CHAPTER - 2

REVIEW OF EXPERIMENTAL TECHNIQUES AND LOW ENERGY MEASUREMENTS

2.1 INTRODUCTION

The first experimental determination of atomic pair production cross section was in cloud chamber by Chadwick, Blackett and Occhiallini (Ch-34), who used ThC " source to measure σ for lead. Their result was σ=2.80 barns where as σ_B = 2.54 barns. Zuber (Zu-42) used cloud chamber containing Argon to measure cross section for Argon at the same energy. His result was σ= 0.131 $\pm$ 0.012 barns and σ_B= 0.122 barns.

Later, cloud chamber method has been replaced by other experimental techniques. One method is to measure the total attenuation of photons from which pair production cross section may be evaluated by subtraction of the theoretical values for the competing interactions viz, Compton and photoelectric effect and a number of other corrections. This method is most satisfactory at high energy where pair production phenomenon accounts for a large part of the total attenuation. For lower energy (1-3 Mev) Compton and photoelectric effects are dominating and as pair production cross section decreases very fast with decreasing energy, contribution of pair production events to total attenuation becomes decreasingly small. Also accurate theoretical calculations for photoelectric effect and photon scattering were not available in the sixties and total attenuation measurement method was not very accurate for the extraction of pair production cross section at lower energy.

2.2 Experimental Techniques and Measurements

Total attenuation measurements with photon energy 10 Mev have been made by Davission and Evans (Da-51), Colgate (Co-52), Rosenblum, Shrader and Warner (Ro-52), Paul (Pa-54), Berlett and Donahue (Ba-65), Barkan (Ba-70) Henry and Kennett (He-71) for the extraction of pair production cross section.

The other method is known as direct method where a pair production event may be separated from the Compton and photoelectric interaction by the detection of two .511 Mev photons resulting from the annihilation of the positron of the pair in the target. These photons come out in opposite directions, since nearly all the positrons are slowed down before annihilation. By placing the target on the line between the scintillation detectors one may detect in coincidence a certain fraction of the total number of annihilation quanta. The coincidence technique was first used by Hahn, Baldinger and Huber (Ha-52). Afterwards the method was used by Dayton

(Da-53) Schmid and Huber (Sc-54,55) Staub and Winkler (St-54), Standil and Moore (St-56), Shkolnik and Standil (Sh-57), Standil and Shkolnik (St-58) Rao et al (Ra-63), Henry and Kennett (He-72). Recently, this method has been modified by Avignon~~n~~e and Blankenship (Av-74) who used an internal source to have a spherical symmetry of the target and embedded the source inside the target. Montecarlo Code was used for correction of the data for absorption and scattering of the annihilation as well as incident photons. Subsequently, such measurements have been reported by Girard et al (Gi-78,79). Avignonne et al (Av-81) using a double escape peak pair spectrometer consisting of a 2.44 cm diameter by thick intrinsic planer Ge detector inside a split NaI (Tl) annulus made measurements on Ge at 1.064 Mev relative to pair production cross section at 1.770 Mev on the same target.

Very recently Avignone et al (Av-82) has improved the internal source technique by using the large intrinsic Ge detectors.

An experiment that combines the coincidence method with absorption measurements has been reported by Bak and Weinzirl (Ba-66).

A modification of the coincidence method is the three crystal scintillation pair spectrometer method which was used by Griffiths and Warren (Gr-52), West (We-56), Singh, Dosso and Griffiths (Si-59), Huck (Hu-64,65), Yamazaki (Ya-65, 80), and Coquette (Coq-77,80), Euyo et al (Eu-80) . This method consists in observing the energy distribution of the created pairs. The total pair production cross section is obtained by integrating over the energy distribution. Usually a thin target is bombarded with photons having energy above threshold for pair production and the resulting pairs escaping from the radiator with forward momenta are subjected to a homogenous magnetic field and energies determined from radii measurement. The main advantage of the method is that one may use sources with cascade γ -rays and measure the cross section for each energy. Also the efficiency is greater particularly at low energy where the cross section is small. However the method is restricted for those targets only which can be used as scintillators. In the type of experiments referred to above use has been made of NaI (Tl), NaI (Thl), Ge(Li) and Anthracene.

?

Barkan (Ba-54,56) and Titus and Levy (Ti-66) have used β -ray spectrometer obtaining pair production cross section in terms of differential compton scattering cross section at the same photon energy.

Finally Garitson (Ga-68) and Piowaty (Pi-69) have used a technique involving bremsstrahlung produced by electrons from an accelerator. The post bremsstrahlung electrons are energy analysed and focused on an electron detector. The pulses from this detector are used to gate the output of a NaI (Tl) photon detector which is thereby made to count .511 Mev annihilation quanta from the positrons.

2.3 Comparison of the results of differant experiments

Although different experimental techniques have been used by various authors, many of the experiments have used photon sources of same energy and same target material for determination of the pair production cross section. An analysis of the results of different experiments on common targets at the same photon energy reveal wide variation in the measured results and no general agreement with any theoretical calculation could be found. Experimental results some times favouring one or the other theoretical calculations are inconsistent with each other. As it is easier to compare the experimental results in terms of Born approximation cross section, we have tabulated the different experimental results relative to

Born approximation cross section in table 2.1. Also the theoretical cross sections by different authors that are available at present have been displayed in Fig. 2.1 - 2.3 relative to Born approximation results along with experimental values for three most commonly used targets i.e. copper, tin and lead. It appears from the table and also from the graph that some sort of systematic errors must have been inherent in these experimental measurements resulting in the inconsistancy in the results Mutual disagreement between the results of different authors are now understandable because of various corrections and assumptions which were made in the reduction of the data.

2.4 Proposed Method

2.4.1 In view of the mutual disagreement between the results of different experiments and inconsistencies in the data, and in the light of the new theoretical calculations which have been discussed in Chapter II, it is thought desirable to perform precise experiments to test the results of new calculations. Since the disagreement is more prominent at lower energy region near threshold it is apparent that uncertainties and sources

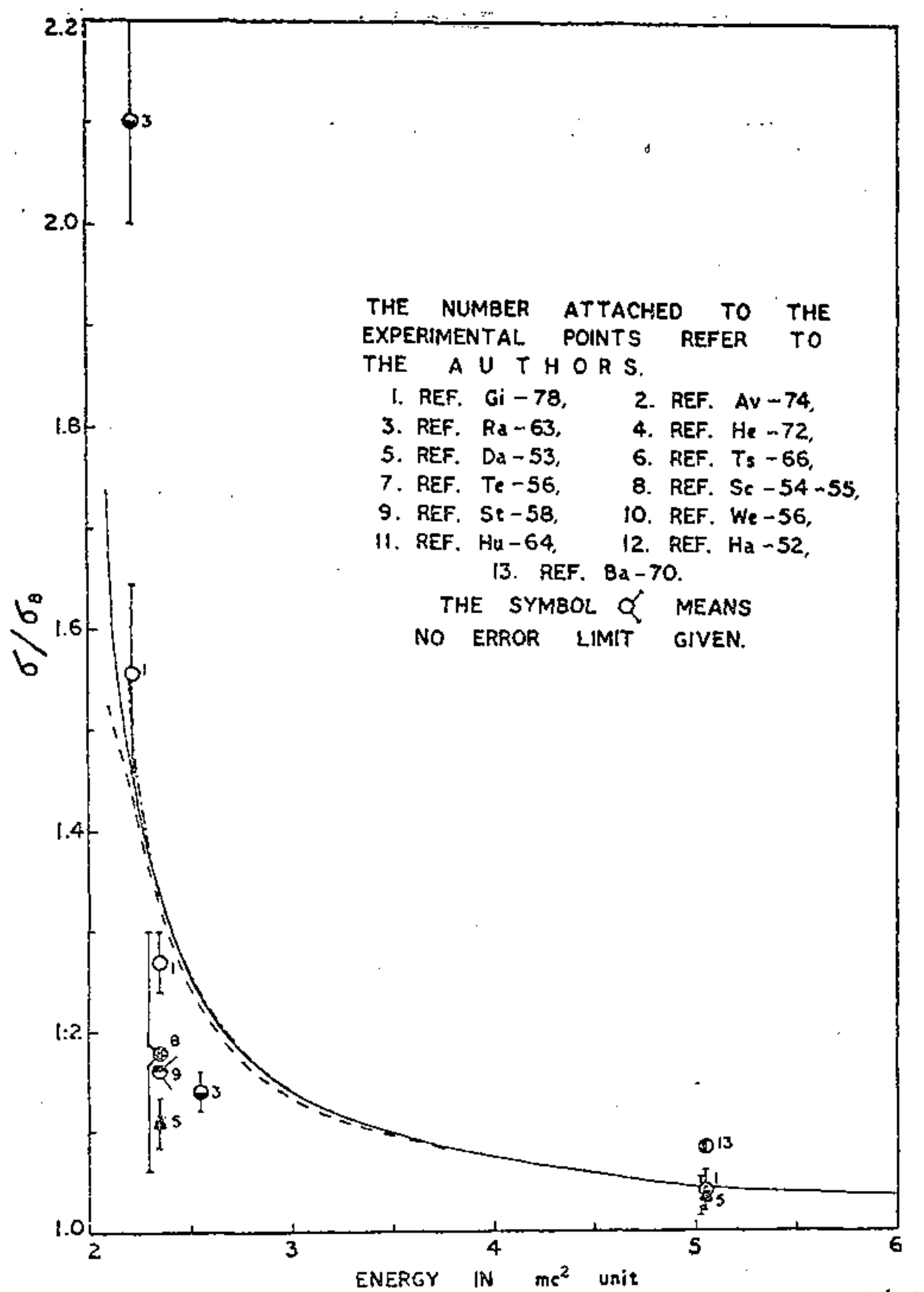

FIG. 2.1. COMPARISON BETWEEN THE RATIOS σ/σ_B ACCORDING TO DIFFERENT THEORETICAL CALCULATIONS & EXPERIMENTS FOR COPPER ($Z = 29$). – – – – σ/σ_B Øverbo REF. (Øo – 67), ——— σ/σ_B Tseng Pratt REF. (Ts – 72) AND –·–·–·– σ/σ_B Øverbo REF. (Øo – 79).

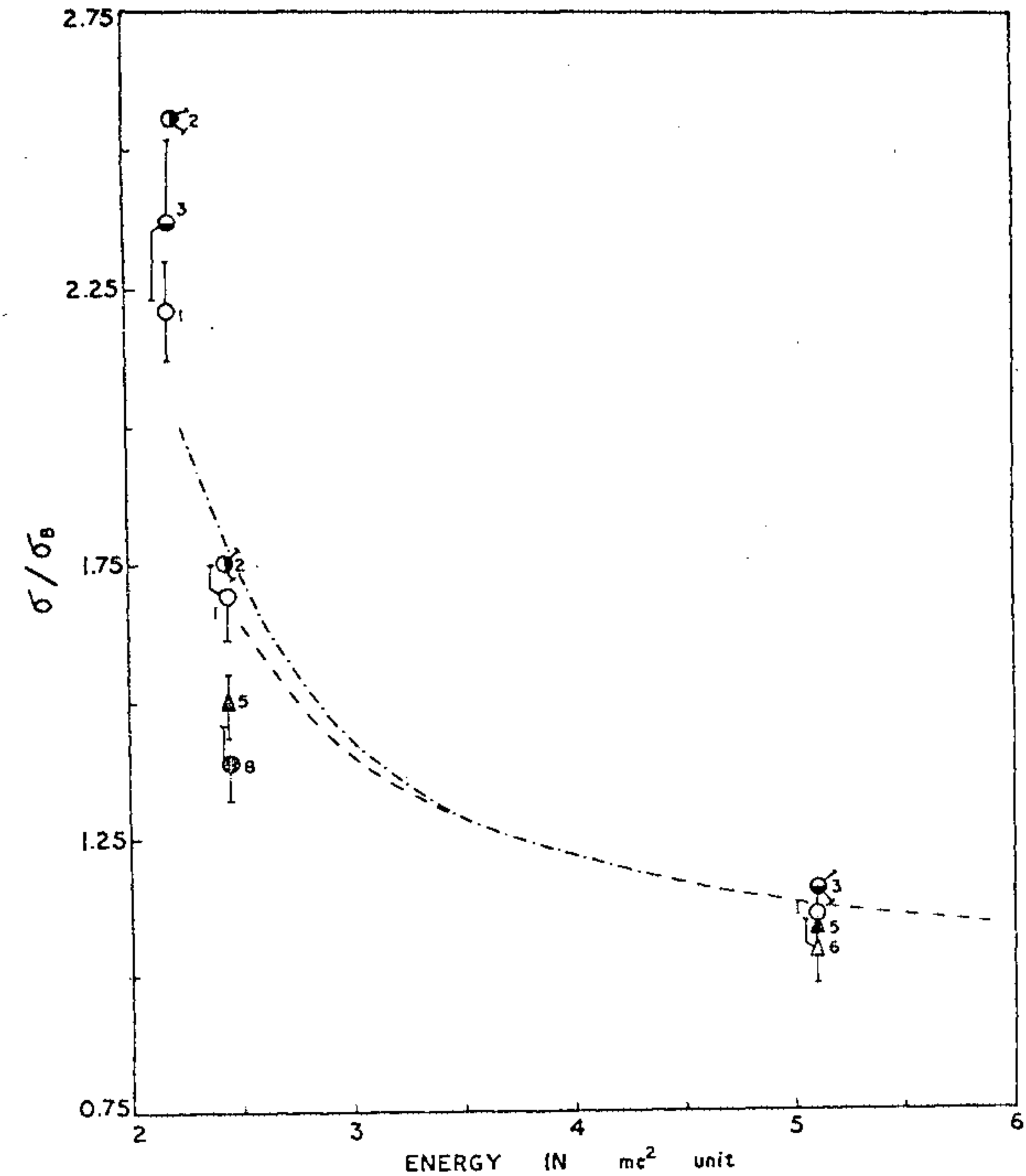

FIG. 2.2. SAME AS IN FIG. 2.1 WITH Z = 50.

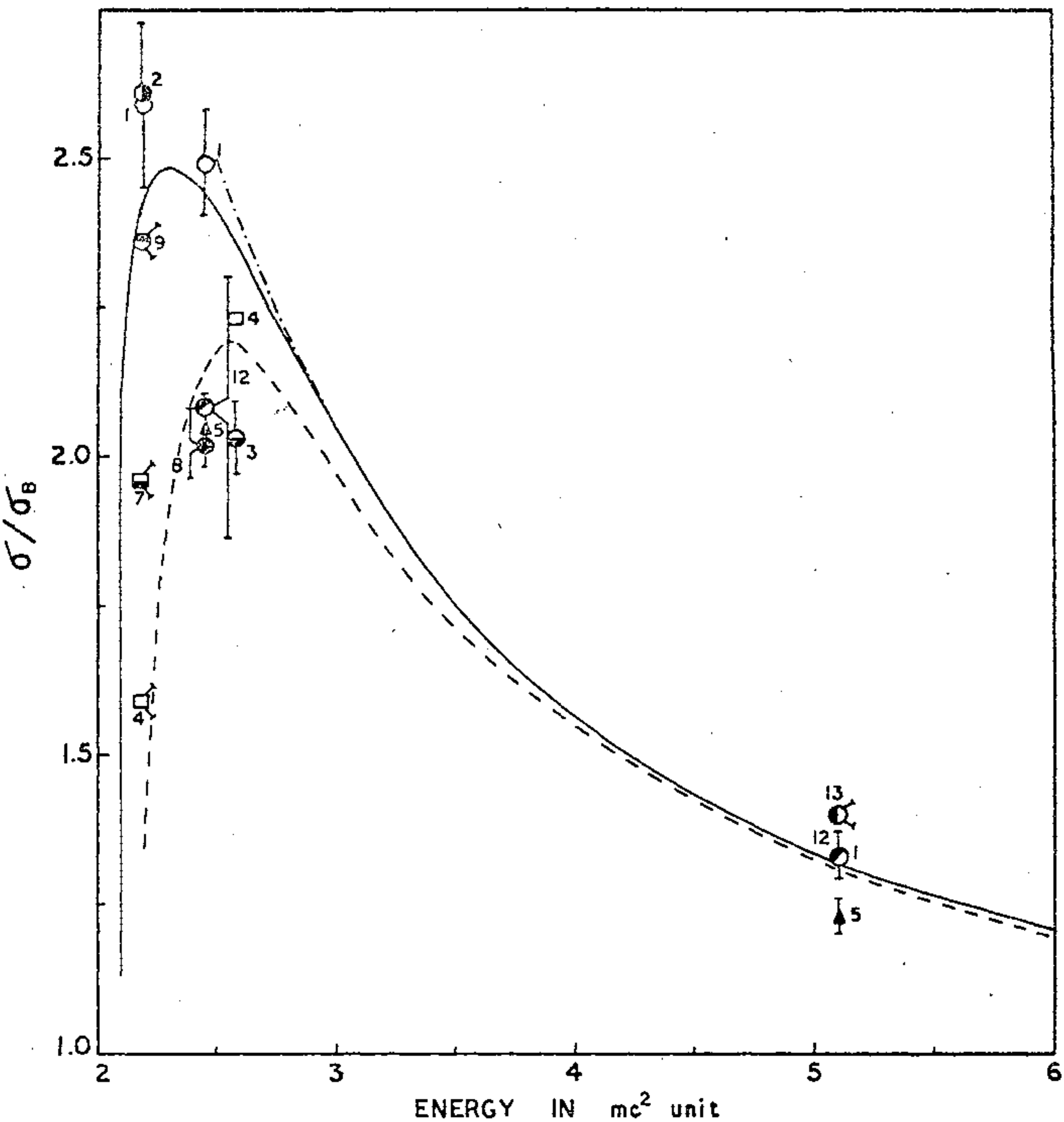

FIG. 2.3. SAME AS IN FIG. 2.1 WITH Z = 82.

Table - 2.1

Comparison of the Measured Pair Production cross section by different authors using different techniques.

Photon energy in Mev	Target atomic number	σ_1/σ_B	σ_2/σ_B	σ_3/σ_B	σ_4/σ_B	σ_5/σ_B	σ_6/σ_B	σ_7/σ_B	σ_8/σ_B	σ_9/σ_B	σ_{10}/σ_B	σ_{11}/σ_B	σ_{12}/σ_B	σ_{13}/σ_B	σ_{14}/σ_B
1.119	29	1.54±.05	1.56±.09		2.10±.12										
	50	1.97±.07	2.21±.009	2.56	2.37±.14										
	82	2.237±.08	2.59±.14			1.59±.16			1.96		2.36				
	92	2.183±.07	2.435±.07												
	13		1.26±.06				.997±.05				1.04				
1.173	26	1.19±.05	1.21±.05								1.10				
1.332	29	1.237±.04	1.27±.06				1.111±.05			1.18±.12	1.16				
	50	1.622±.07	1.69±.08	1.75			1.49±.06			1.38±.07					
	82	2.36±.07	2.49±.09				2.04±.06			2.02±.06				2.08±.22	
	92	2.573±.098													
	29				1.14	1.14±.09									
1.332	53											1.46±.04	1.29±.09		
	82				2.23	2.04±.06									

Table - 2.1 (Contd..)

Photon energy in Mev	Target atomic number	σ_1/σ_B	σ_2/σ_B	σ_3/σ_B	σ_4/σ_B	σ_5/σ_B	σ_6/σ_B	σ_7/σ_B	σ_8/σ_B	σ_9/σ_B	σ_{10}/σ_B	σ_{11}/σ_B	σ_{12}/σ_B	σ_{13}/σ_B	σ_{14}/σ_B
	13		1.02±.05				1.006 ±.002								1.008
2.615	29	1.032±.03	1.04±.04				1.03±.02								1.085
	50	1.116±.02	1.11±.04	1.16			1.08±.02		1.04 ±.06						
	82	1.315±.02	1.33±.04				1.229 ±.03							1.33±.03	1.40
	92	1.363±.03	1.33±.04												

σ_B- Born approximation cross section, 1-Avignone et al (Av-82), 2-Girard et al (Gi-78), 3-Avignone et al (Av-74), 4- Rao et al (Ra-63), 5-Henry and Kennett (He-72), 6-Dayton (Da-53), 7-Titus and Levy (Ti-66), 8-Jenkins (Je-56), 9-Schmidt et al (Sc-54,55), 10 -Standil et al (St - 58), 11-West (We-56), 12-Huck (Hu-64), 13- Hahn et al (Ha-52) 14-Barkan (Ba-70).

of errors are very difficult to eliminate in the low energy region. It is therefore desirable to make relative measurements at low energy, since it is easier to perform relative measurements avoiding the determination of various factors that lead to uncertainty and errors in the measurement. A relative measurement means comparing the counting rate for a target with the counting rate of a standard target in identical geometry for which pair production cross section must be known very accurately. As shown in table a.5 Born approximation gives almost correct result for light elements at lower energy region, but trident production and incoherent pair production events contribute significantly for small Z at low energy. None of these effects are very well known theoretically. Also the counting rates will be very small because pair production cross section is small for low Z elements at low energy. So the standard target should be of intermediate Z because this will give larger counting rates and the effect of trident production and incoherent pair production will be insignificant (MO-69). Also while recording the coincidence of two .511 Mev photons resulting from the annihilation of positron, false and accidental coincidences may give rise to significant error in the measurement if the resolving time of the coincident circuit is high. So in order to keep the error resulting from the finite resolving time of the coincidence circuit to a minimum, the coincident circuit should have a low resolving time.

In Chapter III a coincidence circuit having a resolving time of 40 ns designed to record the annihilation of positrons for making measurements of pair production cross section has been described. The standard target selected for making measurements is copper.

2.4.2 Total cross section measurement

Again, pair production cross section can be extracted to a very high degree of accuracy from attenuation measurement provided the cross sections for the competing interactions are known accurately. Recent accurate calculation of photo electric cross section (Sc-73) and coherent -incoherent scattering has provided an opportunity to extract pair production cross section from the measured total cross section which was not possible in the sixties due to lack of accurate calculations of these cross sections.

In view of new calculation it is also desirable to reanalyse all the total cross section measurement results which were intended for extraction of pair production cross section. In Chapter IV the present total cross section measurements have been described. Extracted pair production cross sections from the measured total cross section has been compared with recent theoretical calculations and with results of some of the direct experiments. Some of the existing accurate total cross section data have been reanalysed and pair production cross sections have been extracted. The reanalysed results have been compared with theoretical calculations.