Study of Cosmic Ray Produced Short-Lived P^{32}, P^{33}, Be^7, and S^{35} in Tropical Latitudes

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Abstract

The fall-out rate of four short-lived isotopes P^{32}, P^{33}, Be^7 and S^{35}, produced in the collisions of cosmic ray particles with air nuclei, has been measured at a number of stations in India and compared with the calculated rate of production. In the case of Be^7, the agreement between the calculated and measured values is good. The fall-out rates of P^{32} and P^{33} are not inconsistent with the calculated values; that of S^{35}, however, is about five times higher than expected.

The absolute concentrations of an individual isotope in various rain falls have been found to vary by more than a factor of forty; relative concentrations of the different isotopes, however, stayed within fairly narrow limits. The ratio of the concentration of the isotope Be^7 to that of the isotope P^{32} in individual rain samples has been used to find out the periods for which various air masses had been irradiated in the interval between two successive precipitations. The mean period of irradiation is found to be about thirty-five days.

Our results are consistent with the view that, in these tropical latitudes, intrusions of stratospheric air into the troposphere are either rare or weak in intensity.

The method seems capable of further development as a tool for studying meteorological problems.

Introduction

Cosmic rays, in their passage through the atmosphere, collide with the nuclei of air and produce a number of radio-isotopes. Some of these, which have half-lives suitable for studying short and long term large scale air circulation in the atmosphere, have been discovered in rain water. They are:

P^{32} (14 d, 1.7 MeV β^-)
(MARQUEZ and COSTA, 1955)
P^{33} (25 d, 0.25 MeV β^-)
(LAL, NARASAPPAYA and ZUTSHI, 1956)
Be^7 (53 d, 0.48 MeV γ)
(ARNOLD and AL-SALIH, 1955; GOEL et al 1956)
S^{35} (87 d, 0.17 MeV β^-)
(GOEL, 1956)
Na^{22} (2.6 y, 0.54 MeV β^+, 1.3 MeV γ)
(MARQUEZ, COSTA and ALMEIDA, 1957)
H^3 (12.5 y, 18 KeV β^-)
(FALTINGS and HARTECK, 1950)

Their production rates are strongly dependent on latitude and altitude but are independent of time. They can, therefore, be used as tracers of the movements of air masses. In fact it could even be useful to define an air mass by its content of cosmic ray produced radio-activity.

For the present we have confined ourselves to the study of the four short-lived isotopes P^{32}, P^{33}, Be^7 and S^{35}.

In this paper we present:

1. Their annual deposition rates at a number of stations in India, (from 10° N to 34° N geographic latitudes).

2. Their relative concentrations in some individual rains.

By comparing the observed and calculated fall-out rates of these isotopes we infer that no significant fraction of P^{32}, P^{33} and Be^{7} fall-outs could be bomb-produced. However, the possibility of an appreciable contribution to S^{35} fall-out by nuclear explosions, whilst unlikely, cannot be ruled out; this possibility is discussed later in this paper.

As a means of exploring theories of the cellular structure of the troposphere, (from a study of the intrusion of stratospheric air into it), as also for investigating the nature of mixing processes in the stratosphere, we believe that measurements of this kind, if conducted in the middle and polar latitudes, could yield important information.

Experimental

The experimental procedure consists in extracting the elements sulphur, phosphorus and beryllium from rain water by chemical procedures and measuring their disintegration rates. The details are given in the appendix.

Results

In Table I we present the concentrations, (number of atoms ml^{-1}), of the various isotopes in rain water. In order to check the self consistency of the measurements, we sometimes prepared two or more samples from the same homogenized rain water. These results are also included in Table I.

The errors shown in Table I are the statistical errors of counting expressed as a standard deviation. It can be seen that the Be^{7}, P^{32} and S^{35} measurements are accurate to about ten per cent. The error in the measurement of P^{33} is fairly large, because the observed counting rate for the P^{33} activity was small and was measured in the presence of a comparatively large number of counts due to P^{32}.

If we consider the errors due to other factors such as non-uniformity of source deposition, determination of chemical efficiency, correction for absorption etc., we estimate that the overall error in the determination of the ratios Be^{7}/P^{32} and Be^{7}/S^{35} is in most cases $\sim$ 20 %; while the S^{35}/P^{32} ratios may be in error by $\sim$ 30 %. The errors in the P^{33}/P^{32} ratio might be as high as fifty per cent. Apart from these errors there may exist a systematic error of $\sim$ 20 % in the concentrations of P^{32}, P^{33} and S^{35} isotopes.

These errors were estimated by observations on a number of samples derived from the same homogenized rain water.

Discussion

Though the present measurements are not yet very precise, they clearly exhibit certain general features:

1. The absolute concentrations of any individual isotope may vary by more than a factor of forty in different rain samples; but the relative concentrations of different isotopes stay within comparatively narrow limits and have similar values at all stations.

2. The average concentrations, (obtained from measurements made over a period of five months), of the isotopes at Shillong is about four times smaller than at other stations. This can perhaps be attributed to the fact that the region around Shillong has one of the highest recorded rain falls in the world.

All of our rain collecting stations were situated in the latitude belt from 10° N to 34° N, (geographic). In order to estimate the annual deposition rates of the various isotopes we proceed as follows:

(a) We first find out the average concentration of each isotope in rain water. The average for each of the isotopes Be^{7} and S^{35} is obtained from all the measured concentrations at all stations, (except Shillong[1]). In case of Be^{7} we have included the data obtained in 1956 at Bombay and Kodaikanal, (RAMA THOR and ZUTSHI, 1958). For P^{32} and P^{33}, we have used the data from Bombay only, since the measurement of these isotopes at other stations is uncertain by one factor of about two.

(b) We multiply the average concentration of each isotope by 99, which is the average annual rainfall, in cms., in our latitude belt, (BROOKS and HUNT, 1932). This is assumed to lead to an estimate of the average deposition

[1] The data from Shillong are excluded because of the abnormal rainfall in that region.

Table 1

No.	Date	Atoms/ml			Ratios			Remarks
		Be^7	P^{32}	S^{35}	Be^7/P^{32}	S^{35}/P^{32}	P^{33}/P^{32}	
				BOMBAY				
		Latitude 19° N		Longitude 73° E		Height-Oft. above sea level		
1.	25.5.57	130±100						
2.	22.6.57	1,750±100						
3.	23.6.57	2,000±150						
4.	28.6.57	3,900±200						10-00 to 12-00 hrs.
5.	28.6.57	1,400±100						12-30 to 13-30 hrs.
6.	30.6.57	2,600±200						
7.	5.7.57	1,700±100						09-15 to 09-45 hrs.
8.	5.7.57	6,200±300						10-00 to 12-00 hrs.
9.	5.7.57	3,300±150						12-00 to 14-00 hrs.
10.	6.7.57	2,500±100						
11.	13.7.57	5,900±200						
	(a)	9,000±500					1.5	
12.	20.7.57		44±2.5	690±100	207±16	15.7±2.5		Homogenised rain water
	(b)	9,200±500					1.8	
	(a)	5,700±250					2.1	
13.	22.7.57		26±1	690±160	220±12	26.5±6.1		—Do—
	(b)	5,750±250					2.1	
	(a)	3,500±250						
14.	26.7.57		36±4	—	95±12	—	2.4	—Do—
	(b)	3,200±250						
	(a)	2,800±200						
15.	5.8.57							—Do—
	(b)	2,500±200						
	(a)	3,400±200					1.4	
16.	6.8.57		32±1		110±7			—Do—
	(b)	3,600±200					1.8	
	(a)	3,000±200						—Do—
17.	7.8.57							
	(b)	2,800±200						
	(a)	5,000±250						
18.	11.8.57		32±2		160±7		1.9	—Do—
	(b)	5,400±250						
	(a)	5,900±700						
19.	16.8.57		19±2		290±15			—Do—
	(b)	5,400±400						
	(a)	2,700±150						
20.	18.8.57		18±1		140±12		2.2	—Do—
	(b)	2,400±150						
	(a)	3,300±250						
21.	20.8.57 (b)	3,100±250	26±2		130±20		2.2	—Do—
	(c)	3,200±200	22±2					
	(a)	3,500±250						
22.	22.8.57		26±1		130±20			—Do—
	(b)	3,100±600						
	(a)	2,300±150						
23.	10.11.57		13±1		180±30		2.8	—Do—
	(b)	2,400±150						
	(a)	1,700±200	18±1					
	(b)	1,800±200	21±1	130±15				
24.	11.11.57							—Do—
	(c)	1,900±200	17±2	110±15	95±10	6±.5	2.1	
	(d)	—	19±1					
	Average	3,400	25	500				

Table 1 (cont.)

No.	Date	Atoms/ml			Ratios			Remarks
		Be^7	P^{32}	S^{35}	Be^7/P^{32}	S^{35}/p^{32}	P^{33}/P^{32}	
		KODAI-KANAL						
		Latitude 10° N	Longitude 77° E		Height 7,700 ft. above sea level			
1.	1.2.57	650±300						
2.	4.3.57	2,200±400						
3.	13.4.57	3,800±200						
4.	14.5.57	3,300±200						
5.	8.6.57	1,800±200						
6.	26.6.57	2,800±150						
7.	4.7.57	700±100						
8.	25.8.57	1,300±100	5—9		130—280			
9.	28.9.57	2,000±100						
10.	6.10.57	2,300±100						
11.	4.11.57	400±100						
12.	10.11.57	2,500±100	20—40	124±15	60—130	3—7		
13.	14.11.57	850±100		20±10				
14.	28.11.57	1,800±200	15—30	220±100	55—135	4—22		
15.	4.12.57	1,300±150						
16.	18.12.57	1,100±100						
	Average	1,900	10—20	120				
		SHILLONG						
		Latitude 25° N	Longitude 91° E		Height 4,900 ft. above sea level			
1.	4.6.57	3,000±150		225—25				
2.	7.6.57	3,800±300						
3.	23.6.57	1,200±150						
4.	4.7.57	700±100						
5.	11.7.57	430±100						
6.	2.8.57	530±300						
7.	4.8.57	150±100	0±2					
8.	29.8.57	720±70	2.5—5		130—310			
9.	5.9.57	780±90	2—5		140—435			
10.	7.9.57	270±100	2—4		42—185			
11.	26.9.57	350±100						
12.	26.9.57	260±100						
13.	5.10.57	165±165						
14.	6.10.57	50±150						
15.	11.10.57	1,100±100						
16.	12.10.57	2,800±200						
	Average	1,020	2—4	225				
		MUSSOORIE						
		Latitude 30° N	Longitude 78° E		Height 7,000 ft. above sea level			
1.	1.6.57	3,900±100						
2.	10.7.57	2,600±100						
3.	11.8.57	2,300±100	7—18		125—340			
4.	31.8.57	1,500±100	6—13		110—265			
5.	13.9.57	600±100	2—10		50—350			
6.	12.10.57	6,400±200						
7.	20.11.57	5,000±300	11—25	275+30	190—480	9—28	3.1	
8.	12.12.57	2,800±250		(350±100)				
	Average	3,100	7—17	310				

Table 1 (cont.)

No.	Date	Atoms/ml			Ratios			Remarks
		Be^7	P^{32}	S^{35}	Be^7/P^{32}	S^{35}/P^{32}	P^{33}/P^{32}	
				DELHI				
	Latitude 29° N		Longitude 77° E			Height (above sea level) 720 ft.		
1.	20.11.57	7,100±300	37—70	260±100	100—200	2.5—10	2.8	
2.	11.12.57	2,300±550		160±15				
3.	28.1.58	1,450±400						
	Average	3,900	37—70	210				
				PATHANKOT				
	Latitude 32° N		Longitude 73° E			Height (above sea level) 1,000 ft.		
1.	20.11.57	9,500±500	60—150	460—50	60—170	3—8	1.3	
2.	7.12.57	7,400±400		590±60				
3.	11.12.57	3,400±300	17—60	170±20	50—220	2.5—11		
	Average	6,800	37—100	410				
				SRINAGAR				
	Latitude 34°		Longitude 74° E			Height (above sea level) 5,200 ft.		
1.	20.11.57	3,600±300	30—60	245±15	55—130	4—9	2.3	
2.	24.11.57	1,160±250						
3.	2.12.57	5,500±500		420±70				
4.	5.12.57	5,700±300	36—50		110—170			
5.	11.12.57	6,300±400	40—60		100—170		1.6	
	Average	4,500	35—57	330				

rates of the various isotopes. We list them in Table II.

The expected fall-out rates of these isotopes on the earth's surface have been estimated (PETERS 1958 and LAL, MALHOTRA and PETERS 1958) on the basis of the following assumptions.

1. The fall-out of the cosmic ray produced short-lived isotopes derives mainly from their tropospheric production. In view of the long residence time in the stratosphere, the stratospheric contribution to their fall-out should be negligible.

2. There exists good vertical mixing in the troposphere.

3. The mean removal period of the activity from the troposphere is about thirty days, (STEWART ET AL., 1957). We list their estimates for the tropical latitudes together with the measured fall-out rates in Table II.

The experimental and calculated deposition rates for Be^7 are in good agreement. There is a discrepancy between the observed and calculated fall-out rates of P^{32} and P^{33}. But this discrepancy may still be within the errors of calculation and measurement. The deposition rate of S^{35}, however, is considerably larger, ($\sim$ one factor of 5), than the calculated one and cannot easily be accounted for. This discrepancy can perhaps be explained if one assumes that the nuclear test explosions contribute sufficiently to S^{35} fall-out. If that be the case, the ratio of bomb-produced S^{35} to

Table 2

ISOTOPE	P^{32}	P^{33}	Be^7	S^{35}
Atoms ml^{-1} of rain water (average) ...	26	55	3,400	316
Deposition rate, atoms cm^{-2} yr^{-1} in the Tropical Latitudes.....	2,600	5,500	3.4×10^5	31,000
Calculated deposition rate, atoms cm^{-2} yr^{-1} in the Tropical Latitudes.	1,650	2,400	4.7×10^5	6,200

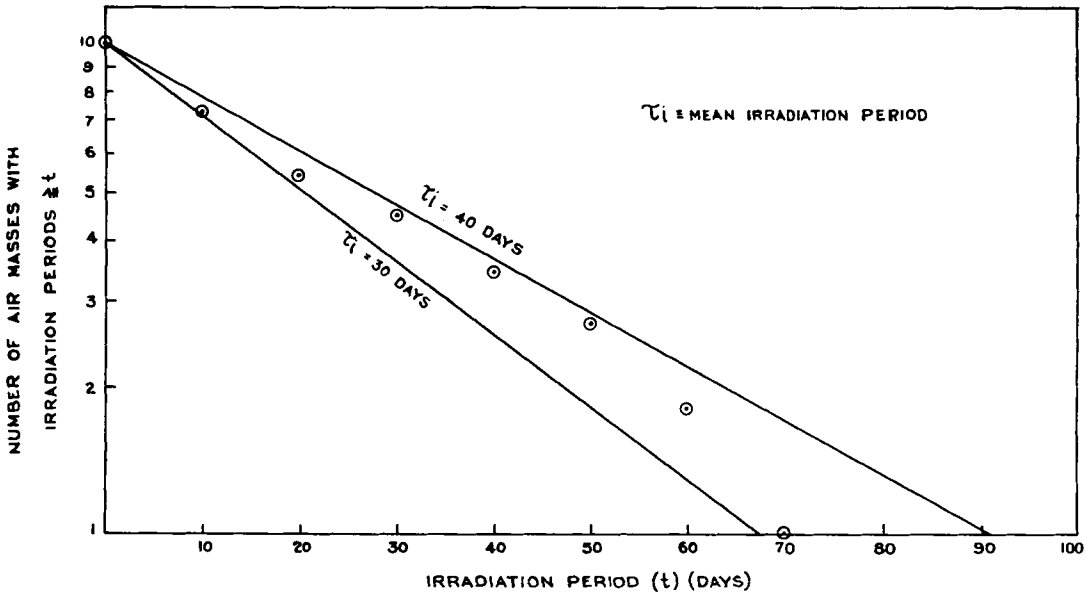

FIG.1 INTEGRAL DISTRIBUTION OF IRRADIATION-PERIODS OF AIR MASSES.

Fig. 1.

Be^7, (which is not bomb-produced), (RAMA THOR and ZUTSHI, 1958), should shoot up to very high values just after the explosions. The observed fluctuations of the S^{35}/Be^7 ratio are, however, rather small, (Table I). This argument, nevertheless, does not entirely rule out the possibility of bomb-produced S^{35} in fall-out; there may exist a large reservoir of bomb-produced S^{35} in the stratosphere from where it may be leaking into the troposphere at an approximately constant rate. In that case no large fluctuations in the S^{35}/Be^7 ratio would occur.

There is of course the possibility that the production rate of S^{35} by cosmic rays has been underestimated; this requires a mechanism which leads to the preferential production of S^{35} as compared to the other isotopes.

It has been shown earlier, (RAMA THOR and ZUTSHI, 1958), that the fall-out of cosmic ray produced Be^7 in the tropical latitudes derives mainly from its tropospheric production, and that the contribution from the stratosphere is not appreciable. The same should be true for the cosmic ray produced P^{32}, P^{33} and S^{35} isotopes as well. Our present investigations are consistent with this view.

The most accurate among our measurements of relative concentrations of various isotopes is that of Be^7 to P^{32} at Bombay. From Table I, we see that this ratio varies from 100 to 300 in different rain samples. We believe that this variation cannot arise from errors in measurements and must be genuine. If we assume that this variation is not caused by the differences in the precipitation mechanisms of Be^7 and P^{32}, then each observed Be^7/P^{32} ratio in rain water can be taken to represent the actual Be^7/P^{32} ratio in the air mass from which the rainfall resulted. We may, therefore, say that the Be^7/P^{32} ratio has varied from 100 to 300 in individual air masses studied by us.

Since, the relative rates of production of Be^7 and P^{32} in the atmosphere are constant and P^{32} has a shorter half-life than Be^7, the ratio Be^7/P^{32} will increase with time and may be taken as a measure of the irradiation period of an air mass, between two successive precipitations.

We now assume that the lowest experimental ratio of 100 for Be^7/P^{32}, (Table I), represents the ratio of their production rates. In other words, an air mass will have Be^7/P^{32} ratio equal to 100 soon after ridding itself of its previous radio-activity by rainfall. This ratio will increase with the time of irradiation and will approach a value $100 \times \tau_{Be^7}/\tau_{P^{32}} = 380$[1].

We have attempted to find out the irradia-

tion periods of various air masses from the experimental Be^7/P^{32} ratios. The integral distribution of these periods is plotted in Fig. 1, and corresponds to a mean irradiation period of about thirty-five days, which agrees well with the wash-out period of thirty days, (STEWART ET AL., 1957), in the troposphere.

Since the stratospheric air is expected to receive irradiation for very long periods, its Be^7/P^{32} ratio should be about 380[2]. If such air descends to the troposphere, this ratio should increase still further, (LAL, MALHOTRA and PETERS, 1958). The fact that we never observe such high ratios shows that the intrusions of stratospheric air into the troposphere of the tropical latitudes are either rare or very weak in intensity.

Conclusion

1. The measured fall-out rates in wet precipitation in tropical latitudes of the cosmic ray produced isotopes Be^7, P^{32}, P^{33} and S^{35} have been compared with their calculated values. We find that the measured and calculated fall-out rates agree well in the case of Be^7 and are not inconsistent in the case of P^{32} and P^{33}; whilst the observed fall-out rate of S^{35} is considerably in excess of the calculated value, by one factor of about five.

2. The Be^7/P^{32} ratios have been used to find out the periods of irradiation of various air masses by cosmic rays. Their observed distribution indicates a mean irradiation period of about thirty-five days, between two successive precipitations.

3. The absence of very high values, ($\sim$380) of the Be^7/P^{32} ratio among the measured ones has been taken as indicating that air masses having predominantly stratospheric air are either absent or rare, below the cloud forming altitudes, in the tropics.

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[1] This value will be reached only after infinite time. It will take about 300 days of irradiation to reach 95 % of this value.

[2] This value will be proportionately lowered to the extent the ratio Be^7/P^{32}, at production, is less than 100.

APPENDIX

The experimental procedure

The experimental procedure is described under the following three sub-heads:

I. Chemical extraction of the isotopes from rain water.
II. Determination of extraction efficiencies.
III. Measurement of disintegration rates.

I. *Chemical Extraction of the Isotopes from Rain Water:*

The methods for extracting phosphorus, beryllium and sulphur activities from rain water have been described in earlier papers by MARQUEZ and COSTA, 1955, RAMA THOR and ZUTSHI, 1958 and GOEL, 1956; respectively.

In rain water there always exists some dust which may collect some of the activities at the natural pH of rain water. Therefore, the pH of rain water was adjusted to 2. At this pH all the four isotopes go into solution and no significant fraction remains absorbed either on dust or on the containers. The dust filtered from water at pH 2 was checked and found to be completely free of beryllium, sulphur and phosphorus activities.

A schematic representation of the chemical procedure adopted is given below.

The radio-chemical purity of the final samples was checked by measuring their specific activities after repeating the purifications as follows:

(a) *Beryllium Samples:* Beryllium oxide was dissolved by prolonged heating with sulphuric acid. From the solution $Be(OH)_2$ was precipitated in presence of an adequate amount of ammonium salt of E.D.T.A. The $Be(OH)_2$ precipitate was reignited to BeO.

(b) *Sulphur Samples:* Sulphur was resublimed on to a different source holder.

(c) *Phosphorus Samples:* $Mg_2P_2O_7$ was dissolved in dilute HCl, passed through Dowex: 50 resin at pH 2. From the effluent, magnenium ammonium phosphate was precipitated and reignited to $Mg_2P_2O_7$.

After repurification, the samples showed no observable decrease in their specific activities.

In addition, the beta and gamma energies and the half-lives of the isotopes were periodically checked. They were found to agree with the known values.

II. *Determination of Chemical Extraction Efficiencies:*

(a) *Beryllium:* 36 mg of Be^{++} carrier in the form of $BeCl_2$ was added to the rain water and the weight of Be in the final BeO sample was determined. Since there is no appreciable amount of natural stable beryllium in rain water, the determination of chemical yield is straightforward.

(b) *Sulphur:* Rain water often contains an appreciable quantity of stable sulphur in the form of sulphates. However, 60 mg of stable sulphur in the form of K_2So_4 were added to each rain sample. For the determination of chemical efficiency it is necessary to know exactly the total quantity of sulphur in the rain sample. This was done in the following way:

The rain water was passed through IRA-400 resin, which adsorbs the sulphate quantitatively. After eluting the resin, sulphates were precipitated as $BaSO_4$ and weighed. Since the precipitation of SO_4 as $BaSO_4$ is also quantitative, the weight of $BaSO_4$ gives the total amount of sulphur in rain sample. By comparing this with the amount of sulphur recovered after further purification, the chemical yield was obtained.

(c) *Phosphorus:* The presence of substantial amounts of stable phosphates in rain water made it necessary to adopt the following procedure:

The rain water was divided into two equal portions (A) and (B). To (A) was added 4 mg and to (B) 80 mg of phosphate carrier in the form of disodium hydrogen phosphate. The weights and the P^{32} beta activities of both the final samples (A) and (B), were measured. From these four measurements the chemical yield and the weight of natural phosphate in rain water were calculated. Usually, the amount of natural phosphate in rain water is less than 0.2 mg/liter. Sample A was used to determine the ratio P^{33}/P^{32}. Sample B, because of its lower specific activity, was unsuited for this purpose.

III. *Measurement of Disintegration Rates:*

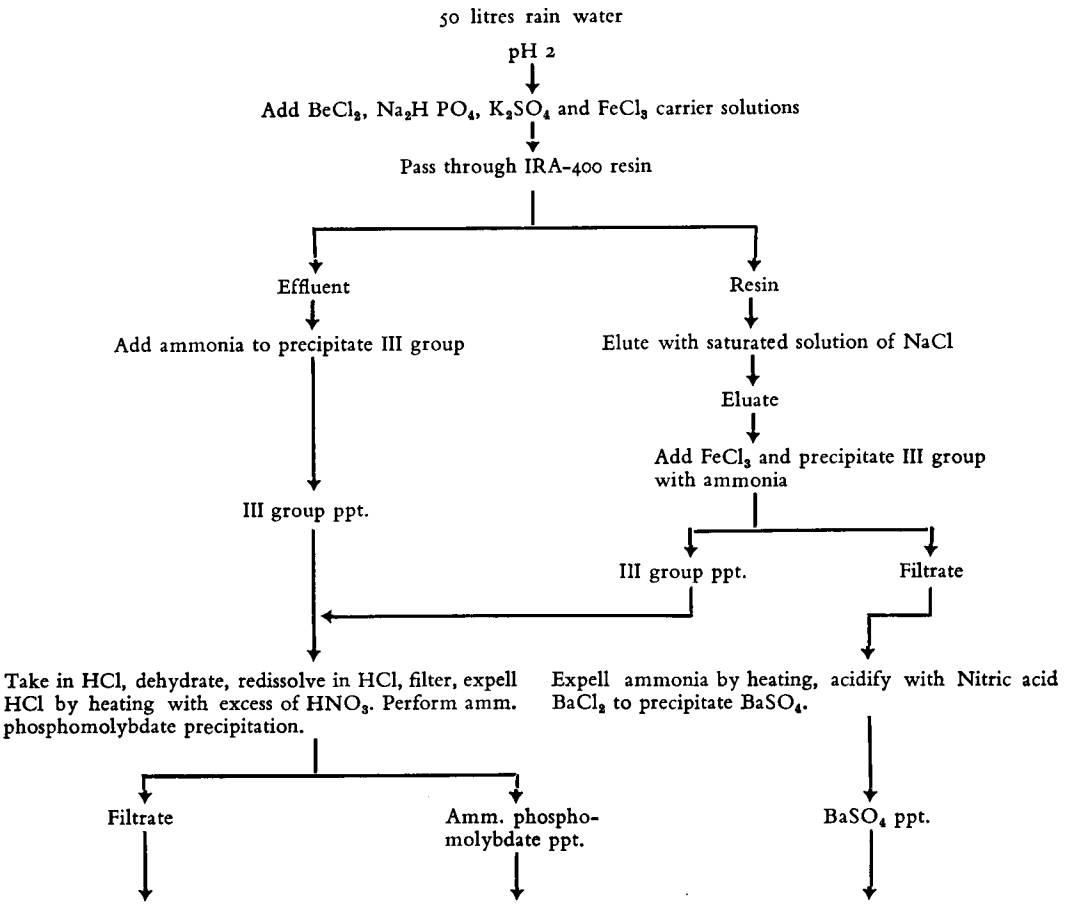
Counting Equipment: The activities of the isotopes S^{35}, P^{32} and P^{33} were measured on an end-window beta counter, shielded by 1″ mercury, 4″ iron and 2″ lead. The usual anti-coincidence arrangement was employed to eliminate μ-mesons. The beta counter has a back-ground of 60 cph inside the shield.

The gamma activity of the isotope Be^7 was measured on a Sodium Iodide crystal spectrometer, (RAMA THOR and ZUTSHI, 1958). The crystal was shielded by 4″ of lead and has a back-ground of 5.5 cpm in the counting channel, which comprises 80 % of the photo peak.

Source Deposition: Phosphorus-32 and 33, Sulfur-35 beta sources ware deposited on stainless steel planchets $^1/_8$″ thick and 1″ diameter, equal to that of the counter window. The phosphorus samples, (in $Mg_2P_2O_7$ form), were made into a fine slurry with water and deposited on the planchet, dried and covered with a thin (0.6 mg/cm^2) mylar film. The sulfur samples were deposited simply by subliming sulfur on to a standard planchet.

There is no problem about the source deposition in case of Beryllium. Beryllium oxide is simply put in a glass tube which goes freely into the crystal well.

Measurement of Counting Rates: The beta



sources on the planchets were placed accurately at a distance of 4 mm from the mica window and counted.

S^{35} samples: These were counted without any external absorber. Mostly, the specific activity of S^{35} samples was found to be sufficient to give easily measurable counting rates even in thick sources ($\sim$ 10 mg/cm^2).

P^{32} samples: Sample (B), containing 80 mg of $Mg_2P_2O_7$ was counted with 28 mg/cm^2 external aluminium absorber. This absorber removes P^{33} counts almost completely (99 %) and reduced P^{32} counts only by 24 %.

P^{33} sample: The amount of P^{32} in rain sample was known from counting of sample (B). The ratio of P^{33}/P^{32} was determined by using sample (A) in which only 4 mg of carrier had been added. The fraction P^{33}/P^{32} was obtained by counting the sample with and without the absorber (28 mg/cm^2 of aluminium).

Calculations of Disintegration Rates

In order to calculate the disintegration rates of the isotopes from their observed

counting rates, one requires to know the following:

1. Counting efficiency (cpm/dpm).
2. Correction for self-absorption.
3. Correction for external absorption.

1. Counting Efficiency:

The counting efficiencies for electrons of different energies were determined by preparing identical sources with known amounts of calibrated solutions of different radio-isotopes. The solutions were calibrated against "Atomics" and "Tracerlab" reference sources.

The method for determining the counting efficiency for Be^7 γ-rays has been described earlier (GOEL ET AL., 1956).

2. Correction for Self-Absorption:

The correction factor for P^{32} due to self-absorption of its electrons in the source was obtained by depositing different weights of $Mg_2P_2O_7$ containing artificial P^{32} and measuring their counting rates.

The self-absorption factor for S^{35} betas was similarly determined by using $BaSO_4$ containing artificial S^{35}.

The factor for P^{33} should have normally been obtained by using $Mg_2P_2O_7$ containing artificial P^{33}. But because of some difficulty in procuring P^{33} activity, the isotope Co^{60} was used instead. The maximum energy of Co^{60} betas is fairly close to that of P^{33} betas. Cobalt phosphate (containing Co^{60}) was used for the purpose.

3. Correction for External Absorption:

The absorption corrections for beta rays emitted by the various isotopes were obtained by measuring their counting rates with different thicknesses of aluminium foils between the source and the mica window.

Since Be^7 emits high energy (0.48 MeV) γ-rays, the self absorption and external absorption corrections are negligible.

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