec. in duration, neither notched nor slurred and less than 25 per cent of the amplitude of the following R wave. The range of normal values for the Q wave in leads 3 and AVF may vary considerably from the above values.

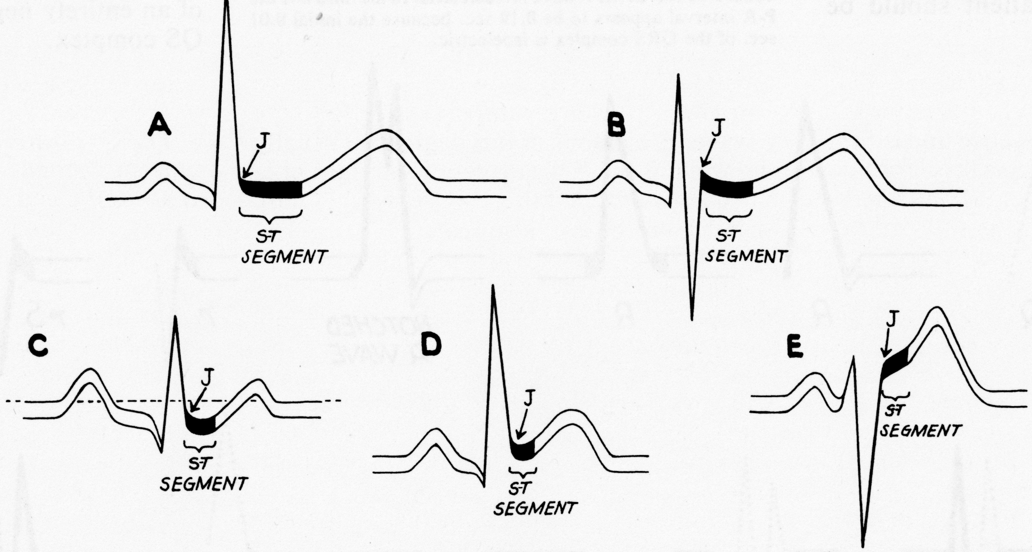

Fig. 1-53. A, The junction (J) between the QRS complex and the S-T segment is isoelectric, as is the S-T segment. B, The J is slightly elevated; the S-T segment is isoelectric. This is a normal variant. C, The J and S-T segment are slightly depressed; the P-R segment is also depressed. This S-T segment depression is within normal limits and is due to the repolarization wave of P (T_a wave). D, The J and the S-T segment are slightly elevated. Note that the S-T segment is concave. This shift of J and S-T is usually within normal limits. E, The J and S-T segment are elevated. The S-T segment is slightly concave. Note the deep S wave and tall upright T associated with the shift of J and S-T. This type of S-T segment displacement is normal in right precordial leads.

Mean Electrical Axis of QRS. The mean electrical axis of QRS normally lies between zero degrees and +90 degrees. The detailed method for calculating the mean electrical axis is presented on pages 6–14.

The S-T Segment. The interval between the end of the QRS complex and the beginning of the T wave is the S-T segment or, in the absence of an S wave, the RS-T segment. For the sake of simplicity this segment will be referred to as the S-T segment throughout this text. The point on the tracing where the QRS ends and the S-T segment begins has been designated as the S-T junction, or simply J (Fig. 1-53A thru E). The J can be identified as that point at which the near vertical slope of QRS is replaced by the more horizontal slope of S-T.

The S-T segment merges imperceptibly with the T wave. The duration of the S-T segment varies with the cardiac rate, the faster the rate, the shorter the S-T segment. The exact length is usually very difficult to measure and has little clinical application.

Elevation or depression of the S-T segment is measured against the isoelectric line, that interval during which there is no net recorded electrical activity. The isoelectric line is first identified. If the T-P segment is level for two or three complexes and no artifacts are present, it may be assumed that the interval between T and P is at the isoelectric line.

The T-P interval may not be isoelectric or it may be absent, as in tachycardia when the P is superimposed on the previous T wave. The P-R segment is then used as the isoelectric line. The P-R segment may, however, be depressed by the T wave of the P (T_a wave) (Fig. 1-53C). This T_a may also result in depression of the J. Therefore, when the T-P interval is absent and the P-R segment is depressed, no true isoelectric line is available for reference and no true measurement of the S-T level can be made. When the T-P segment is isoelectric and the P-R segment is depressed, minimal depression of the J is not abnormal.

The S-T segment is depressed physiologically by increased duration of QRS and steep descent of the activity curve of QRS. The S-T segment also has a tendency to be displaced in the direction of the T wave. In normal hearts the latter tendency predominates.

The S-T segment is usually isoelectric but may, even in the normal, be slightly elevated (Fig. 1-53D) or depressed (Fig. 1-53E).

1. Depression of the S-T segment exceeding 0.5 mm. in L1 and L2 is usually considered abnormal.
2. Depression of the S-T segment of 0.75 mm. is abnormal in any lead except L3.
3. Depression of S-T is most common in L3, especially when the following T wave is low or inverted.
4. Elevation of S-T of less than 1.5 mm. in the limb leads is normal if the following T is tall and upright and especially if S-T is concave. In the presence of a deep S wave and a tall T wave, the S-T segment may be elevated as much as 3.5 mm. and still be normal. This combination is most commonly seen in V2 and V3 (Fig. 1-53E). This S-T upward slope is gradual and merges imperceptibly into the T wave. Elevations of this degree are usually abnormal if the S-T segment is straight or is bowed upward, or if the T wave is only 1 mm. higher than the S-T segment.

When the S-T segment is not isoelectric, its contour is described as being concave, convex, or flat and this shape is always related to the upper border of the segment. S-T depression or elevation can then be related to the elevation or depression of the S-T junction, to the height and direction of the following T wave, and to the preceding ventricular complex.

At times it is difficult to distinguish the normal from the abnormal S-T segment. In doubtful cases, the history, physical examination, and the use of serial electrocardiograms will usually establish the correct diagnosis.

The T Wave. The T wave usually starts near the isoelectric line, having begun imperceptibly in the S-T segment (Fig. 1-46). It rises gradually to its apex and returns to the baseline somewhat more rapidly. It is usually neither notched nor slurred. Its electrical axis lies in the same general direction as that of the QRS, usually within 60 degrees of it (see p. 6). The T wave, therefore, tends to be upright in those leads where QRS is upright and inverted in those where QRS is negative. In the normal it is always upright in L1, usually upright in L2, and often diphasic or inverted in L3. The T wave is usually upright in AVL and AVF, but may occasionally be diphasic or inverted in these leads. It is always inverted in AVR. In the standard limb leads the amplitude of T does not usually exceed 3 mm., although on occasion it may reach 8 mm. The T wave is usually inverted in V1 and upright in the remainder of the V leads. In children and young adults, particularly Negroes, it may normally be inverted as far to the left as V2 and V3 and rarely to V4, becoming less negative across the chest from right to left. The positive T wave in the precordial leads is usually 5 to 7 mm. tall, but may on occasion reach 10 to 18 mm.

The Q-T Interval. The Q-T interval is the time in seconds from the beginning of the QRS to the end of the T wave (Fig. 1-46). It varies with the sex, age, and heart rate. The upper limit of normal is 0.40 sec., at a cardiac rate of 70 beats per minute. It is difficult to accurately measure the Q-T interval, but marked deviations are readily detected.

The U Wave. The U wave is a small rounded deflection which follows the T wave and is best seen in the right precordial leads when the heart rate is slow (Fig. 1-46). Little is known of its clinical significance. It is often difficult to clearly separate the U wave from the T wave. Fusion of the T and U waves may cause the T wave to appear notched and also make it very difficult if not impossible to accurately measure the Q-T interval. When a U wave is present in L1 or L2 or V4 to V6, it is always positive in the normal ECG.

TABLE 1-1.
UPPER LIMITS OF NORMAL VALUES FOR P-R INTERVALS (DURATION IN SECONDS)

	Rate below 70	Rate 71–90	Rate 91–110	Rate 111–130	Rate above 130
Adults	0.20–0.21	0.19–0.20	0.18–0.19	0.17–0.18	0.16–0.17
Children, 7–17 yrs.	0.18–0.19	0.17–0.18	0.16–0.17	0.15–0.16	0.14–0.15
Children up to 7 yrs.	0.16–0.17	0.15–0.165	0.145–0.155	0.135–0.145	0.125–0.135

TABLE 1-2.
CONVERSION CHART: HEART RATE CALCULATED FROM ELECTROCARDIOGRAPH CHART BOXES

No. of 0.2 sec. spaces in R-R interval (large boxes)	No. of 0.04 sec. spaces in R-R interval (small boxes)	Rate per minute
1	5	300
	6	250
	7	214
	8	188
	9	167
2	10	150
	11	136
	12	125
	13	115
	14	107
3	15	100
	16	94
	17	88
	18	84
	19	79
4	20	75
	21	72
	22	68
	23	65
	24	63
5	25	60
	26	58
	27	56
	28	54
	29	52
6	30	50
	31	48
	32	47
	33	45
	34	44
7	35	43
	36	42
	37	41
	38	40
	39	39
8	40	38
9	45	33
10	50	30

CHAPTER 2

Differential Diagnosis of the Arrhythmias

METHOD FOR EXAMINATION OF THE PROBLEM ELECTROCARDIOGRAM WHEN AN ARRHYTHMIA IS PRESENT

By following the method to be described, it is possible to determine the nature of the disturbances in the vast majority of arrhythmias (see Figs. 2-1–2-3):

The electrocardiogram is spread flat on a table. It is inspected for the determination of the presence of normal or abnormal P waves and normal or abnormal QRS complexes. The straight edge of a piece of plain white paper is brought up to the baseline of the ECG complexes. The QRS is identified and a mark made on the paper under the same peak on each of several of the complexes. The P waves, whether normal or abnormal, or replaced by F or f waves, are identified and a smaller mark is made on the measuring paper directly under the same point on each of these waves.

When five or six complexes have thus been identified and their respective points transferred to the paper, the strip is moved to another section of the ECG tracing in the same lead and the marks are then matched with the P waves and the QRS complexes in the new location. From the marks on the strip of paper, it is easily determined whether the atrial rate is regular or irregular and also whether the ventricular rate is regular or irregular. The relation between the P waves and the QRS complexes can also usually be established. When irregularities are present in the ventricular rate, the marks indicating the P waves on the paper will aid in locating the points where an obscured P wave should be present.

The R wave rate is determined from the R-R interval (Table 1-2, p. 24). If the P-R interval is constant, the atrial and ventricular rates are identical. If not, the P wave rate is measured separately. If the R to R interval is irregular, the ventricular rate can be calculated as follows: Average the number of R waves in several different groups of 15 large boxes, and multiply this average figure by 20 to get the rate per minute. If the P to P interval is irregular, the atrial rate can be calculated in a similar manner.

The P-R interval is measured in that lead with the most prominent P waves, usually L2. The measurement is made from the beginning of the P wave to the initial deflection of the QRS. Measure the P-R interval of several successive complexes. Determine if it is constant or inconstant. If it is constant, measure its duration and determine if it is normal or abnormal. If the P-R interval is inconstant, determine whether there is any relationship between P and R by measuring the interval in several successive complexes. Note if there is any pattern in the successive changes of the P-R interval duration.

The rhythm of the P wave is determined by the matching of the P wave marks on the paper strip to a succession of P waves on other parts of the ECG strip. The rhythm may be absolutely regular, it may be slightly irregular, or it may be interrupted by an early or late P wave. Similarly, early or late QRS complexes are readily identified and their relationship to the P rhythm is noted. At this time the P and QRS may also be examined in further detail for any deviation from the normal. The detailed description of the normal P and normal QRS are found elsewhere in the text (see pp. 20 and 21–22).

Atrial activity may appear to be entirely absent for many beats in the ECG. When a P wave cannot be identified, the electrocardiogram is examined to determine if the P is superimposed on the QRS complex, the S-T segment, or the T wave, by comparing these waves with the same segment in other leads or in distant parts of the same lead. If the P wave cannot be identified after careful examination of the 12 lead ECG, it may be necessary to take additional exploratory leads. CR leads, and, in exceptional cases, esophageal or atrial leads, may furnish the desired information. A CR lead is taken by connecting the left arm wire of the patient cable to the chest electrode. The electrocardiogram is recorded in the standard lead 1 position. The other limb lead wires are left in their usual place. The P waves are usually best seen when the CR exploring electrode is over the right side of the chest and in positions higher and further to the right than the standard V1 position.

After a study of the problem electrocardiogram, the reader should determine whether the disturbance in rhythm is due primarily to abnormalities of the P-P, P-R, or R-R intervals. Depending upon which of these is found to deviate most strikingly from the normal, the appropriate portion of the following section is consulted to determine the diagnosis of the arrhythmia. Difficulties in determining the most striking deviation from the normal need not interfere with the use of this section, since the majority of the arrhythmias are cross-referenced under each main heading. If a satisfactory conclusion is not reached in one section, the other section should be consulted.

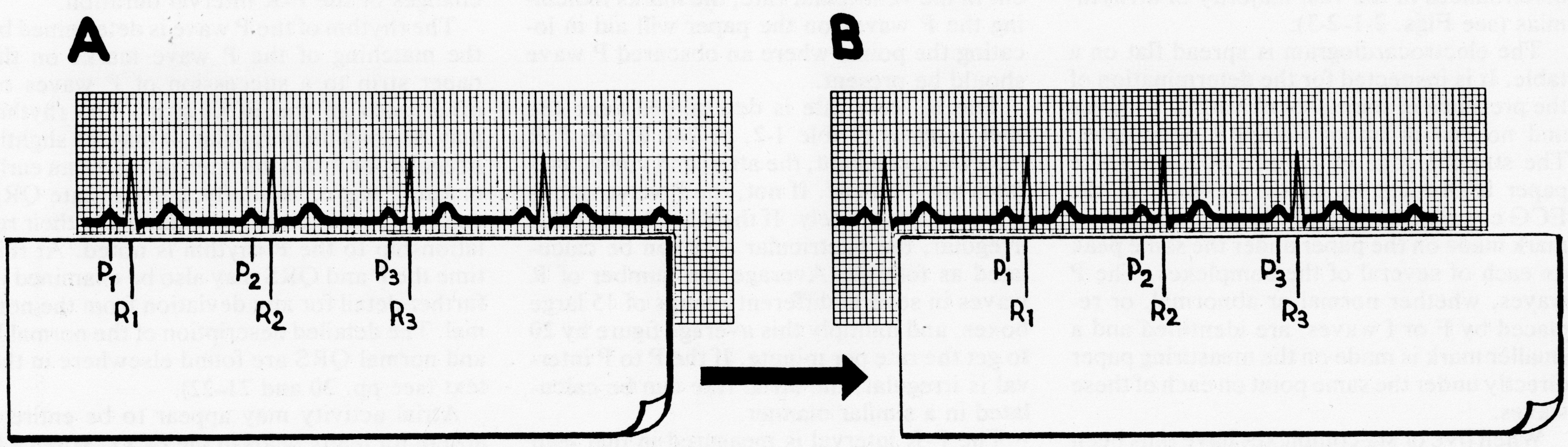

Fig. 2-1. A, A mark has been placed under each of the first three P waves and the first three R waves. B, When the paper is moved one complex to the right, all the P waves match the previous P wave marks, all the R waves match the previous R wave marks, and the new P and QRS match the old P and QRS marks. The P wave is normal, the QRS is normal, the P-R interval is normal, the P-P interval is regular, the R-R interval is regular. Therefore, this is a *regular sinus rhythm*.

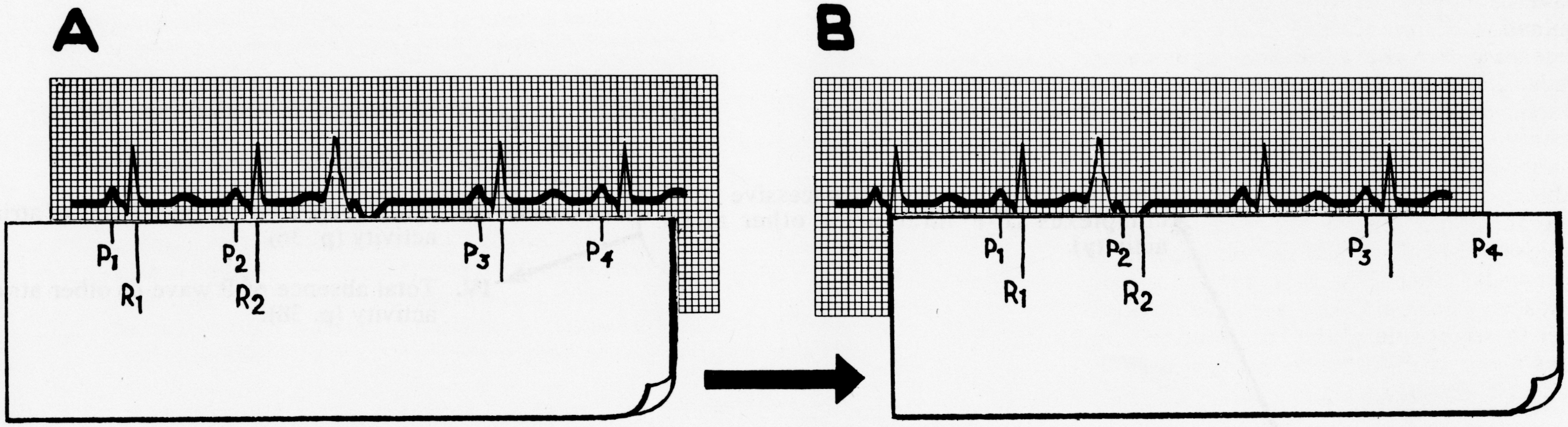

Fig. 2-2. The first two P waves and R waves are marked, the unidentified complex is skipped and the next two P waves are marked. B, When the paper is shifted one complex to the right, the P and the QRS complexes are found to match in the first and third complexes. In the second complex, the P matches but the QRS is (1) early (it precedes the R mark as well as the P wave) and (2) it is abnormal in form (prolonged more than 0.12 sec.). Since the P wave is on time, this is a *premature ventricular contraction*.

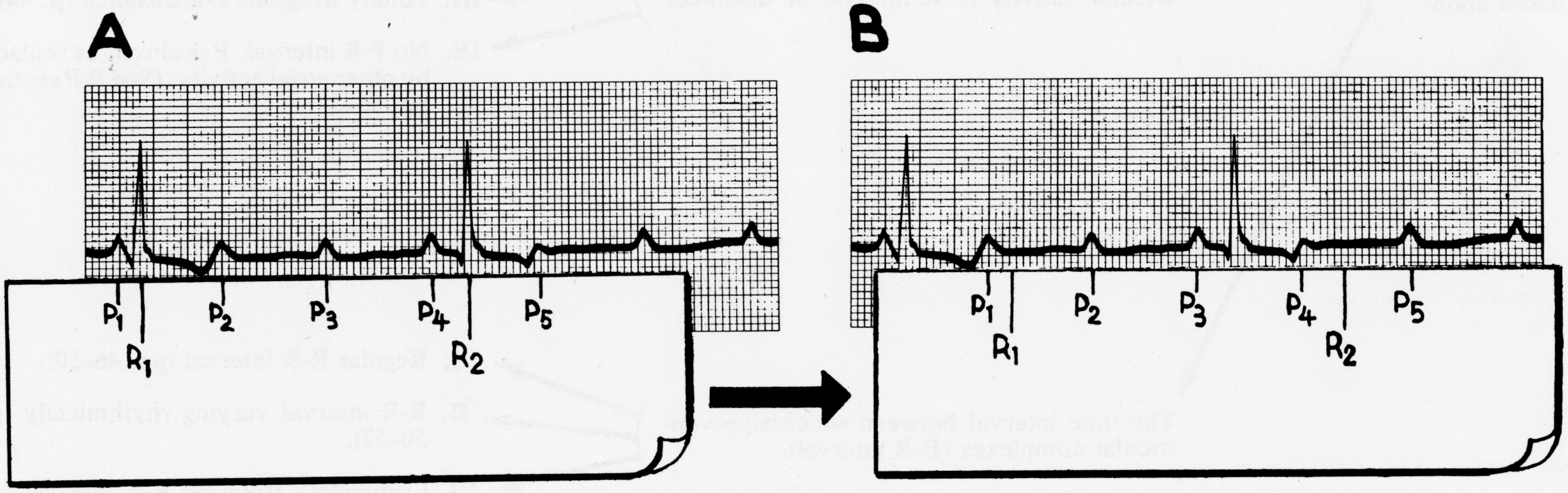

Fig. 2-3. A, A short mark is made under the first five P waves, a long mark under the two R waves. B, When the paper is moved one P complex to the right, the remainder of the P waves match the P wave marks of the previous complexes. Therefore, the P-P interval is constant and the P wave is completely regular. There are, however, no R waves constantly associated with the P marks. The paper is next moved down to where the R1 mark coincides with the second QRS complex. If the electrocardiogram strip were longer, there would then appear a QRS complex over the R2 mark. The R-R interval would therefore be regular, but at a very slow rate and independent of the P wave. The diagnosis is then *complete heart block* with independent atrial and ventricular rhythms. The origin of the ventricular rhythm is determined by the form of the QRS complex.

ARRHYTHMIAS
Diagnoses based upon:

- The time interval between successive atrial complexes (P-P interval or other atrial activity).
  - **I.** Constant P-P interval (pp. 30–34).
  - **II.** Varying P-P interval (pp. 34–36).
  - **III.** P wave replaced by other forms of atrial activity (p. 36).
  - **IV.** Total absence of P wave or other atrial activity (p. 38).
- The time interval between atrial and ventricular activity (P-R interval or distance).
  - **I.** Constant P-R interval (pp. 40–42).
  - **II.** Regularly varying P-R interval (p. 42).
  - **III.** Totally irregular P-R distance (p. 44).
  - **IV.** No P-R interval. P is absent or replaced by other atrial activity. (See P-P section, pp. 36–38).
- The time interval between successive ventricular complexes (R-R interval).
  - **I.** Regular R-R interval (pp. 46–50).
  - **II.** R-R interval varying rhythmically (pp. 50–52).
  - **III.** Completely irregular R-R interval (pp. 52–54).

ARRHYTHMIAS
Diagnoses based upon:

- Occasional interruptions of the regular dominant rhythm.
  - **I.** Dominant rhythm essentially regular, but with intermittent interruptions (pp. 56–60).
  - **II.** Dominant rhythm essentially regular, but rhythm of P and QRS independent of each other, at different rates, and with occasional interruption of the R rhythm (p. 60).
- Occasional disturbances of the irregular dominant rhythm.
  - **I.** Dominant rhythm irregular and with atrial fibrillation (p. 62).
  - **II.** Dominant rhythm irregular but without atrial fibrillation (p. 62).