

Probability

Lest men suspect your tale untrue Keep probability in view.....Gay, John

There are various phenomena in nature, leading to an outcome, which cannot be predicted apriori e.g. in tossing of a coin, a head or a tail may result. Probability theory aims at measuring the uncertainties of such outcomes.

(I) Important terminology :

(i) Random experiment:

It is a process which results in an outcome which is one of the various possible outcomes that are known to us before hand e.g. throwing of a die is a random experiment as it leads to fall of one of the outcome from {1, 2, 3, 4, 5, 6}. Similarly taking a card from a pack of 52 cards is also a random experiment.

(ii) Sample space :

It is the set of all possible outcomes of a random experiment e.g. {H, T} is the sample space associated with tossing of a coin.

In set notation it can be interpreted as the universal set.



Example # 1 : Write the sample space of the experiment 'A coin is tossed and a die is thrown'.

Solution : The sample space $S = \{H1, H2, H3, H4, H5, H6, T1, T2, T3, T4, T5, T6\}$.

Example # 2 : Write the sample space of the experiment 'A coin is tossed, if it shows head a coin tossed again else a die is thrown.

Solution : The sample space $S = \{HH, HT, T1, T2, T3, T4, T5, T6\}$

Example # 3 : Find the sample space associated with the experiment of rolling a pair of dice (plural of die) once. Also find the number of elements of the sample space.

Solution : Let one die be blue and the other be green. Suppose '1' appears on blue die and '2' appears on green die. We denote this outcome by an ordered pair (1, 2). Similarly, if '3' appears on blue die and '5' appears on green die, we denote this outcome by (3, 5) and so on. Thus, each outcome can be denoted by an ordered pair (x, y), where x is the number appeared on the first die (blue die) and y appeared on the second die (green die). Thus, the sample space is given by

$S = \{(x, y) \mid x \text{ is the number on blue die and } y \text{ is the number on green die}\}$
We now list all the possible outcomes (figure)

	1	2	3	4	5	6
1	(1, 1)	(1, 2)	(1, 3)	(1, 4)	(1, 5)	(1, 6)
2	(2, 1)	(2, 2)	(2, 3)	(2, 4)	(2, 5)	(2, 6)
3	(3, 1)	(3, 2)	(3, 3)	(3, 4)	(3, 5)	(3, 6)
4	(4, 1)	(4, 2)	(4, 3)	(4, 4)	(4, 5)	(4, 6)
5	(5, 1)	(5, 2)	(5, 3)	(5, 4)	(5, 5)	(5, 6)
6	(6, 1)	(6, 2)	(6, 3)	(6, 4)	(6, 5)	(6, 6)

Figure

Number of elements (outcomes) of the above sample space is 6×6 i.e., 36

Self practice problems :

- (1) A coin is tossed twice, if the second throw results in head, a die is thrown then write sample space of the experiment.
- (2) An urn contains 3 red balls and 2 blue balls. Write sample space of the experiment 'Selection of a ball from the urn at random'.

Ans.

- (1) {HT, TT, HH1, HH2, HH3, HH4, HH5, HH6, TH1, TH2, TH3, TH4, TH5, TH6}.
- (2) {R₁, R₂, R₃, B₁, B₂}. (Here the balls are distinguished from one and other by naming red balls as R₁, R₂ and R₃ and the blue balls as B₁ and B₂.)

(iii) Event :

It is subset of sample space. e.g. getting a head in tossing a coin or getting a prime number in throwing a die. In general if a sample space consists 'n' elements, then a maximum of 2ⁿ events can be associated with it.

**(iv) Complement of event :**

The complement of an event 'A' with respect to a sample space S is the set of all elements of 'S' which are not in A. It is usually denoted by A', or A^c.

(v) Simple event :

If an event covers only one point of sample space, then it is called a simple event e.g. getting a head followed by a tail in throwing of a coin 2 times is a simple event.

(vi) Compound event :

When two or more than two events occur simultaneously, the event is said to be a compound event. Symbolically A ∩ B or AB represent the occurrence of both A & B simultaneously.

Note : "A ∪ B" or A + B represent the occurrence of either A or B.

Example # 4 : Write down all the events of the experiment 'tossing of a coin'.

Solution : S = {H, T}
the events are \emptyset , {H}, {T}, {H, T}

Example # 5 : A die is thrown. Let A be the event ' an odd number turns up' and B be the event 'a number divisible by 3 turns up'. Write the events (a) A or B (b) A and B

Solution : A = {1, 3, 5}, B = {3, 6}
 \therefore A or B = A ∪ B = {1, 3, 5, 6}
A and B = A ∩ B = {3}

Self practice problems :

- (3) A coin is tossed and a die is thrown. Let A be the event 'H turns up on the coin and odd number turns up on the die' and B be the event ' T turns up on the coin and an even number turns up on the die'. Write the events (a) A or B (b) A and B.
- (4) In tossing of two coins, let A = {HH, HT} and B = {HT, TT}. Then write the events (a) A or B (b) A and B.

Ans.

(3)	(a) {H1, H3, H5, T2, T4, T6}	(b) \emptyset
(4)	(a) {HH, HT, TT}	(b) {HT}

(vii) Equally likely events :

If events have same chance of occurrence, then they are said to be equally likely.

e.g

- (i) In a single toss of a fair coin, the events {H} and {T} are equally likely.
- (ii) In a single throw of an unbiased die the events {1}, {2}, {3} and {4}, are equally likely.
- (iii) In tossing a biased coin the events {H} and {T} are not equally likely.

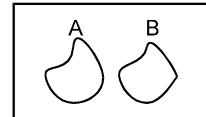
(viii) Mutually exclusive / disjoint / incompatible events :

Two events are said to be mutually exclusive if occurrence of one of them rejects the possibility of occurrence of the other i.e. both cannot occur simultaneously.

In the vein diagram the events A and B are mutually exclusive. Mathematically, we write $A \cap B = \emptyset$

Events $A_1, A_2, A_3, \dots, A_n$ are said to be mutually exclusive events iff

$A_i \cap A_j = \emptyset \forall i, j \in \{1, 2, \dots, n\}$ where $i \neq j$



Note : If $A_i \cap A_j = \emptyset \forall i, j \in \{1, 2, \dots, n\}$ where $i \neq j$, then $A_1 \cap A_2 \cap A_3 \dots \cap A_n = \emptyset$ but converse need not to be true.

Example # 6 : In a single toss of a coin find whether the events {H}, {T} are mutually exclusive or not.

Solution : Since $\{H\} \cap \{T\} = \emptyset$,

\therefore the events are mutually exclusive.

Example # 7 : In a single throw of a die, find whether the events {1, 2}, {2, 3} are mutually exclusive or not.

Solution : Since $\{1, 2\} \cap \{2, 3\} = \{2\} \neq \emptyset \quad \therefore$ the events are not mutually exclusive.

Self practice problems :

(5) In throwing of a die write whether the events 'Coming up of an odd number' and 'Coming up of an even number' are mutually exclusive or not.

(6) An experiment involves rolling a pair of dice and recording the numbers that come up. Describe the following events :

A : the sum is greater than 8.

B : 2 occurs on either die.

C : the sum is at least 7 and a multiple of 3.

Also, find $A \cap B$, $B \cap C$ and $A \cap C$.

Are (i) A and B mutually exclusive ?

(ii) B and C mutually exclusive ?

(iii) A and C mutually exclusive ?

Ans. (5) Yes

(6) $A = \{(3, 6), (4, 5), (5, 4), (6, 3), (4, 6), (5, 5), (6, 4), (5, 6), (6, 5), (6, 6)\}$

$B = \{(1, 2), (2, 2), (3, 2), (4, 2), (5, 2), (6, 2), (2, 1), (2, 3), (2, 4), (2, 5), (2, 6)\}$

$C = \{(3, 6), (6, 3), (5, 4), (4, 5), (6, 6)\}$

$A \cap B = \emptyset, B \cap C = \emptyset, A \cap C = \{(3, 6), (6, 3), (5, 4), (4, 5), (6, 6)\}$

(i) Yes (ii) Yes (iii) No.

(ix) Exhaustive system of events :

If each outcome of an experiment is associated with at least one of the events $E_1, E_2, E_3, \dots, E_n$, then collectively the events are said to be exhaustive. Mathematically we write

$E_1 \cup E_2 \cup E_3 \dots \cup E_n = S$. (Sample space)

Example # 8 : In throwing of a die, let A be the event 'even number turns up', B be the event 'an odd prime turns up' and C be the event 'a numbers less than 4 turns up'. Find whether the events A, B and C form an exhaustive system or not.

Solution : $A = \{2, 4, 6\}$, $B = \{3, 5\}$ and $C = \{1, 2, 3\}$.

Clearly $A \cup B \cup C = \{1, 2, 3, 4, 5, 6\} = S$. Hence the system of events is exhaustive.

Example # 9 : Three coins are tossed. Describe

- (i) two events A and B which are mutually exclusive
- (ii) three events A, B and C which are mutually exclusive and exhaustive.
- (iii) two events A and B which are not mutually exclusive.
- (iv) two events A and B which are mutually exclusive but not exhaustive.
- (v) three events A, B and C which are mutually exclusive but not exhaustive.

Ans.

(i)	A : "getting at least two heads"	B : "getting at least two tails"
(ii)	A : "getting at most one heads"	B : "getting exactly two heads"
	C : "getting exactly three heads"	
(iii)	A : "getting at most two tails"	B : "getting exactly two heads"
(iv)	A : "getting exactly one head"	B : "getting exactly two heads"
(v)	A : "getting exactly one tail"	B : "getting exactly two tails"
	C : "getting exactly three tails"	

[Note : There may be other cases also]

Self practice problems :

(7) In throwing of a die which of the following pair of events are mutually exclusive?

- the events 'coming up of an odd number' and 'coming up of an even number'
- the events 'coming up of an odd number' and 'coming up of a number ≥ 4 '

(8) In throwing of a die which of the following system of events are exhaustive ?

- the events 'an odd number turns up', 'a number ≤ 4 turns up' and 'the number 5 turns up'.
- the events 'a number ≤ 4 turns up', 'a number > 4 turns up'.
- the events 'an even number turns up', 'a number divisible by 3 turns up', 'number 1 or 2 turns up' and 'the number 6 turns up'.

Ans. (7) (a) (8) (b)

(II) Classical (a priori) definition of probability :

If an experiment results in a total of $(m + n)$ outcomes which are equally likely and if 'm' outcomes are favorable to an event 'A' while 'n' are unfavorable, then the probability of occurrence of the event 'A', denoted by $P(A)$, is defined by
$$\frac{m}{m+n} = \frac{\text{number of favourable outcomes}}{\text{total number of outcomes}}$$

$$\text{i.e. } P(A) = \frac{m}{m+n}.$$

Here we say that odds in favour of 'A' are $m : n$, while odds against 'A' are $n : m$.

Note that $P(\bar{A})$ or $P(A')$ or $P(A^c)$, i.e. probability of non-occurrence of A = $\frac{n}{m+n} = 1 - P(A)$

In the above we shall denote the number of outcomes favourable to the event A by $n(A)$ and the total number of outcomes in the sample space S by $n(S)$.

$$\therefore P(A) = \frac{n(A)}{n(S)}.$$

Example # 10 : In throwing of a fair die find the probability of the event 'a number ≤ 3 turns up'.

Solution : Sample space $S = \{1, 2, 3, 4, 5, 6\}$; event $A = \{1, 2, 3\}$

$$\therefore n(A) = 3 \text{ and } n(S) = 6$$

$$\therefore P(A) = \frac{n(A)}{n(S)} = \frac{3}{6} = \frac{1}{2}.$$

Example # 11 : In throwing of a fair die, find the probability of turning up of an odd number ≥ 4 .

Solution : $S = \{1, 2, 3, 4, 5, 6\}$

Let E be the event 'turning up of an odd number ≥ 4 '

then $E = \{5\}$

$$\therefore P(E) = \frac{n(E)}{n(S)} = \frac{1}{6}.$$

Example # 12 : In throwing a pair of fair dice, find the probability of getting a total of 10.

Solution : When a pair of dice is thrown the sample space consists

$$\begin{aligned} &\{(1, 1) (1, 2) \dots (1, 6) \\ &(2, 1) (2, 2) \dots (2, 6) \end{aligned}$$

...

...

(6, 1), (6, 2) ... (6, 6)

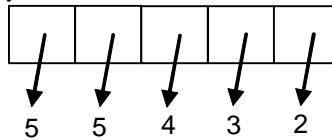
Note that (1, 2) and (2, 1) are considered as separate points to make each outcome as equally likely.

To get a total of '10', favourable outcomes are, (4, 6) (5, 5) and (6, 4)

$$\text{Hence required probability} = \frac{3}{36} = \frac{1}{12}$$

Example # 13 : A five digit number is formed using the digits 0, 1, 2, 3, 4, 5 without repetition. Find the probability that it is divisible by 4

Solution : Total 5 digit numbers formed



$$\text{Total ways} = 5 \times 5 \times 4 \times 3 \times 2 = 600$$

Now, A number is divisible by 4, if last two digits of the number is divisible by 4

Hence we can have

			0	4
			1,3 or 5	2
			2 or 4	0
			2	4

→ first 3 places can be filled in $4 \times 3 \times 2 = 24$ ways

→ first 4 places can be filled in $3 \times 3 \times 2 \times 3 = 54$ ways

→ first 4 places can be filled in $4 \times 3 \times 2 \times 2 = 48$ ways

→ first 3 places can be filled in $3 \times 3 \times 2 = 18$ ways

Total number of ways

144 ways

$$\text{probability} = \frac{\text{favorable outcomes}}{\text{Total outcomes}} = \frac{144}{600} = \frac{6}{25} \text{ Ans.}$$

Self practice problems :

(9) A bag contains 4 white, 3 red and 2 blue balls. A ball is drawn at random. Find the probability of the event the ball drawn is blue or red

(10) In throwing a pair of fair dice find the probability of the events ' a total of of less than or equal to 9".

Ans. (9) 5/9 (10) 5/6.

(III) Addition theorem of probability :

If 'A' and 'B' are any two events associated with an experiment, then

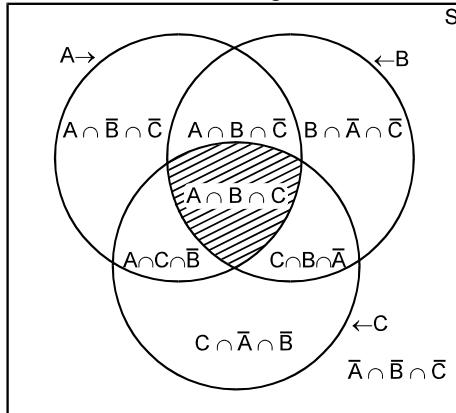
$$P(A \cup B) = P(A) + P(B) - P(A \cap B)$$

De Morgan's laws : If A & B are two subsets of a universal set U, then

(a) $(A \cup B)^c = A^c \cap B^c$
(b) $(A \cap B)^c = A^c \cup B^c$

Distributive laws : (a) $A \cup (B \cap C) = (A \cup B) \cap (A \cup C)$
(b) $A \cap (B \cup C) = (A \cap B) \cup (A \cap C)$

For any three events A, B and C we have the figure



- (i) $P(A \text{ or } B \text{ or } C) = P(A) + P(B) + P(C) - P(A \cap B) - P(B \cap C) - P(C \cap A) + P(A \cap B \cap C)$
- (ii) $P(\text{at least two of } A, B, C \text{ occur}) = P(B \cap C) + P(C \cap A) + P(A \cap B) - 2P(A \cap B \cap C)$
- (iii) $P(\text{exactly two of } A, B, C \text{ occur}) = P(B \cap C) + P(C \cap A) + P(A \cap B) - 3P(A \cap B \cap C)$
- (iv) $P(\text{exactly one of } A, B, C \text{ occur}) = P(A) + P(B) + P(C) - 2P(B \cap C) - 2P(C \cap A) - 2P(A \cap B) + 3P(A \cap B \cap C)$

Example # 14 : A bag contains 4 white, 3 red and 4 green balls. A ball is drawn at random. Find the probability of the event 'the ball drawn is white or green'.

Solution : Let A be the event 'the ball drawn is white' and B be the event 'the ball drawn is green'.

$$P(\text{The ball drawn is white or green}) = P(A \cup B) = P(A) + P(B) - P(A \cap B) = \frac{8}{11}$$

Example # 15 : In throwing of a die, let A be the event 'an odd number turns up', B be the event 'a number divisible by 3 turns up' and C be the event 'a number ≤ 4 turns up'. Then find the probability that atleast one of A, B, C occur.

Solution : Event A = {1, 3, 5}, event B = {3, 6} and event C = {1, 2, 3, 4}
 $\therefore A \cap B = \{3\}$, $B \cap C = \{3\}$, $A \cap C = \{1, 3\}$ and $A \cap B \cap C = \{3\}$.

Thus

$$\begin{aligned} P(A \text{ or } B \text{ or } C) &= P(A) + P(B) + P(C) - P(A \cap B) - P(B \cap C) - P(C \cap A) + P(A \cap B \cap C) \\ &= \frac{3}{6} + \frac{2}{6} + \frac{4}{6} - \frac{1}{6} - \frac{1}{6} - \frac{2}{6} + \frac{1}{6} = 1 \end{aligned}$$

Self practice problems :

- (11) In throwing of a die, let A be the event 'an odd number turns up', B be the event 'a number divisible by 3 turns up' and C be the event 'a number ≤ 4 turns up'. Then find the probability that atleast two of A, B and C occur.
- (12) In the problem number 11, find the probability that exactly one of A, B and C occurs.

Ans. (11) $\frac{1}{3}$ (12) $\frac{2}{3}$

(IV) Conditional probability

If A and B are two events, then $P(A|B) = \frac{P(A \cap B)}{P(B)}$.

Note that for mutually exclusive events $P(A|B) = 0$.

Example # 16 : If $P(A|B) = 0.2$ and $P(B) = 0.5$ and $P(A) = 0.2$. Find $P(A \cap B)$.

Solution : $P(A \cap B) = P(A) - P(A \cap B)$

$$\text{Also } P(A|B) = \frac{P(A \cap B)}{P(B)} \Rightarrow P(A \cap B) = 0.1$$

From given data,

$$P(A \cap B) = 0.1$$

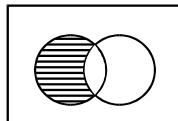
Example # 17 : If $P(A) = 0.25$, $P(B) = 0.5$ and $P(A \cap B) = 0.14$, find probability that neither 'A' nor 'B' occurs.

Also find $P(A \cap \bar{B})$

Solution : We have to find $P(\bar{A} \cap \bar{B}) = 1 - P(A \cup B)$ (by De-Morgan's law)

Also, $P(A \cup B) = P(A) + P(B) - P(A \cap B)$

putting data we get, $P(\bar{A} \cap \bar{B}) = 0.39$



The shaded region denotes the simultaneous occurrence of A and \bar{B}

Hence $P(A \cap \bar{B}) = P(A) - P(A \cap B) = 0.11$

Self practice problem :

(13) If $P(\bar{A} / \bar{B}) = 0.3$, $P(A \cup B) = 0.8$, then find $P(A \cap \bar{B})$?

Ans. $\frac{7}{15}$

(V) Independent and dependent events

If two events are such that occurrence or non-occurrence of one does not affect the chances of occurrence or non-occurrence of the other event, then the events are said to be independent. Mathematically : if $P(A \cap B) = P(A) P(B)$, then A and B are independent.

Note: (i) If A and B are independent, then

- (a) A' and B' are independent,
- (b) A and B' are independent and
- (c) A' and B are independent.

(ii) If A and B are independent, then $P(A / B) = P(A)$.

If events are not independent then they are said to be dependent.

Independency of three or more events

Three events A, B & C are independent if & only if all the following conditions hold :

$$P(A \cap B) = P(A) \cdot P(B) ; \quad P(B \cap C) = P(B) \cdot P(C)$$

$$P(C \cap A) = P(C) \cdot P(A) ; \quad P(A \cap B \cap C) = P(A) \cdot P(B) \cdot P(C)$$

Example # 18 : A pair of fair coins is tossed yielding the equiprobable space $S = \{HH, HT, TH, TT\}$. Consider the events:

$A = \{\text{head on first coin}\} = \{HH, HT\}$, $B = \{\text{head on second coin}\} = \{HH, TH\}$

$C = \{\text{head on exactly one coin}\} = \{HT, TH\}$

Then check whether A, B, C are independent or not.

Solution : $P(A) = P(B) = P(C) = \frac{2}{4} = \frac{1}{2}$.

Also $P(A \cap B) = \frac{1}{4} = P(A) P(B)$, $P(A \cap C) = \frac{1}{4} = P(A) P(C)$, $P(B \cap C) = \frac{1}{4} = P(B) P(C)$

but $P(A \cap B \cap C) = 0 \neq P(A) P(B) P(C)$

\therefore A, B & C are not independent

Example # 19 : In drawing two balls from a box containing 7 red and 4 white balls without replacement, which of the following pairs is independent ?

(a) Red on first draw and red on second draw

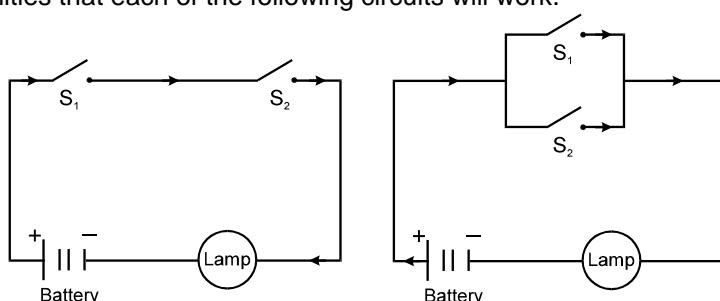
(b) Red on first draw and white on second draw

Solution : Let E be the event 'Red on first draw', F be the event 'Red on second draw' and G be the event 'white on second draw'.

$$P(E) = \frac{7}{11}, P(F) = \frac{7}{11}, P(G) = \frac{4}{11}$$

$$\begin{aligned}
 (a) \quad P(E \cap F) &= \frac{^7P_2}{^{11}P_2} = \frac{21}{55} \\
 P(E) \cdot P(F) &= \frac{7}{11} \times \frac{7}{11} = \frac{49}{121} \neq \frac{21}{55} \quad \Rightarrow \quad E \text{ and } F \text{ are not independent} \\
 (b) \quad P(E) \cdot P(G) &= \frac{7}{11} \times \frac{4}{11} = \frac{28}{121} \\
 P(E \cap G) &= \frac{^7P_1 \times ^4P_1}{^{11}P_2} = \frac{14}{55} \\
 \therefore P(E) \cdot P(G) &\neq P(E \cap G) \quad \Rightarrow \quad E \text{ and } G \text{ are not independent}
 \end{aligned}$$

Example # 20 : If two switches S_1 and S_2 have respectively 90% and 80% chances of working. Find the probabilities that each of the following circuits will work.



Solution : Consider the following events :

A = Switch S_1 works,

B = Switch S_2 works,

We have,

$$P(A) = \frac{90}{100} = \frac{9}{10} \text{ and } P(B) = \frac{80}{100} = \frac{8}{10}$$

(i) The circuit will work if the current flows in the circuit. This is possible only when both the switches work together. Therefore, Required probability

$$\begin{aligned}
 &= P(A \cap B) = P(A) P(B) \quad [\because A \text{ and } B \text{ are independent events}] \\
 &= \frac{9}{10} \times \frac{8}{10} = \frac{72}{100} = \frac{18}{25}
 \end{aligned}$$

(ii) The circuit will work if the current flows in the circuit. This is possible only when at least one of the two switches S_1, S_2 works. Therefore,

Required Probability

$$\begin{aligned}
 &= P(A \cup B) = 1 - P(\bar{A}) P(\bar{B}) \quad [\because A, B \text{ are independent events}] \\
 &= 1 - \left(1 - \frac{9}{10}\right) \left(1 - \frac{8}{10}\right) = 1 - \frac{1}{10} \times \frac{2}{10} = \frac{49}{50}
 \end{aligned}$$

Example # 21 : A speaks truth in 60% of the cases and B in 90% of the cases. In what percentage of cases are they likely to contradict each other in stating the same fact?

Solution : Let E be the event that A speaks truth and F be the event that B speaks truth. Then E and F are independent events such that

$$P(E) = \frac{60}{100} = \frac{3}{5} \text{ and } P(F) = \frac{90}{100} = \frac{9}{10}$$

A and B will contradict each other in narrating the same fact in the following mutually exclusive ways:

$$\begin{aligned}
 (i) \quad &A \text{ speaks truth and } B \text{ tells a lie i.e. } E \cap \bar{F} \\
 (ii) \quad &A \text{ tells a lie and } B \text{ speaks truth i.e. } \bar{E} \cap F \\
 \therefore \quad &P(A \text{ and } B \text{ contradict each other}) \\
 &= P(I \text{ or } II) = (I \cup II) = P[(E \cap \bar{F}) \cup (\bar{E} \cap F)] \\
 &= P(E \cap \bar{F}) + P(\bar{E} \cap F) \quad [\because E \cap \bar{F} \text{ and } \bar{E} \cap F \text{ are mutually exclusive}]
 \end{aligned}$$

Aliter :

'NNNA' is the arrangement then we desire in taking out cards, one by one

Hence required chance is $\frac{48}{52} \times \frac{47}{51} \times \frac{46}{50} \times \frac{4}{49}$

Self practice problems :

(VI) Total probability theorem

If an event A can occur with one of the n mutually exclusive and exhaustive events B_1, B_2, \dots, B_n and the probabilities $P(A/B_1), P(A/B_2), \dots, P(A/B_n)$ are known, then

$$P(A) = \sum_{i=1}^n P(B_i) \cdot P(A/B_i)$$

Proof :

The event A occurs with one of the n mutually exclusive and exhaustive events $B_1, B_2, B_3, \dots, B_n$

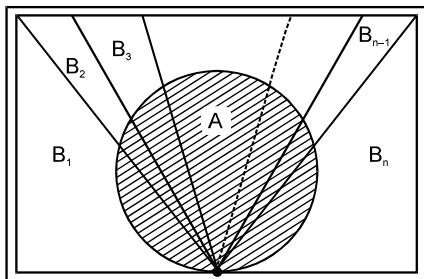
$$A = (A \cap B_1) \cup (A \cap B_2) \cup (A \cap B_3) \cup \dots \cup (A \cap B_n)$$

$$P(A) = P(A \cap B_1) + P(A \cap B_2) + \dots + P(A \cap B_n) = \sum_{i=1}^n P(A \cap B_i)$$

Now,

$$P(A \cap B_i) = P(A) \cdot P(B_i | A) = P(B_i) \cdot P(A | B_i)$$

$$\therefore P(A) = \sum_{i=1}^n P(B_i) \cdot P(A/B_i)$$



Example # 25 : Box - I contains 6 red and 3 white balls while box - II contains 4 red and 3 white balls. A fair die is thrown. If it turns up a multiple of 3, a ball is drawn from box - I else a ball is drawn from box - II. Find the probability that the ball drawn is white.

Solution : Let A be the event 'a multiple of 3 turns up on the die' and R be the event 'the ball drawn is white'
then $P(\text{ball drawn is white})$

$$= P(A) \cdot P(R / A) + P(\bar{A}) \cdot P(R / \bar{A}) = \frac{2}{6} \times \frac{3}{9} + \left(1 - \frac{2}{6}\right) \frac{3}{7} = \frac{25}{63}$$

Example # 26 : Cards of an ordinary deck of playing cards are placed into two heaps. Heap - I consists of all the red cards and heap - II consists of all the black cards. A heap is chosen at random and a card is drawn, find the probability that the card drawn is a king.

Solution : Let I and II be the events that heap - I and heap - II are chosen respectively. Then

$$P(I) = P(II) = \frac{1}{2}$$

Let K be the event 'the card drawn is a king'

$$\therefore P(K / I) = \frac{2}{26} \quad \text{and} \quad P(K / II) = \frac{2}{26}$$

$$\therefore P(K) = P(I) P(K / I) + P(II) P(K / II) = \frac{1}{2} \times \frac{2}{26} + \frac{1}{2} \times \frac{2}{26} = \frac{1}{13}.$$

Self practice problems :

(20) Box - I contains 3 red and 6 blue balls while box - II contains 5 red and 4 blue balls. A fair coin is tossed. If it turns up head, a ball is drawn from box - I, else a ball is drawn from box - II . Find the probability that the ball drawn is red.

(21) There are 5 brilliant students in class XI and 8 brilliant students in class XII. Each class has 50 students. The odds in favour of choosing the class XI are 2 : 3. If the class XI is not chosen then the class XII is chosen. Find the probability of selecting a brilliant student.

Ans. (20) $\frac{4}{9}$ (21) $\frac{17}{125}$.

(VII) Bayes' theorem :

If an event A can occur with one of the n mutually exclusive and exhaustive events B_1, B_2, \dots, B_n and the probabilities $P(A/B_1), P(A/B_2), \dots, P(A/B_n)$ are known, then $P(B_i / A) = \frac{P(B_i) \cdot P(A/B_i)}{\sum_{i=1}^n P(B_i) \cdot P(A/B_i)}$

Proof :

The event A occurs with one of the n mutually exclusive and exhaustive events

$B_1, B_2, B_3, \dots, B_n$

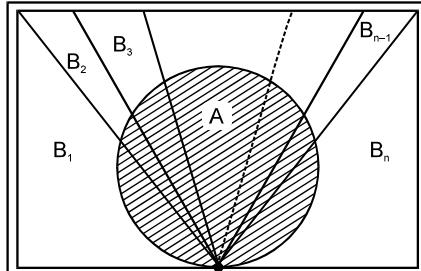
$$A = (A \cap B_1) \cup (A \cap B_2) \cup (A \cap B_3) \cup \dots \cup (A \cap B_n)$$

$$P(A) = P(A \cap B_1) + P(A \cap B_2) + \dots + P(A \cap B_n) = \sum_{i=1}^n P(A \cap B_i)$$

Now, $P(A \cap B_i) = P(A) \cdot P(B_i/A) = P(B_i) \cdot P(A/B_i)$

$$P(B_i/A) = \frac{P(B_i) \cdot P(A/B_i)}{P(A)} = \frac{P(B_i) \cdot P(A/B_i)}{\sum_{i=1}^n P(A \cap B_i)}$$

$$P(B/A) = \frac{P(B_i) \cdot P(A/B_i)}{\sum P(B_i) \cdot P(A/B_i)}$$



Example # 27 : Pal's gardener is not dependable, the probability that he will forget to water the rose bush is $\frac{2}{3}$.

The rose bush is in questionable condition any how, if watered the probability of its withering is $\frac{1}{2}$, if not watered, the probability of its withering is $\frac{3}{4}$. Pal went out of station and upon returning, he finds that the rose bush has withered, what is the probability that the gardener did not water the bush.

[Here result is known that the rose bush has withered, therefore. Bayes's theorem should be used]

Solution : Let A = the event that the rose bush has withered
Let A_1 = the event that the gardener did not water.
 A_2 = the event that the gardener watered.

By Bayes's theorem required probability,

$$P(A_1/A) = \frac{P(A_1) \cdot P(A/A_1)}{P(A_1) \cdot P(A/A_1) + P(A_2) \cdot P(A/A_2)} \quad \dots \dots (i)$$

$$\text{Given, } P(A_1) = \frac{2}{3} \quad \therefore \quad P(A_2) = \frac{1}{3}$$

$$P(A/A_1) = \frac{3}{4}, P(A/A_2) = \frac{1}{2} \quad \text{From (1), } P(A_1/A) = \frac{\frac{2}{3} \cdot \frac{3}{4}}{\frac{2}{3} \cdot \frac{3}{4} + \frac{1}{3} \cdot \frac{1}{2}} = \frac{6}{6+2} = \frac{3}{4}$$

Example # 28 : There are 5 brilliant students in class XI and 8 brilliant students in class XII. Each class has 50 students. The odds in favour of choosing the class XI are 2 : 3. If the class XI is not chosen then the class XII is chosen. A student is chosen and is found to be brilliant, find the probability that the chosen student is from class XI.

Solution : Let E and F be the events 'Class XI is chosen' and 'Class XII is chosen' respectively.

$$\text{Then } P(E) = \frac{2}{5}, P(F) = \frac{3}{5}$$

Let A be the event 'Student chosen is brilliant'. Then $P(A/E) = \frac{5}{50}$ and $P(A/F) = \frac{8}{50}$.

$$\therefore P(A) = P(E) \cdot P(A/E) + P(F) \cdot P(A/F) = \frac{2}{5} \cdot \frac{5}{50} + \frac{3}{5} \cdot \frac{8}{50} = \frac{34}{250}.$$

$$\therefore P(E/A) = \frac{P(E) \cdot P(A/E)}{P(E) \cdot P(A/E) + P(F) \cdot P(A/F)} = \frac{5}{17}.$$

Example # 29 : A pack of cards is counted with face downwards. It is found that one card is missing. One card is drawn and is found to be red. Find the probability that the missing card is red.

Solution : Let A be the event of drawing a red card when one card is drawn out of 51 cards (excluding missing card.) Let A_1 be the event that the missing card is red and A_2 be the event that the missing card is black.

Now by Bayes's theorem, required probability,

$$P(A_1/A) = \frac{P(A_1) \cdot (P(A/A_1))}{P(A_1) \cdot P(A/A_1) + P(A_2) \cdot P(A/A_2)} \quad \dots \dots \dots \text{(i)}$$

In a pack of 52 cards 26 are red and 26 are black.

$$\text{Now } P(A_1) = \text{probability that the missing card is red} = \frac{26}{52} = \frac{26}{52} = \frac{1}{2}$$

$$P(A_2) = \text{probability that the missing card is black} = \frac{26}{52} = \frac{1}{2}$$

$P(A/A_1)$ = probability of drawing a red card when the missing card is red.

$$= \frac{25}{51}$$

[\because Total number of cards left is 51 out of which 25 are red and 26 are black as the missing card is red]

$$\text{Again } P(A/A_2) = \text{Probability of drawing a red card when the missing card is black} = \frac{26}{51}$$

$$\text{Now from (i), required probability, } P(A_1/A) = \frac{\frac{1}{2} \cdot \frac{25}{51}}{\frac{1}{2} \cdot \frac{25}{51} + \frac{1}{2} \cdot \frac{26}{51}} = \frac{25}{51}$$

Example # 30 : A bag contains 6 white and an unknown number of black balls (≤ 3). Balls are drawn one by one with replacement from this bag twice and is found to be white on both occasion. Find the probability that the bag had exactly '3' Black balls.

Solution : A priori, we can think of the following possibilities

- (i) E_1 6W , 0 B
- (ii) E_2 6W , 1 B
- (iii) E_3 6W , 2 B
- (iv) E_4 6W , 3 B

$$\text{Clearly } P(E_1) = P(E_2) = P(E_3) = P(E_4) = \frac{1}{4}$$

Let 'A' be the event that two balls drawn one by one with replacement are both white therefore

we have to find $P\left(\frac{E_4}{A}\right)$

$$\text{By Baye's theorem } P\left(\frac{E_4}{A}\right) = \frac{P\left(\frac{A}{E_4}\right) \times P(E_4)}{P\left(\frac{A}{E_1}\right) \times P(E_1) + P\left(\frac{A}{E_2}\right) \times P(E_2) + P\left(\frac{A}{E_3}\right) \times P(E_3) + P\left(\frac{A}{E_4}\right) \times P(E_4)}$$

$$P\left(\frac{A}{E_4}\right) = \frac{6}{9} \times \frac{6}{9}; \quad P\left(\frac{A}{E_3}\right) = \frac{6}{8} \times \frac{6}{8}; \quad P\left(\frac{A}{E_2}\right) = \frac{6}{7} \times \frac{6}{7}; \quad P\left(\frac{A}{E_1}\right) = \frac{6}{6} \times \frac{6}{6};$$

$$\text{Putting values } P\left(\frac{E_4}{A}\right) = \frac{\frac{1}{81} \times \frac{1}{4}}{\frac{1}{4} \left[\frac{1}{81} + \frac{1}{64} + \frac{1}{49} + \frac{1}{36} \right]}$$

Self practice problems :

(22) Box-I contains 3 red and 2 blue balls while box-II contains 2 red and 3 blue balls. A fair coin is tossed. If it turns up head, a ball is drawn from box-I, else a ball is drawn from box-II. If the ball drawn is red, then find the probability that the ball is drawn from box-II.

(23) Cards of an ordinary deck of playing cards are placed into two heaps. Heap - I consists of all the red cards and heap - II consists of all the black cards. A heap is chosen at random and a card is drawn, if the card drawn is found to be a king, find the probability that the card drawn is from the heap - II.

Ans. (22) $\frac{2}{5}$ (23) $\frac{1}{2}$

(VIII) Binomial probability theorem :

If an experiment is such that the probability of success or failure does not change with trials, then the probability of getting exactly r success in n trials of such an experiment is ${}^nC_r p^r q^{n-r}$, where 'p' is the probability of a success and q is the probability of a failure in one particular experiment. Note that $p + q = 1$.

Example 31 : A pair of dice is thrown 7 times. Find the probability of getting a doublet thrice

Solution : In a single throw of a pair of dice probability of getting a doublet is $\frac{1}{6}$

considering it to be a success, $p = \frac{1}{6}$

$$\therefore q = 1 - \frac{1}{6} = \frac{5}{6}$$

number of success $r = 3$

$$\therefore P(r = 3) = {}^7C_3 p^3 q^4 = 35 \left(\frac{1}{6}\right)^3 \left(\frac{5}{6}\right)^4$$

Example # 32 : A pair of dice is thrown 4 times. If getting 'a total of 7' in a single throw is considered as a success then find the probability of getting 'a total of 7' thrice.

Solution : $p = \text{probability of getting 'a total of 7'} = \frac{6}{36} = \frac{1}{6}$

$$\therefore q = 1 - \frac{1}{6} = \frac{5}{6}$$

$r = 3, n = 4$

$$\therefore P(r = 3) = {}^4C_3 p^3 q = 4 \left(\frac{1}{6}\right)^3 \left(\frac{5}{6}\right) = \frac{5}{324}$$

Example # 33 : In an examination of 10 multiple choice questions (1 or more can be correct out of 3 options). A student decides to mark the answers at random. Find the probability that he gets exactly two questions correct.

Solution : A student can mark 7 different answers to a MCQ with 3 option i.e. ${}^3C_1 + {}^3C_2 + {}^3C_3 = 7$

Hence if he marks the answer at random, chance that his answer is correct $= \frac{1}{7}$ and

being incorrecting $\frac{6}{7}$ Thus $p = \frac{1}{7}, q = \frac{6}{7}$

$$P(\text{2 success}) = {}^{10}C_2 \times \left(\frac{1}{7}\right)^2 \times \left(\frac{6}{7}\right)^8$$

Example # 34 : A family has three children. Event 'A' is that family has at most one boy, Event 'B' is that family has at least one boy and one girl, Event 'C' is that the family has at most one girl. Find whether events 'A' and 'B' are independent. Also find whether A, B, C are independent or not.

Solution : A family of three children can have

(i) All 3 boys (ii) 2 boys + 1 girl (iii) 1 boy + 2 girls (iv) 3 girls

$$(i) P(3 \text{ boys}) = {}^3C_0 \left(\frac{1}{2}\right)^3 = \frac{1}{8} \text{ (Since each child is equally likely to be a boy or a girl)}$$

$$(ii) P(2 \text{ boys} + 1 \text{ girl}) = {}^3C_1 \times \left(\frac{1}{2}\right)^2 \times \frac{1}{2} = \frac{3}{8}$$

(Note that there are three cases BBG, BGB, GBB)

$$(iii) P(1 \text{ boy} + 2 \text{ girls}) = {}^3C_2 \times \left(\frac{1}{2}\right)^1 \times \left(\frac{1}{2}\right)^2 = \frac{3}{8}$$

$$(iv) P(3 \text{ girls}) = \frac{1}{8}$$

Event 'A' is associated with (iii) & (iv). Hence $P(A) = \frac{1}{2}$

Event 'B' is associated with (ii) & (iii). Hence $P(B) = \frac{3}{4}$

Event 'C' is associated with (i) & (ii). Hence $P(C) = \frac{1}{2}$

$P(A \cap B) = P(\text{iii}) = \frac{3}{8} = P(A) \cdot P(B)$. Hence A and B are independent of each other

$P(A \cap C) = 0 \neq P(A) \cdot P(C)$. Hence A, B, C are not independent

Self practice problems :

(24) A box contains 4 red and 5 blue balls. Two balls are drawn successively without replacement. If getting 'a red ball on first draw and a blue ball on second draw' is considered a success, then find the probability of 2 successes in 3 performances.

(25) Probability that a bulb produced by a factory will fuse after an year of use is 0.2. Find the probability that out of 5 such bulbs exactly 2 bulb will fuse after an year of use.

Ans. (24) $\frac{325}{1944}$ (25) $\frac{640}{3125}$

(IX) Probability distribution :

A probability distribution spells out how a total probability of 1 is distributed over several values of a random variable (i.e. how possibilities)

(X) Expectation :

If there are n possibilities A_1, A_2, \dots, A_n in an experiment having the probabilities p_1, p_2, \dots, p_n respectively. If value M_1, M_2, \dots, M_n are associated with the respective possibility. Then the expected

value of the experiment is given by $\sum_{i=1}^n p_i \cdot M_i$

Note: (i) Mean of any probability distribution of a random variable is given by :

$$\mu = \frac{\sum p_i x_i}{\sum p_i} = \sum p_i x_i \quad (\text{Since } \sum p_i = 1)$$

Its also known as expectation.

(ii) Variance of a random variable is given by, $\sigma^2 = \sum (x_i - \mu)^2 \cdot p_i$

$$\therefore \sigma^2 = \sum p_i x_i^2 - \mu^2 \quad (\text{Note that SD} = +\sqrt{\sigma^2})$$

(iii) The probability distribution for a binomial variate 'X' is given by :
 $P(X = r) = {}^nC_r p^r q^{n-r}$ where $P(X = r)$ is the probability of r successes.

The recurrence formula $\frac{P(r+1)}{P(r)} = \frac{n-r}{r+1} \cdot \frac{p}{q}$, is very helpful for quickly computing

$P(1)$. $P(2)$. $P(3)$ etc. if $P(0)$ is known.

Mean of Binomial Probability Distribution = np ; variance of Binomial Probability Distribution = npq .

(iv) If p represents a person's chance of success in any venture and 'M' the sum of money which he will receive in case of success, then his expectations or probable value = pM

Example # 35 : A random variable X has the following probability distribution :

X	0	1	2	3	4	5	6	7
$P(X)$	0	$2k$	$3k$	k	0	k^2+k	$2k^2$	$5k^2$

Determine

(i) k (ii) $P(X < 3)$ (iii) $P(X \geq 6)$ (iv) $P(0 < X \leq 3)$

Hints : Use $\sum P(X) = 1$ to determine k , $P(X < 3) = P(0) + P(1) + P(2)$, $P(X \geq 6) = P(6) + (P(7))$, $P(0 < X \leq 3) = P(0) + P(1) + P(2) + P(3)$

Ans. (i) $\frac{1}{8}$ (ii) $\frac{5}{8}$ (iii) $\frac{7}{64}$ (iv) $\frac{3}{4}$

Example # 36 : A fair die is tossed. If 2, 3 or 5 occurs, the player wins that number of rupees, but if 1, 4, or 6 occurs, the player loses that number of rupees. First complete probability distribution table. Hence find expectation.

A_i	2	3	5	1	4	6
M_i	2	3	5	-1	-4	-6
P_i	$1/6$	$1/6$	$1/6$	$1/6$	$1/6$	$1/6$

Then expected value E of the game payoffs for the player

$$= 2 \left(\frac{1}{6} \right) + 3 \left(\frac{1}{6} \right) + 5 \left(\frac{1}{6} \right) - 1 \left(\frac{1}{6} \right) - 4 \left(\frac{1}{6} \right) - 6 \left(\frac{1}{6} \right) = -\left(\frac{1}{6} \right)$$

Since E is negative therefore game is unfavorable to the player.

Example # 37 : There are 50 tickets in a raffle (Lottery). There is 1 prize each of Rs. 800/-, Rs. 300/- and Rs. 200/-. Remaining tickets are blank. Find the expected price of one such ticket.

Solution : Expectation = $\sum p_i M_i$

$$\text{Probability of 1 ticket} = \frac{1}{50}$$

$$\text{expected price} = 800 \times \frac{1}{50} + 300 \times \frac{1}{50} + 200 \times \frac{1}{50} + \frac{47}{50} \times 0 = 26 \text{ Rs.}$$

Example # 38 : A purse contains four coins each of which is either five rupees or two rupees coin. Find the expected value of a coin in that purse.

Solution : Various possibilities of coins in the purse can be

5Rs.	2Rs.	} equally likely $1/5$
0	4	
1	3	
2	2	
3	1	
4	0	

expected value per coin

$$= \frac{1}{5} [5 \times 0 + 4 \times 2] + \frac{1}{5} [5 \times 1 + 3 \times 2] + \frac{1}{5} [5 \times 2 + 2 \times 2] + \frac{1}{5} [5 \times 3 + 2 \times 1] + \frac{1}{5} [5 \times 4 + 2 \times 0] = 14$$

Example # 39 : A pair of dice is thrown 7 times. If getting a doublet is considered as a success, then find the mean and variance of successes.

Solution : In a single throw of a pair of dice, probability of getting a doublet = $\frac{1}{6}$
 considering it to be a success, $p = \frac{1}{6}$ $\therefore q = 1 - \frac{1}{6} = \frac{5}{6}$
 $\text{mean} = 7 \times \frac{1}{6} = \frac{7}{6}$, $\text{variance} = 7 \times \frac{1}{6} \times \frac{5}{6} = \frac{35}{36}$

Example # 40 : A pair of dice is thrown 4 times. If getting a total of 7 in a single throw is considered as a success then find the mean and variance of successes.

Solution : $p = \text{probability of getting a total of 7} = \frac{6}{36} = \frac{1}{6}$
 $\therefore q = 1 - \frac{1}{6} = \frac{5}{6}$
 $\therefore \text{mean} = np = 4 \times \frac{1}{6} = \frac{2}{3}$
 $\text{variance} = npq = 4 \times \frac{1}{6} \times \frac{5}{6} = \frac{5}{9}$

Example # 41 : Difference between mean and variance of a Binomial variate is '1' and difference between their squares is '11'. Find the probability of getting exactly three success

Solution : Mean = np & variance = npq
 therefore, $np - npq = 1$ (i)
 $n^2p^2 - n^2p^2q^2 = 11$ (ii)
 Also, we know that $p + q = 1$ (iii)
 Divide equation (ii) by square of (i) and solve, we get, $q = \frac{5}{6}$, $p = \frac{1}{6}$ & $n = 36$
 Hence probability of '3' success = ${}^{36}C_3 \times \left(\frac{1}{6}\right)^3 \times \left(\frac{5}{6}\right)^{33}$

Self practice problems :

- (26) From a bag containing 2 one rupee and 3 two rupee coins a person is allowed to draw 2 coins simultaneously ; find the value of his expectation.
- (27) A box contains 2 red and 3 blue balls. Two balls are drawn successively without replacement. If getting 'a red ball on first draw and a blue ball on second draw' is considered a success, then find the mean and variance of successes.
- (28) Probability that a bulb produced by a factory will fuse after an year of use is 0.2. If fusing of a bulb is considered an failure, find the mean and variance of successes for a sample of 10 bulbs.
- (29) A random variable X is specified by the following distribution law :

X	2	3	4
$P(X = x)$	0.3	0.4	0.3

Find the variance of this distribution.

Ans. (26) Rs. 3.20 (27) mean = 2.1, $\sigma^2 = .63$ (28) mean = 8 and variance = 1.6
 (29) 0.6