Resistance of insects to insecticides, though first observed by John B. Smith in 1907 (Porter, 1952), did not come into prominence until 1914, when Melander found the San Jose scale, Aspidiotus perniciosus Comst., unaffected by a dose of lime sulphur ten times greater than that which successfully controlled it in the past. This rang the bell of alarm and entomologists all over the world started testing the resistance of various insect species to insecticides; so much so that at present many insect species are known to have developed resistant strains. Quayle (1916) found the California red scale, Aonidiella aurantii Mask and black scale, Saissetia oleae Bernard resistant to HCII fumigation, while Boyce (1923) discovered the same phenomenon for Drosophila melanogaster Meigen and Aphis gossypii Glov. Gough (1939) observed a progeny of Tribolium confusum Duval resistant to HCII and Mosna (1947) described a strain of Culex molestus Forskal (pipiens autogynicus) resistant to DDT. Deonier and Gilbert (1950) reported increased resistance to DDT in both the larvae and the adults of Aedes taeniorhynchus Wicd., and Aedes sollicitans Walker.

Reports on the development of DDT-resistance in
human body louse are somewhat vague. As pointed out by Hurlbut et al. (1952) it is not clear whether the failure of DDT to control lice in Korea was a consequence of wide and effective use of this insecticide or that the Korean lice were naturally more resistant than the European strains. Busvine and Harrison (1953) after rearing six colonies of body lice under laboratory conditions for at least one generation tested them for insecticide-resistance and found that resistance of adults declined with age. This is somewhat contradictory to the findings of King (1950) that Pediculus humanus corporis de G. does not show increased resistance to DDT after exposure to sublethal dosages.

Kilpatrick and Fay (1952) studied the resistance of the oriental rat flea, Xenopsylla cheopis Roth to DDT and found that under selection exerted by exposure to 5% DDT in Pyrophyllite applied as a dust at the rate of 50 mg. per square foot, the oriental flea showed increased resistance through F3 generation. Another striking fact noted by these workers was that in contradiction to many insect species, the mortality was much higher (75%) in females than in males (43%) of this species.

DDT-resistance has also been reported in Blatella germanica Linn. (Heal et al., 1953) and Munson
(1953) observed that female nymphs of *Periplaneta americana* Linn. were more resistant to DDT than the male nymphs. Roaches stored at temperatures which produce relatively saturated lipids were markedly less resistant to DDT than those stored at temperatures producing unsaturated lipids.

Numerous investigations have been made on the insecticide-resistance of the housefly, *Musca domestica* which is known to have developed strains resistant to a number of chlorinated hydrocarbon insecticides and Pyrethrins. It is, however, a curious fact that no insecticide-resistance has yet been reported under natural conditions in the case of the Indian housefly, *Musca nebulo*, inspite of the fact that houses are being regularly sprayed with DDT for the last several years. Pal (1951), however, raised a DDT-resistant strain of this species by selective breeding under laboratory conditions, but the degree of resistance developed never reached the high levels of resistance which have been reported in the case of *Musca domestica*.

Though the houseflies readily develop insecticide-resistance in the laboratory, there is a considerable variation in the rate of development of such resistance because of the genetical differences, climatic factors,
concentrations and formulations of the chemicals used, time of insecticidal applications, number of generations in the year and some unknown factors. Thus houseflies are known to have developed DDT-resistance as early as the first season of insecticidal applications and as late as the sixth season.

Pimental, et al. (1953) state that the rate of development of insecticide-resistance in Musca domestica not only depends on the intensity of selection but is also related to the chemical nature of insecticides used, as for instance DDT and gamma BHC-resistance proceeds rapidly while Parathion-resistance increases slowly and the rate of development of Dieldrin-resistance is intermediate between the two groups of insecticides mentioned. Another very important point is the difference in the degree of resistance obtained by various workers, because of their using different solvents. Busvine (1951) found a particular strain of housefly to resist a dose of DDT in oil 13 times than that resisted by a susceptible strain, whereas this difference with DDT in acetone was 300 times.

The degree of insecticide-resistance also depends on testing techniques. As reported by Busvine (1951), two strains of houseflies were equally affected by DDT in oil applied to the thorax whereas only one of them
was resistant to the paralyzing effect of DDT applied as dry deposit on glass. The other one readily succumbed to such an application, inspite of the fact that the flies of this strain recovered when removed from the treated surface. Pimentel, et al. (1953), however, argue that there is a limit to which a strain can become resistant to a particular chemical and a similar report has been given by Pal, Sharma and Krishnamurthy (1952) in case of Musca nebulo, which developed DDT-resistance quickly in the first three generations of selection but after that ceased to show any increased tolerance.

Researches on resistant strains of Musca domestica have shown that flies resistant to an insecticide may also become resistant to other insecticides. Keiding and Van Deurs (1949) observed a DDT-resistant strain of Musca domestica which was resistant to DDT and Methoxychlor but not to gamma BHC, Chlordane and Toxaphene. On the other hand a DDT-resistant strain showing tolerance for gamma BHC, Aldrin, Dieldrin, Heptachlor and Toxaphene has been reported by March and Metcalf (1951). Again Harrison (1950) observed Pyrethrum resisting capacity in a DDT-resistant progeny which was susceptible to gamma BHC. Bruce and Decker (1950) have rather generalised this discrepancy and state that the aquisition of tolerance
for one chemical may predispose a strain to rapid development of resistance to other insecticides. There are, however, any exceptions to this rule, as for instance it has been found out that Methoxychlor-resistant flies are not resistant to DDT, whereas DDT-resistant flies are resistant to Methoxychlor.

Busvine (1951) found a DDT-resistant strain of Musca domestica somewhat resistant to pyrethrins but not to any other chlorinated hydrocarbon insecticide, in contrast to another DDT-resistant strain from Sardinia — prevalent there because of DDT, Chlordane and gamma BHC spraying — which was susceptible to Pyrethin but showed some resistance to insecticides such as Dieldrin and Toxaphene which were never used on that island. This led him to conclude that resistance to gamma BHC and Chlordane is probably independent of DDT tolerance, while the resistance to gamma BHC, Chlordane and Dieldrin are linked together. It is quite possible then that a single defence mechanism copes with a range of these compounds.

That there is a decline in the DDT-resistance of houseflies when reared under laboratory conditions without any exposure to insecticides for several generations, has also been investigated. Harrison (1950) on rearing a four times resistant strain of Musca domestica without
any insecticidal contact for six months, found it to be only 1.2 times as resistant as the non-resistant strain. Somewhat similar results have been obtained in the case of Musca nebulo by Pal, et. al. (1952), who found this species completely losing its DDT-resistance in only three generations of rearing in the absence of the insecticide.

Contrary to the above findings, there are records of Musca domestica retaining its DDT-resistance even after thirty generations of freedom from DDT and workers at Riverside, California have shown their resistant flies to be capable of maintaining their insecticidal resistance for more than thirty generations (Brown, 1951).

It is possible that because of their producing fewer progeny, having a longer life-cycle and higher respiratory rates, the resistant flies are not so well adapted physiologically to their environment as the susceptible ones. Thus there can be a gradual loss of resistance among field strains of flies as the susceptible strains literally out-reproduce the resistant ones (Bruce, 1952).

Pimental, et al. (1953) also reported the loss of DDT-resistance in Musca domestica and suggested that such a loss depends on the initial level of resistance. They also pointed out that the number of generations required to accomplish complete loss of DDT-resistance in houseflies may range from ten to twenty.
Various theories have been propounded to explain the mechanism of insecticide-resistance in insects. Moore (1933) found that the main difference between resistant and non-resistant scale insects in California were due to the differences in their reaction to concentration, exposure and the temperature at which fumigation was conducted; while Hardman and Craig (1941) explained the phenomenon of insecticide-resistance on the basis of the power of closure and opening of spiracles. Quayle (1943), reasoning on the behaviour of the two strains towards protective stupefaction, did not believe that the ability to keep spiracles closed could explain the phenomenon of insecticide resistance.

Weismann (1947) tried to explain DDT-resistance in houseflies on a morphological basis and observed that DDT-resistant houseflies had thickened pulvilli and articular membranes of the joints which prevented lethal quantities of DDT from reaching the site where physiological actions could take place. His conclusions, however, could not be supported by subsequent workers. Bettini (1948) and March and Metcalf (1949) on injecting DDT solutions directly into the haemocoel of the flies found the same degree of resistance as was noted by topical applications.
and thus concluded that neither thickness of the cuticula nor general body vigour were in any way concerned with the power of resistance. Again, the differences in the dimensions of the tarsal segments of the two strains taken were neither sufficiently uniform nor large enough to indicate that they were of any value to the flies in developing insecticide-resistance.

That the site of DDT application has a bearing on resistance has been observed by Neri (1943). He observed varying mortalities on applying DDT to various parts of the insect body. In resistant flies, however, no difference was observed except for applications on the antennae which in no case were lethal to the flies.

Ecological factors, like temperature and humidity, may play an important role in the development of insecticide-resistance. Roth and Lindquist (1953) suggested that at higher temperatures, the rate of penetration of DDT was much higher and the flies degraded DDT into some non-toxic substance with greater speed, which resulted in decreased mortality. At low temperatures, however, the penetration of insecticide was much decreased but the flies could not metabolise DDT as rapidly as at higher temperatures. Thus mortality was higher at such temperatures. Tahori and Hoskins (1953), however, argue that this difference in mortality may not be because of differences in the metabolic rates at varying temperatures but may be due
to some other conditions not fully understood. March and Motcalf (1950) also studied the metabolic processes of resistant and non-resistant flies and concluded that while both DDT-resistant and non-resistant flies metabolised DDT into DDE, the resistant flies did it at a much higher rate. Contrary to this Sternburg et al. (1950) reported that while resistant flies could metabolise DDT into non-toxic DDE and a small amount of TDA, the non-resistant strains did not possess any such power of converting the toxic chemicals into non-toxic compounds and thus died off.

That the insecticide-resistance in houseflies has a genetical basis has also been advocated. Bruce and Decker (1950) regarded it a multiple-gene factor carried out by both the parents, whereas Harrison (1951) as a result of individual crossing experiments with reciprocal matings between males and females of resistant and susceptible strains of Musca domestica came to the conclusion that DDT-resistance in this case was controlled by a single pair of alleles. She found that while $F_1$ generation was only slightly more resistant than the non-resistant parents, the $F_2$ generation gave 75% susceptible and 25% resistant progeny. Back-crossing $F_1$ generation with parental stocks, she obtained 100%
susceptible progeny when mating was allowed with non-resistant parent and a 50% resistant progeny when it was done with resistant parent.

Harrison's conclusions of single-gene factor for resistance though quite convincing, have one drawback. As pointed out by Busvine (1953), she used the time before knockdown by DDT as an index for resistance, a character which is not always correlated with resistance to the lethal effect of DDT and which may be inherited by a different mechanism.

The 'Theory of Multiple-gene factor' for resistance has also been supported by Busvine and Khan (1955) in the case of a gamma BHC-resistant strain of *Musca domestica*.

The above review clearly indicates that most of the work on insecticide-resistance has been done with reference to DDT alone, with little or no attention being paid to other synthetic insecticides. Again, most of the work has been done with *Musca domestica* and practically nothing is known about the causes and mechanism of insecticide-resistance even in so closely related species as the Indian housefly, *Musca nebulo*. The present work was, therefore, undertaken with a view to study the nature of insecticide-resistance, its causes and effects on the Indian housefly, *Musca nebulo*. 