JOURNAL ACADEMICA

VOLUME 2, NO. 3, September 29 2012

H. BHARDWAJ / S. HADJ ZOBIR / R. KIHAL / W. YAKHLEF / K. DAGHBOUCHE

JOURNAL ACADEMICA • NEW YORK

VOLUME 2, NO. 3, SEPTEMBER 29 2012

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Journal Academica Vol. 2(3), pp. 99-126, September 29 2012 - Zoology - ISSN 2161-3338
online edition www.journalacademica.org

Full Length Research Paper

A Study on Insect Visitors of Certain Cucurbit Vegetable Crops in an Agro- Ecosystem near Bikaner, Rajasthan, India

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Accepted September 21 2012

ABSTRACT

Pollinators, including insects play a crucial role in reproduction of flowering plants and in the production of most fruits and vegetables. The relationship between pollinators and flowering plants is one of the mutually beneficial relationships in the natural world. Without the assistance of pollinators, most plants cannot reproduce. Different pollinators prefer different types of flowers. Studying the relationships between flowers and their pollinators is thus very useful to help maintain endangered species. The loss of a pollinator could cause the collapse of an ecosystem. Pollinators are also required for the successful proliferating communities and wildlife habitats. Estimates suggest that approximately 73 percent of the world's cultivated crops are pollinated by some varieties of bees, 19 percent by flies, 6.5 percent by bats, 5 percent by wasps, 5 percent by beetles, 4 percent by birds and 4 percent by butterflies, indicating that most of the plat species rely on insects for pollination. Looking into the importance of insect pollinators, agricultural practices should be designed to incorporate the protection and sustainable management of pollinators.

Key words: pollinators, flowering plants, Cucubitaceae, insects

1. INTRODUCTION

Over the last few decades the perception has been growing among pollination biologists that pollinators have declined in numbers resulting in decreased seed and fruit set in the plants that they service. Threats to pollinators include habitat reduction, use of pesticides and other agrochemicals, invasive species, fungal, protozoan and bacterial diseases, modern agricultural practices etc.

The present study was therefore planned to observe and document insects visiting different vegetable crops belonging to family Cucurbitaceae, in an agro-ecosystem existing in the vicinity of Bikaner (Rajasthan, India) and to monitor some of their biological activities.

2. THE STUDY AREA

The state of Rajasthan is the largest state of Indian republic located between 23º3' to 20'13 N latitude and 69º30' to 78º17'C longitudes. The area under study falls in the Indian desert near Bikaner situated in Western Rajasthan along the international border. The agro-ecosystem *Vallabh Garden Agriculture Farm*, the area under study, lies 10 km away from Bikaner, at *Gharsisar* village. It is a crop field where seasonal crops are grown. It is irrigated by sewage water.

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3. METHODOLOGY

The crop field comprised of different crops but this study concentrated on insect visitors of Cucurbitaceae family only, which included cucumber, bottle gourd, ridged gourd and pumpkin. As the study was on pollinators, therefore, the flowering period in different crops was also recorded. The flower status whether solitary or in the form of inflorescence was noted. The color and size of flowers were also documented. It was also noted that whether the flowers released scent or not. Visit of a particular species to a specific flower was documented and expressed as number of visits/man/h. The insect visitors to different flowering crops were surveyed and collected every week from December 2007 to November 2008. For the study, the field area was divided into five stations from where the insect visitors on flowers were collected. An indigenously designed cage net of 1mx1mx1m size and sweep net were used for insect collection. The insects collected by the above method were transferred to killing bottles, killed and preserved. Large winged insects were put to dry preservation by pinning them in insect boxes, while smaller insects were preserved in 70% alcohol. The fauna were sorted out group-wise and help from the Section of Entomology, Department of Agriculture, Bikaner and Desert Regional Station of the Zoological Survey of India, Jodhpur was also taken for identification and for confirmation. Besides, the reference collection in the Department of Zoology, Dungar College was also consulted.

4. RESULTS

Hymenoptera

Apidae

This family comprising of the bees was the dominating family amongst hymenopterans represented by three species *viz*. *Apis mellifera, Xylocopa fenestrata and X. virginica.* Most number of visits was noted on flowers of *L. cylindrica* followed by *C. melo, L. siceraria* and *C. maxima*. In April and May it was noted in good numbers on *Cucumis melo* making 192 and 141 visits /man /h respectively. During the next four months the bee population showed a decline while, in October its population again increased and was noted on flowers of *Luffa cylindrica*, making 452 visits /man/h. The honeybee showed more foraging activity in the afternoon. *Xylocopa fenestrata* and *X. virginica* were the two carpenter bees observed during the present study from the agro-ecosystem. Although *X. fenestrata* was observed nearly throughout the study period as a frequent visitor, *X. virginica* was rarely observed. The visits of *X. fenestrata* on different flowers ranged from 1 to 266 visits /man/h. Most number of visits was noted on flowers of *L. cylindrica*, followed by *C. melo* and *C. maxima*. It was a major contributor to the bee family when the flowers of *Luffa cylindrica* were present in the crop field making 182 to 266 visits /man/h. It was intermittently documented. The visits of *X. virginica* ranged between 1 to 5 visits /man/ h only. It preferred *Luffa* flowers. *X. virginica* was found to show more foraging activity in the forenoon, while, *X. fenestrata* in the afternoon.

Vespidae

Two wasps observed to visit flowers of different crops during the present study were *Polistes carolina* and *Polistes sp. P. carolina* preferred flowers of *Luffa cylindrica* and *C. melo*. Of these, *Polistes*

sp. was reckoned nearly throughout the study period as a frequent visitor, while, *P. carolina* was observed from April to November only, as a rare visitor. In April, 18 visits/man/h on *Luffa*, in September and 14visits/man/h on *Lagenaria* were documented. Most number of visits was noted on *C. melo* followed by *L. siceraria* and *L. cylindrica*. While, *P. carolina* preferred to visit flowers more during forenoon, *Polistes sp.* showed this activity more during afternoon.

Megachilidae

Only one member, *Coelioxys capitatus* belonging to this family was reckoned during the present study visiting different flowers. It was a rare visitor. The number of visits ranged from 1 to 9 visits/man /h. The insects were found to visit flowers of *Cucumis*. As observed in small numbers not much difference in the time of the foraging activity could be adjudged. In April it was present in maximum numbers making 9 visits /man/h.

Scoliidae

Scolia specifica was only one wasp representative of this family documented from the crop field. It was observed nearly during all the months of study, although its number was high during May to October. Its most number of visits was noted on flowers of *L. cylindrica* followed by *L. siceraria*, *C. melo* and *C. maxima*. It was found to visit the flowers of *Luffa cylindrica* at 469 visits/man/ h and on flowers of *Lagenaria* at 292 visits/man/ h in the month of September when it was noticed in maximum number. These were also observed frequently on flowers of *Cucumis*. *S. specifica* preferred to visit flowers more during forenoon.

Sphecidae

The sole member belonging to this family documented from the study area was *Sphex sp.* Occurrence of *Sphex sp.* Except for February and October; it was noted during all other months. In July it was noticed in maximum number. Its visits on different flowers ranged from 1-14 visits/man/h. It was a frequent visitor on the crops. The wasp was found to prefer flowers of *Luffa* and *Cucumis*. It was not found to visit the flowers of *Lagenaria* at all. This wasp also showed more foraging activity during forenoon.

Ichneumonidae

Ichneumonid wasp *Xanthopimpla stemattor* was documented on flowers of *Lagenaria* and *Luffa*. It was intermittently observed during the study period. Although, the flowers of *L. cylindrica* were rarely visited by the wasp, it was found to make frequent visits to flowers of *L. siceraria*, the number ranging from 19 to 22 visits /man/h, especially during forenoon. Its maximum visits were observed in the month of September. *X. stemattor* was found to show more foraging activity in the forenoon as compared to afternoon. It was a frequent visitor on the crops. Its most number of visits was noted on *L. siceraria* followed by *L. cylindrica*.

Lepidoptera

This order includes moths, skippers and butterflies. These 'scale winged insects' possess a proboscis for feeding nectar from flowers along with which they also carry pollen and serve as important pollinators of several agricultural crops. In all 12 *Lepidopteran* representatives of 9 families were documented to visit different flowers during the course of study which are as follows:

Danaidae

Only one member *Danaus chrysippus*, commonly known as the 'plain tiger' belonging to this family was reckoned from the agro ecosystem during the present study. It was noted through out the study period. Except for pumpkin, the butterfly was observed to visit flowers of all the other crops grown in the field. Its most number of visits was noted on flowers *L. cylindrica* followed by *C. melo*, *L. siceraria* and *C. maxima*. A minimum of 5 visits /man/h were observed in the month of January. The butterfly frequently visited flowers of crops like cucumber in the month of April to August, cucurbits (except pumpkin) during May to October. On all these crops the number of visits ranged between 6 to 35 visits /man/h. It was found to visit the flowers more during forenoon as compared to afternoon.

Lycaenidae

Lampides boeticus was the only representative belonging to this family which was observed during the present study. Except for February, March and September, it was observed during rest of the nine months. Of the various crops, it preferred to visit flowers of only cucumber and ridged gourd and was not at all observed on rest of the crops (bottle gourd, pumpkin) in the field during the study period cultivated. It was a frequent visitor. It was found to visit flowers of cucumber at the rate of 48 visits /man/h in the month of May. The flowers of ridged gourd were rarely visited (3-4 visits/man/h). It showed complete absence from the field during February, March and September. It preferred to visit the flowers more in the afternoon.

Nymphalidae

Vanessa cardui and *V. annabela* were the members belonging to this family and reckoned from the agro ecosystem during the present study. As *V. annabela* was observed throughout the year it was found to visit all the crops, while, *V. cardui* was observed intermittently for six months and was noted to visit cucumber flowers only. The visits of *V. annabela* ranged between 1 to 5 visits /man/h. It usually preferred to visit the flowers in the forenoon. The other nymphalid, *V. cardui* was found to visit only flowers of cucumber. It was a rare visitor making 1 visit/man/h. This butterfly also preferred to move about and visit flowers in the forenoon as did *V. annabela*.

Pieridae

This family comprising of yellow butterflies was represented by two species *viz*., *P. edusa* and *Catopsilia pomona*. *C. pomona* was noted throughout the study period, although in small numbers. Further, it was found to visit flowers of all the crops during the study period. Its population too was found to be high during winter months of October and November. This butterfly preferred to visit the flowers more during forenoon. *P. edusa* showed a different trend and was documented from April to January, with maximum number of 28 visits /man/h in the month of November. It was also found to be active during forenoon.

Hesperidae

Only one skipper, *Hesperilla ornata* was noted from the study area. This butterfly was not observed during January to April. Most number of visits was noted on flowers of *C. melo*, *L. cylindrica*, followed by *L siceraria*. It made its appearance from May onwards up to December and was found to visit flowers of bottle gourd and ridged gourd, showing preference towards the latter. During July and August when the flowers of cucumber were in their full bloom the

skipper showed greatest preference towards them visiting these flowers at the rate of 26 and 39 visits/man/h respectively during the two months. In August it was noticed in maximum number. *H. ornata* was found to visit the flowers more during forenoon.

Pyralidae

This family of moths was represented by two members, *viz*. *Margaronia indica* and *Hymenia fascialis* during the present study. *H. fascialis* was reckoned throughout the study period except in the month of February when it was not documented. It was a frequent visitor while *Margaronia* was a rare visitor. Most number of visits were noted on *L. siceraria*, *L. cylindrica*, followed by *C. melo* and *C. maxima*. Its number of visits ranged from 5 to 207 visits /man/h on different flowers present in the agro-ecosystem. It was mostly found on flowers of bottle gourd, ridged gourd and cucumber. It was frequently also noted on flowers of pumpkin. It was found to visit flowers more during forenoon. The moth was noticed in large numbers in the month of October. *M. indica*, in general was hardly observed from November to April and showed its appearance from May and continued to appear till October. Most number of visits was noted on flowers of *C. melo*, *L. siceraria* and *L. cylindrica*l. Its maximum number of visits was noted during August (20 visits /man/h). Its order of preference towards the flowers was cucumber followed by ridged gourd and bottle gourd. *M. indica* was found to visit the flowers during afternoon.

Arctiidae

Only one species, *Utethesia pulchella* belonging to this family was collected from the agro-ecosystem during the present study. It was documented throughout the study period except during November. Its number of visits ranged from one in February to 101 visits /man/h in April. It was observed to visit flowers of bottle gourd and cucumber. *Utethesia pulchella* preferred to visit the flowers in forenoon. It was a frequent visitor.

Noctuidae

Agrotis ipsilon belonging to family Noctuidae was yet another moth observed on flowers of different crops located in the agro- ecosystem during the present study. It was a rare visitor. Most number of visits was noted on *C. melo*, *L. siceraria* and *C. maxima*. This moth although showed its appearance from March to November was found in very few numbers. The number of visits ranged from 1 to 4 visits /man/h concentrating mostly on flowers of bottle gourd. It was also found to visit flowers in forenoon.

Gelechiidae

This family was represented by *Pectinophora gossypiella* which was reckoned throughout the study period except for winter months of January and February. Its maximum visits of 73 visits /man/h were recorded during September on flowers of bottle gourd. It was a frequent visitor throughout the year. Besides this crop, it was observed on flowers of ridged gourd and cucumber. *P. gossypiella* was found to visit the flowers more during forenoon as compared to afternoon.

Diptera

The two winged insects comprising of true flies belong to this order which possess sponging and lapping type of mouth parts. Most of the flies survive on honeydew, nectar or exudates of various plants and animals, and decomposing organic matter. The *dipterans* noted to visit flowers of various crops cultivated

in the agro-ecosystem studied belonged to the following families:

Culicidae
Culex pipiens was the only member belonging to this family found to visit the flowers and reckoned throughout the study period except in the month of September. These occurred in large numbers during November and December. *C. pipiens* was observed on the flowers of *C. maxima* followed by, *Cucumis* and *Lagenaria*. It was not recorded from the flowers of *Luffa*. It was a rare visitor. Its maximum visits of 14v/m/h on *C. maxima* were noted during December. It preferred to visit the flowers in the forenoon.

Muscidae
This family was represented by *Musca domestica* and was reckoned throughout the study period. Maximum of 166 visits /man/h by *M. domestica* were noted on flowers of *Lagenaria* in the month of October. It was a frequent visitor. This was the month when it was present in maximum numbers. This *Dipteran*, although recorded on flowers of *Cucumis* and *Luffa*, was found to prefer *Lagenaria*. The flies preferred to visit the flowers in the forenoon.

Syrphidae
The member belonging to this family collected during the present study was *Eristalis sp.* which was noticed throughout the study period except in the month of November. Its maximum number of visits on various flowers was noted in the month of April. It was a frequent visitor. It was found to visit the flowers of *Lagenaria*, *Luffa* and *Cucumis*. It showed preference towards cucumber on which 80 visits/man/ h was documented in the month of April. It was noticed to visit the flowers in forenoon as compared to afternoon.

Tephritidae
The fly belonging to this family documented during the present study was *Dacus cucurbitae* which was collected throughout the study period except November. It was observed to visit flowers of cucumber, ridged and bottle gourd. It showed slightly more preference towards *Luffa* flowers on which 15 visits /man/h) was recorded in the month of September. It was also noticed to visit the flowers in forenoon.

Tabanidae
Tabanus sp. was the member belonging to this family which was observed in the agro-ecosystem.. It was present throughout the study period in good numbers and was noted on flowers of *Cucumis*, *Lagenaria* and *Luffa*. It preferred the flowers of *Luffa*, but was never documented on the flowers of *C. maxima*. In both forenoon and afternoon it was noticed in almost equal numbers.

Sarcophagidae
Only one member *Sarcophoga bravicornis* belonging to this family was reckoned during the present study visiting the flowers of *Cucumis*, *Lagenaria* and *Luffa*. The number of visits ranged from 1 to 13/man/h. In October it was present in maximum numbers. It was not observed in the month of November, December, February and April. This dipteran preferred to visit the flowers more during forenoon.

Coleoptera
The *coleopteran*s bearing 'sheathed wings' or 'elytra' are the insects commonly known as beetles and are found in almost all habitats, interacting with their ecosystem in several ways. This group was represented by only one family during the present study:

Coccinellidae
Only two insects belonging to order *Coleoptera* were observed on flowers of different crops in the agro-ecosystem studied, both belonged to family Coccinellidae. These were *Coccinella septempunctata* and *Menochilus sexmaculatus*. *C. septempunctata* was documented more frequently as compared to *Menochilus sexmaculatus* which was rarely observed. The former was noted on flowers of cucumber and pumpkin. Both the beetles were not documented on flowers of *Lagenaria* and *Luffa*. These were found more during forenoon as compared to afternoon.

Neuroptera
This order includes lacewings, ant lions, dobson flies, alder flies and snake flies are insects which have 'nerve wings'. In most cases the adults of these insects are predators, the non-predatory species usually feed on nectar, pollen and honeydew. Insect species belonging to the following family was collected during the present study:

Chrysopidae
Chrysopa sp. was the only member belonging to this family which was seen to visit flowers of only on *Cucumis*. This insect was not documented from June to November. It was a rare visitor. It was generally found to visit flowers during forenoon.

Hemiptera
This order comprising of true bugs possessing a beak for sucking the sap and bearing 'hemi elytra' are quite distinctive and during the present study the following families were documented:

Pentatomidae
Only one species belonging to family Pentatomidae were observed to visit flowers of various crops in the agro-ecosystem studied *viz*., *Nezara viridula*. Its visits were noted on only flowers of *C. melo*. The number of visits of *N. viridula* ranged from 1-16 visits /man/ h. Its maximum number was noticed in April. The number of visits was observed to be more during forenoon. Flowers of *Lagenaria*, *Luffa*, and *Cucurbita* were not at all visited by both of the insects as observed during the present study. It was a rare visitor to the crops.

Pyrrhocoridae
This family was also represented by two species *viz*. *Dysdercus cingulatus and D. koengii*. *D. cingulatus* was reckoned throughout the study period and was as a frequent visitor noted on nearly flowers of all the crops. Most number of visits was noted on *C. melo* followed by *L. siceraria* and *L. cylindrica*. Its number of visits on various flowers *viz*. *Cucumis*, *Lagenaria* and *Luffa*, ranged from 1-30 visits/man/h. Its maximum visits were noted during the month of June on flowers of *Cucumis* melo (30 visits /man/h). Not much difference in the time of visit was observed with respect to this insect species. *D. koengii* was documented during December to May. It was a rare visitor. Rarely, it was also seen to visit flowers of *Cucumis*. It was generally found to visit the flowers more during forenoon.

Orthoptera
These 'straight winged' insects include grasshoppers, crickets and locusts which are generally phytophagous, many being omnivorous.

Acrididae
This family was represented by two insects' *viz*. *Ochrilidia sp.* and *Chrotogonus sp. Ochrilidia* was frequently noted from March to November, while, *Chrotogonus sp.* was intermittently noted during the study

period. *Ochrilidia sp.* was documented on flowers of *Cucumis*, *Luffa* and *Cucurbita*. *Chrotogonus sp.* was observed only on *Cucumis*. Both the *acridids* were never seen to visit flowers of *Lagenaria*. *Ochrilidia sp.* was noted as a rare visitor. Maximum visits of *Chrotogonus* (5 visits/man /h) on flowers of *Cucumis* were noted in August. These were noted on the flowers mostly during forenoon.

Odonata

Dragon flies and damsel flies bearing 'strong teeth' are predacious insects which belong to this order. The *odonates* documented during the present study belonged to the following families:

Libellulidae

Only one dragon fly *Pantala flavescens* was observed to visit flowers present in the agro-ecosystem studied. It was documented throughout the period of study. The number of visits ranged from 1 to 40/man/ h on different flowers. These were also seen to visit the flowers mostly in the forenoon.

Coenagrionidae

This family was represented by only *Argiocnemis femina*. The adults were seen from April to October and their number of visits ranged from 1 to 7/man/ h on different flowers. Its maximum number was noticed in the month of April. They visited flowers of *Cucumis* and *Lagenaria*, although *Luffa* flowers were also in their full bloom showing their preference. It was a rare visitor. These were also reckoned more during forenoon.

Crops and their insect visitors

Cucumber (*Cucumis* melo)

Cucumber, belonging to family Cucrubitaceae, commonly known as 'kakri' or 'tar', was one of the major crops grown in the agro-ecosystem studied. The flowering season of the crop was from April to August. The flowers were solitary, yellow in color and scentless. Male and female flowers bloom separately and therefore are cross-pollinated. Out of the total 36 insects documented during the period of study, 34 insects belonging to eight orders were found to visit cucumber flowers.

All the insect representatives belonging to order Neuroptera, Orthoptera and Odonata which were documented during the present study visited the flowers of *Cucumis*; while 85.71% of *Lepidopteran* and dipteran, 75% of hemipteran, 70% of *hymenopteran* and 50% of *coleopteran* insects visited them.

Seven species belonging to order *Hymenoptera* were observed to visit the flowers of *Cucumis* which included *Sphex sp.*, *Polistes sp.*, *A. mellifera*, *X. fenestrata* (17.85% each), *S. specifica* and *C. capitatus* (10.71% each) and *P. carolina* (7.14%). The lepidopterans were the major forms found to visit the flowers of cucumber during the present study. In all twelve *Lepidopteran* species were noted which included *V. annabela*, *C. pomona*, *U. pulchella*, *L. boeticus*, *H. fascialis* each contributing 12.19%, followed by *P. gossypiella* (9.75%), *H. ornata* and *D. chrysippus* (7.31% each), *M. indica*, *Pieris edusa* (4.87% each), *A. ipsilon* and *V. cardui* (2.43% each). Six dipteran forms which were frequently seen to visit the flowers of cucumber during the present study were Sarcophaga carnaria which contributed to only 10.71 %, while, the others which included *C. pipiens*, *Eristalis sp.*, *Tabanus sp.*, *D. Cucurbitae* and *M. domestica* each contributed to 17.85% of the total population. Only one member belonging to order *Coleoptera* and *Neuroptera* each were documented on the flowers of *Cucumis* which were *C. septempunctata* and *Chrysopa sp.* respectively. Among

hemipterans, *D. cingulatus* was the major form visiting cucumber flowers contributing to 55.55% followed by *N. viridula* (33.33%) *and D. koengii* (11.12%). *Orthopterans* were represented by two species *Ochrilidia sp.* contibuting to 55.55% and *Chrotogonus sp.* sharing 44.45% while, between *odonates A. femina* was major visitor (66.66 %) as compared to *P. flavescens* (33.34).

Bottle gourd (*Lagenaria* siceraria)

Bottle gourd commonly known as 'Lauki' or 'Gheeya' was another major summer crops cultivated in the field during April to October, flowering period being May onwards. *Lagenaria* siceraria also has stalked flowers, which are monoecious, solitary, scentless and creamy or white in color and are cross-pollinated as presented in Table 1. Of the total number of insect species documented during the present study, only 66% were found to visit the flowers of bottle gourd.

Insects belonging to order Coleoptera, Neuroptera and Orthoptera were never recorded on flowers of *L. siceraria* during the present study, while, the visits of *odonates* was 100% followed by *dipterans* (85.71 %), lepidopterans (71.42 %), hymenopterans (40 %) and *hemipterans* (25 %).

The flowers of bottle gourd were visited by only four hymenopterans *viz*., *S. specifica* (31.57 %), *A. mellifera* (26.31 %), *X. sexmaculatus* and *Polistes sp.* (21.05 % each). Ten *Lepidopteran* species which were seen to visit the flowers of bottle gourd included *U. pulchella*, *H. fascialis*, *P. gossypiella*, *M. indica* and *C. pomona* (11.76 % each), *A. ipsilon* (9.80 %), *P. edusa*, *D. chrysippus*, *Hesperilla ornata*. and *V. annabela* (7.84% each). Among *dipterans* all the six species were documented on flowers of *L. siceraria*. These included *Eristalis sp*., *Tabanus sp*., *M. domestica* and *Sarcophaga bravicornis* (19.35 % each), *C. pipiens* (12.90 %) and *D. cucurbitae* (9.67 %). Only one hemipteran, *D. cingulatus* was observed to visit the flowers of bottle gourd. Both the odonates, namely *A. femina* and *P. flavescens* (50 % each) were noted to visit the flowers of *L. siceraria*. During the present study 23 insects belonging to Hymenoptera, Lepidoptera, Diptera, Hemiptera and Odonata were found to visit the flowers of bottle gourd while, insects belonging to orders Coleoptera, Neuroptera and Orthoptera were never recorded on flowers of *L. siceraria*.

One of the frequent visitors to the flowers of cucumber during the present study were, the dipterans, which included *C. pipiens*, *Eristalis, Tabanus*, *D. cucurbitae* and *M. domestica*. Although, all the forms were documented throughout the flowering period, *Eristalis*, *M. domestica* and *Tabanus* were major visitors. *D. cucurbitae* was one of the visitors to the flowers of cucumber making 2–7 visits / man / h.

Only one *coleopteran*, *C. septempunctata* was rarely documented on the flowers of *Cucumis* during the present study.

Chrysopa was the only *neuropteran* collected very rarely collected from the flowers of *Cucumis* during the present study.

Of the three hemipteran species documented during the present study *viz*. *D. cingulatus*, *D. koengii* and *N. viridula*, the first one was frequently noted on flowers of *C. melo*, while, the other two forms were very rarely observed.

The two *orthopterans viz*. *Ochrilidia* and *Chrotogonus* and two *odonates* namely *A. femina* and *P. flavescens* were all rare forms visiting flowers of cucumber.

Ridged gourd (*Luffa cylindrica*)

Yet another major cucurbit crop cultivated in the agro-ecosystem studied was *Luffa cylindrica*, commonly known as ridged gourd. The flowering started

May onwards and continued up to October, during which various insects visited them. The flowers are solitary, yellow in color, scentless and although both male and female flowers are present on the same plant, cross-pollination takes place.

Of the total number of insects documented during the present study, only 25 were observed to visit the flowers of *Luffa*. Insects belonging to order Coleoptera and Neuroptera were not recorded, while, the insects belonging to other orders were hymenopterans (80%), *dipterans* (71.42%), lepidopterans (64.28%), *odonates* and *orthopterans* (50% each) and hemipteran (25%).

S. specifica, *A. mellifera*, *P. carolina*, *X. fenestrata* (15 % each), *X. virginica*, *Sphex sp.*, *Xanthopimpla stemmator* and *Polistes sp.* (10 % each) were the eight hymenopterans species found to visit the flowers of ridged gourd during the present study. Nine *Lepidopteran* species which were observed on flowers of *Luffa*, were *D. chrysippus*, *H. fascialis*, *P. gossypiella*, *M. indica*, *H. ornata*, *V. annabela*, *C. pomona* (12 % each), *L. boeticus* and *P. edusa* (8% each). The *dipterans* were represented by *M. domestica*, *Eristalis sp.* (25 % each) and *Sarcophaga bravicornis*, *D. cucurbitae* and *Tabanus sp.* (16.66 % each), visiting the flowers of ridged gourd. Only one *hemipteran* observed was *D. cingulatus*, one *orthopteran Ochrilidia sp.* and one odonate *P. flavescens* was noted on the flowers of this vegetable crop. Of the total number of insects documented during the present study, only 25 were observed to visit the flowers of *Luffa*. Insects belonging to orders *Hymenoptera*, *Lepidoptera*, *Diptera*, Orthoptera, *Hemiptera* and *Odonata* were recorded, while, *Coleoptera* and *Neuroptera* were not noted on these flowers.

Pumpkin (*Cucurbita maxima*)

Pumpkin, *Cucurbita maxima*, in India called 'Sitaphal', 'Halwa Kaddu' or 'Kashiphal', was also cultivated in the crop field. The flowering period of this crop was observed for two months that is November and December. The flowers were the largest of all the flowers and were solitary, yellow colored scentless and cross-pollinated.

Only one fourth of the total number of insects documented, were found to visit the flowers of pumpkin during the present study. The insects belonging to Neuroptera, Hemiptera and Odonata were never reckoned from these flowers while Orthoptera and Coleoptera contributed 50% each, followed by Lepidoptera 35.71%, Hymenoptera 20% and Diptera 14.28%.

Only two hymenopterans *viz*. *S. specifica* (66.66 %) and *A. mellifera* (33.34%) visited the flowers of *C. maxima*.

The *Lepidopteran* fauna which was found to visit pumpkin flowers included *P. edusa*, *H. fascialis*, *A. ipsilon*, *V. annabela*, *C. pomona* (20 % each). Only one dipteran observed was *C. pipiens*, one *coleopteran*, *M. sexmaculatus* and one orthopteran *Ochrilidia sp.* was observed on the flowers of this crop.

In all, eleven insects belonging to five orders *viz*. Hymenoptera, Lepidoptera, Diptera, Coleoptera and Orthoptera were found to visit the flowers of pumpkin, while, *neuropterans*, *hemipterans* and *odonates* were not observed on them during the present study.

5. DISCUSSION

The present findings get support from the work of Thapa (2006) who also reported *A. mellifera*, *A. cerena*, *A. dorsata*, *Xylocopa*, *V. orientalis*, *V. magnifica* and *Sphex* as insect pollinators of cucumber. According to Hodges & Baxendale (2007), cucumber flowers are exclusively pollinated by honeybees and other insect

pollinators. During the present observations also it was found that *A. mellifera* visited *Cucumis* flowers most number of times (192 visits / man / h), especially in the month of April, while, all other *hymenopteran* visitors were rarely found on these flowers. Goodwell & Thompson (2007) suggested *A. mellifera* to be a better pollinator than *Bombus impatiens*. Honeybees have also been observed as pollinators of *C. melo* by Carrillo et al. (2007). According to Cervancia & Bargonha (2000) also, the most common flower visitors of cucumber were *Xylocopa chorna*, *X. philippinensis*, *Megachile afrita* and *A. dorsata*.

During the present study twelve *Lepidopteran* species were documented on the flowers of *C. melo* which included *V. annabela*, *V. cardui*, *C. pomona*, *P. edusa*, *D. chrysippus*, *U. pulchella*, *L. boeticus*, *M. indica*, *H. fascialis*, *H. ornata*, *P. gossypiella* and *A. ipsilon*. Of these, *H. fascialis* was the major visitor followed by *L. boetius*, both visiting the flowers quite frequently during May to August. The other *Lepidopteran* species which were quite often documented mostly during July and August were *M. indica* and *H. ornata*, while rests of the species were rarely observed to visit flowers of *C. melo*. Earlier Thapa (2006) also reported Presis butterfly, skipper *Pleopidas methias* and *Papilio machon* as insect pollinators of this plant.

D. cucurbitae was one of the visitors to the flowers of cucumber making 2–7 visits / man / h, which is supported by the earlier report of Thapa (2006) who has also found this fruit fly to be a pollinator, while, *Bactrocera Cucurbitae* another dipteran has been reported to be a major pest of *C. melo* by Dhillon (2005). Earlier Thapa (2006) reported pumpkin beetle *Aulacphora foveicollis* and pollen beetle *Chiloloba acuta* besides lady beetles *Coccinella* as insect pollinators of cucumber.

No other records of *neuropterans*, *hemipterans*, *orthopterans* and *odonates* as visitors of cucumber flowers are available in the literature referred.

The flowers were visited by four *Hymenopteran* species *viz*. *A. mellifera*, *X. sexmaculatus*, *Polistes sp.* and *S. specifica*. Earlier Morimoto et al. (2004) also observed honeybee *A. mellifera* as active flower visitors of *L. siceraria* in Kenya which is in support of the present findings. Fomekong et al. (2008) also reported *A. mellifera* to be a pollinator of cucurbitaceous plant. *A. mellifera* as a dominant species visiting flowers of Cucurbitaceae was also reported by Rust et al. (2003). In all, 43 species of bees were collected from the flowers of *E. elaterium* a member of Cucuritaceae, of which 33 bee species were found to carry pollen. The present findings also get support from the findings of Valdivia & Niemeyer (2006) who also documented *A. mellifera* and *Polistes buyssoni* to visit flowers of cucurbit *Escallonia myrtoidea*. Besides these, 16 other *hymenopteran* species were reported to visit these flowers by them. While studying the pollination ecology of *Citrullus lanatus* a cucurbit, Njorage et al. (2004) found that this species depends heavily on *A. mellifera* for pollination. Other pollinators identified were *Xylocopa* bees, *halicted* bees and *hypotrigona* bees which corroborate the present findings.

Lepidopteran species which were found to visit the flowers of bottle gourd during the present study included *C. pomona*, *P. edusa*, *D. chryhippus*, *V. annabela*, *U. pulchella*, *H. fascialis*, P. gossypiella, *M. indica*, *A. ipsilon* and *H. ornate*. Srivastava (2000) also reported two lepidopterans, hawk and pyrillid moth as pollinators of cucurbits. Six *Lepidopteran* species were documented by Valdivia & Niemyer (2006) to visit flowers of

cucurbit *E. myrtoidea* including a *nymphalid*, *V. carye*. Thapa (2006) reported only one *Lepidopteran Lampides boeticus* to visit the flowers of *L. siceraria*.

Six *dipterans* were documented on the flowers of *L. siceraria* which included *Eristalis sp*., *Tabanus sp*., *M. domestica*, *C. pipiens*, *D. cucurbitae* and *Sarcophaga bravicornis*. In earlier studies Fomekong et al. (2008) recorded only two *dipterans* including *D. bivitattus* and Kabir et al. (1991) also found that the flowers of bottle gourd attracted *Dacus* fruit fly, which support the present findings wherein *Dacus* was documented. Thapa (2006) also reported only one *syrphid* fly *Syrphus* on flowers of *L. siceraria*. Six dipteran species were reported to visit the flowers of *C. mortoidea* by Valdivia & Niemeyer (2006). These included members belonging to family Syrphidae and Tabanidae which is in conformation with the present study during which the members belonging these two families were documented on flowers of bottle gourd. Baskaran & Eswaran (2004) cited *M. domestica* to be a pollinator of cucurbit *Momordica charantia*. Njorage et al. (2004) identified flies as pollinator of *Citrullus lanatus,* a cucurbit crop, which corroborate the present findings.

D. cingulatus was the only hemipteran observed on flowers of bottle gourd during the present study. Srivastava (2000) also reported bug to pollinate *L. siceraria*, while, in another study conducted on entomofauna, Fomekong et al. (2008) reported twelve hemipteran species as floral visitors of cucurbit plant *Cucumeropsis mannii* which included *D. voelkersi*.

Two odonates, namely *A. femina* and *P. flavescens* were noted as rare visitors on the flowers of *L. siceraria*. No earlier records of *odonates* on flowers of bottle gourd are available in the literature cited.

The present findings are in conformation with the studies done by Agarwal & Rastogi (2008) who also noticed hymenopterans on the flowers of *Luffa cylindrica*. Singh et al. (2000) also recorded members belonging to family Braconidae on cucurbit plant *Luffa cylindrica*. The members of Formicidae on *Luffa* were documented by Okoli et al. (2008). Thapa (2006) reported hymenopterans like bumble bee *Bombus*, golden wasp *Vespa magnifica* and oriental wasp *Vespa orientalis* as pollinators of sponge gourd. Earlier Baskaran & Eswaran (2004) also observed *Apis dorsata* and *A. florea* as pollinators of another gourd *Momordica charantia* which corroborate the present findings.

According to Valdivia & Niemeyer (2006) some cucurbits exhibit floral traits associated with pollination by diurnal butterflies, however, flowers remain open during the night and thus, may also be pollinated by nocturnal moths. During the present study also butterflies as well as moths were documented on the flowers of *Luffa*. Butterflies were also noted as pollinators of a gourd by Baskaran & Eswaran (2004). Thapa (2006) reported lemon butterfly (*Papilio machon*), yellow butterfly (*Therias sp*.), cabbage butterfly (*Pieris brassicae*) and castor butterfly (*Ergolis merione*) as pollinators of sponge gourd which corroborate the present findings. Earlier Srivastava (2000) noted the *hawk* moth as pollinator of *Luffa* acutangula.

M. domestica, *Eristalis sp*., *Sarcophaga bravicornis*, *D. cucurbitae* and *Tabanus sp.* were the *dipterans* recorded on the flowers of *Luffa* during the present study which gets support from the reports of Kabir et al. (1991) who also recorded fruit fly on the flowers of ridged gourd. Thapa (2006) also reported fruit fly *Bactrocera sp*. and Tabanid fly *Tabanus sp.* as pollinators of sponge gourd.

One hemipteran *D. cingulatus* was documented on the flowers of ridged gourd during the present study. Earlier, an oligophagous pentatomid bug *Coridius obscurus* was noted as an egg parasitoid on *Luffa cylindrica* by Senrayan & Annadurai (1991).

One orthopteran, *Ochrilidia sp.* and *P. flavescens* an odonate were noted on the flowers of ridged gourd during the present study as a rare form. No earlier reports on Orthoptera and Odonata visiting flowers of ridged gourd are available in the literature referred.

The hymenopterans visiting the flowers of pumpkin were *S. specifica* and *A. mellifera*. Earlier most of the authorities have considered honeybees to play a major role in pollination of *Cucurbita*, which include the works of Pammel & Bach (1894), Jones & Rosa (1928), Jones & Emsweller (1934), Thompson et al. (1955), Whitaker & Davis (1962), Battaglini (1969), Langridge (1952), Nevkryta (1953), Robinson (1952), Sandulac (1959), Verdieva & Ismalilova (1960) and Wolfenbarger (1962), while, Michel Bacher et al. (1964) and Hurd (1966) gave credit to both honeybees as well as wild bees and thus support the present findings. Alan & Bradley (1966) have also considered bumble bees, carpenter bees, squash bees and honeybees including *A. mellifera* as natural pollinators of pumpkin. Canto Aquliar & Parra – Ptavla (2000) evaluated the pollination efficiency of *Peponapis limitaris* and *A. mellifera* in *Cucurbita moschata* in Mexico and found that *P. limitaris* to be more efficient than *A. mellifera*. Thapa (2006) has also reported *A. cerena* and *Helophilus trivittatus* as insect visitors of *C. maxima* which corroborate the present findings. Agbagwa et al., (2007) also considered *A. mellifera* to play an essential role in pollination of *C. moschata* in Nigeria.

The *Lepidopteran* species, which were found to visit pumpkin flowers during the present study, included *P. edusa*, *V. annabela*, *C. pomona*, *H. fasicalis* and *A. ipsilon*. Although no earlier records of *Lepidopteran* visitors on *C. maxima* are available, nevertheless, Srivastava (2000) and Valdivia & Niemyer (2006) have reported lepidopterans including hawk and pyrillid moth and nymphalid butterfly *V. carye* respectively to visit cucurbit flowers.

Only one dipteran *C. pipiens* was observed on flowers of pumpkin during the present study, while, earlier Thapa (2006) reported syrphid fly *Syrphus sp*., robber fly *Asilus sp*., fruit fly *Bactrocera sp*. and house fly *Musca domestica* to visit the flowers of *C. maxima*.

Menochilus sexmaculatus was the only *coleopteran* species which was documented from the flowers of *C. maxima*. Lady beetle *Coccinella sp*. has been reported by Thapa (2006) as floral visitor of *C. maxima*.

Only one orthopteran, *Ochrilidia sp.* was observed on the flowers of this crop. No earlier records of *orthopterans* on flowers of *C. maxima* are available in the literature referred.

Decline in pollinator populations due to various reasons would have significant ecological as well as economic impact and therefore it becomes imperative to protect and enhance floral visitors of agricultural crops. The present study reveals various insects visiting some plants belonging to family Cucurbitaceae only and emphasizes the importance of natural pollinators in agriculture.

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7. TABLES

Table 1: Floral characteristics of different crops cultivated in *Vallabh Garden Agriculture Farm*, Bikaner, India

Crop	Botanical Name	Family	Inflorescence	Scent	Color	Self or Cross pollination
Cucumber	*Cucumis melo*	*Cucurbita*ceae	Solitary	Scentless	Yellow	Cross
Bottle gourd	*Lagenaria siceraria*	*Cucurbita*ceae	Solitary	Scentless	White or Creamish	Cross
Ridged gourd	*Luffa cylindrica*	*Cucurbita*ceae	Solitary	Scentless	Yellow	Cross
Pumpkin	*Cucurbita maxima*	*Cucurbita*ceae	Solitary	Scentless	Yellow	Cross

Table 2: Insect visitors on flowers of different crops in *Vallabh Garden Agriculture Farm*, Bikaner, India (2008-2009)

Insect visitors	***Cucumis melo*** **(Cucumber)**	***Lagenaria siceraria*** **(Bottle gourd)**	***Luffa cylindrica*** **(Ridged gourd)**	***Cucurbita maxima*** **(Pumpkin)**
HYMENOPTERA				
Family: Apidae				
Apis mellifera Linnaeus	+++	+	+++	++
Xylocopa fenestrata Fabricius	+	-	+++++	-
X. virginica Linnaeus	-	-	+	-

Insect visitors	***Cucumis melo*** **(Cucumber)**	***Lagenaria siceraria*** **(Bottle gourd)**	***Luffa cylindrica*** ***(*****Ridged gourd*****)***	***Cucurbita maxima*** **(Pumpkin)**
Family: Vespidae				
Polistes carolina Linnaeus	+	-	+	-
Polistes sp.	+	++	++	-
Family: Megachilidae				
Coelioxys capitatus Fabricius	+	-	-	-
Family: ***Scoliidae***				
Scolia specifica Smith	++	+++	++++	+
Family: **Sphecidae**				
Sphex sp.	+	-	+	-
Family: Ichneumonidae				
Xanthopimpla stemattor Thunberg	-	++	+	-
LEPIDOPTERA				
Family: Danaidae				
Danaus chrysippus Linnaeus	+	+	++	-
Family: Lycaenidae				
Lampides boeticus Linnaeus	++	-	+	-

Family: Nymphalidae				
Vanessa annabela Field	+	+	+	+
V. cardui Linnaeus	+	-	-	-
Family: Pieridae				
Catopsilia pomona Cramer	+	+	+	+
Pieris edusa Fabricius	+	+	+	+
Family: Hesperiidae				
Hesperilla ornata Leach	++	+	++	-
Family: Arctiidae				
Utetheisia pulchella Linnaeus	+	+	-	-
Family: Gelechiidae				
Pectinophora gossypiella Saunders	+	++	++	-
Family: *Noctuidae*				
Agrotis ipsilon Hufnage	+	+	-	+
Family: Pyralidae				
Hymenia fascialis Cramer	++	+++	+++	+
Margaronia indica Saunders	+	+	+	-

DIPTERA				
Family: Culicidae				
Culex pipiens Gemeine	+	+	-	++
Family: Muscidae				
Musca domestica Linnaeus	++	++	++	-
Family: Syrphidae				
Eristalis sp.	++	+	++	-
Family: Tephritidae				
Dacus cucurbitae Coquillett	+	+	++	-
Family: Tabanidae				
Tabanus sp.	++	+	++	-
Family: *Sarcophagidae*				
Sarcophaga bravicornis Linnaeus	+	+	+	-
COLEOPTERA				
Family: Coccinellidae				
Coccinella septempunctata Linnaeus	+	-	-	+
NEUROPTERA				
Family: Chrysopidae				
Chrysopa sp.	+	-	-	-

HEMIPTERA				
Family: Pentatomidae				
Nezara viridula Linnaeus	+	-	-	-
Family: Pyrrhocoridae				
Dysdercus cingulatus Fabricius	++	+	+	-
D. koengii Fabricius	+	-	-	-
ORTHOPTERA				
Family: Acrididae				
Ochrilidia sp.	+	-	+	+
Chrotogonus sp.	+	-	-	-
ODONATA				
Family: *Libellulidae*				
Pantala flavescens Fabricius	+	+	+	-
Family: Coenagrionidae				
Agriocnemis femina Brauer	+	+	-	-

Number of visits/h: 0-10 = +, 10-50 = ++, 50-100 = +++, 100-200 = ++++.

Table 3: Insect visitors (visits/m/h) of *Cucumis melo* as observed in *Vallabh Garden Agriculture Farm*, Bikaner, India (2008-2009)

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Apis mellifera					192	141	78	4	5			
Xylocopa fenestrata	-	-	-	-	4	3	2	1	3	-	-	-
X. virginica												
Polistes carolina	-	-	-	-	1	1	-	-	-	-	-	-
Polistes sp.	-	-	-	-	4	4	4	2	1	-	-	-
Coelioxys capitatus	-	-	-	-	9	-	1	-	3	-	-	-
Scolia specifica	-	-	-	-	-	1	-	17	80	-	-	-
Sphex sp.	-	-	-	-	1	3	6	10	7	-	-	-
Xanthopimpla stemattor	-	-	-	-	-	-	-	-	-	-	-	-
Danaus chrysippus	-	-	-	-	11	7	3	-	-	-	-	-
Lampides boeticus	-	-	-	-	9	48	23	22	6	-	-	-
Vanessa annabela	-	-	-	-	1	2	1	2	1	-	-	-
V. cardui	-	-	-	-	-	-	-	-	1	-	-	-
Catopsilia pomona	-	-	-	-	1	1	2	1	1	-	-	-
Pieris edusa	-	-	-	-	4	8	-	-	-	-	-	-
Hesperilla ornata	-	-	-	-	-	-	5	26	39	-	-	-
Utetheisia pulchella	-	-	-	-	8	7	14	1	4	-	-	-
Pectinophora gossypiella	-	-	-	-	1	7	-	1	3	-	-	-
Agrotis ipsilon	-	-	-	-	-	1	-	-	-	-	-	-
Hymenia fascialis	-	-	-	-	9	54	61	61	51	-	-	-
Margaronia indica	-	-	-	-	-	-	-	12	20	-	-	-
Culex pipiens	-	-	-	-	8	2	1	2	1	-	-	-
Musca domestica	-	-	-	-	6	21	28	30	22	-	-	-
Eristalis sp.	-	-	-	-	80	28	12	25	26	-	-	-

Dacus cucurbitae	-	-	-	-	2	3	3	7	2	-	-	-
Tabanus sp.	-	-	-	-	31	21	8	21	19	-	-	-
Sarcophaga bravicornis	-	-	-	-	-	-	3	3	8	-	-	-
Coccinella septempunctata	-	-	-	-	1	4	1	1	2	-	-	-
Chrysopa sp.	-	-	-	-	1	3	-	-	-	-	-	-
Nezara viridula					1		1		1			
Dysdercus cingulatus	-	-	-	-	2	4	30	14	2	-	-	-
D. koengii						1						
Ochrilidia sp.	-	-	-	-	1	2	3	1	1	-	-	-
Chrotogonus sp.	-	-	-	-	1	1	2	-	5	-	-	-
Pantala flavescens	-	-	-	-	1	-	-	-	2	-	-	-
Agriocnemis femina	-	-	-	-	1	3	3	-	1	-	-	-

Table 4: Insect visitors (visits/m/h) of *Lagenaria ciceraria* as observed in *Vallabh Garden Agriculture Farm*, Bikaner, India (2008-2009)

Crop	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Apis mellifera	-	-	-	-	-	2	1	3	2	2	-	-
Xylocopa fenestrata	-	-	-	-	-	-	-	-	-	-		
X. virginica												
Polistes carolina	-	-	-	-	-	-	-	-	-	-	-	-
Polistes sp.	-	-	-	-	-	12	-	14	10	14	-	-
Coelioxys capitatus	-	-	-	-	-	-	-	-	-	-	-	-
Scolia specifica	-	-	-	-	-	48	69	36	102	292	30	-
Sphex sp.	-	-	-	-	-	-	-	-	-	-	-	-
Xanthopimpla stemattor	-	-	-	-	-	19	-	21	20	22	-	-
Danaus chrysippus	-	-	-	-	-	5	-	6	4	6	-	-
Lampides boeticus	-	-	-	-	-	-	-	-	-	-	-	-

Vanessa annabela	-	-	-	-	-	2	-	3	4	3	-	-
V. cardui	-	-	-	-	-	-	-	-	-	-	-	-
Catopsilia pomona	-	-	-	-	-	1	1	2	1	2	1	-
Pieris edusa	-	-	-	-	-	4	-	5	4	5	-	-
Hesperilla ornata	-	-	-	-	-	4	-	3	2	2	-	-
Utetheisia pulchella	-	-	-	-	-	7	8	12	13	14	5	-
Pectinophora gossypiella	-	-	-	-	-	15	21	19	32	63	9	-
Agrotis ipsilon	-	-	-	-	-	1	3	2	2	2	-	-
Hymenia fascialis	-	-	-	-	-	62	57	78	89	55	110	-
Margaronia indica	-	-	-	-	-	4	5	3	4	2	6	-
Culex pipiens	-	-	-	-	-	-	6	5	7	-	7	-
Musca domestica	-	-	-	-	-	22	21	24	25	28	166	-
Eristalis sp.	-	-	-	-	-	7	5	8	4	9	2	-
Dacus Cucurbitae	-	-	-	-	-	2	-	2	-	-	3	-
Tabanus sp.	-	-	-	-	-	6	5	7	6	7	5	-
Sarcophaga bravicornis	-	-	-	-	-	2	4	3	4	2	5	-
Coccinella septempunctata	-	-	-	-	-	-	-	-	-	-	-	-
Chrysopa sp.	-	-	-	-		-	-	-	-	-	-	-
Nezara viridula	-	-	-	-	-	-	-	-	-	-	-	-
Dysdercus cingulatus	-	-	-	-	-	8	1	6	9	10	1	-
D. koengii	-	-	-	-	-	-	-	-	-	-	-	-
Ochrilidia sp.	-	-	-	-	-	-	-	-	-	-	-	-
Chrotogonus sp.	-	-	-	-	-	-	-	-	-	-	-	-
Pantala flavescens	-	-	-	-	-	4	6	5	7	2	8	-
Agriocnemis femina	-	-	-	-	-	2	3	2	1	2	5	-

Table 5: Insect visitors (visits/m/h) of *Luffa cylindrica* as observed in *Vallabh Garden Agriculture Farm*, Bikaner, India (2008-2009)

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Apis mellifera	-	-	-	-	-	5	7	2	8	4	452	-
Xylocopa fenestrata	-	-	-	-	-	182	194	246	259	266	184	-
X. virginica	-	-	-	-	-	3	3	-	2	4	-	-
Polistes carolina	-	-	-	-	-	2	3	1	5	1	6	-
Polistes sp.	-	-	-	-	-	15	11	13	-	18	-	-
Coelioxys capitatus	-	-	-	-	-	-	-	-	-	-	-	-
Scolia specifica	-	-	-	-	-	82	96	114	256	469	92	-
Sphex	-	-	-	-	-	12	-	13	13	14	-	-
Xanthopimpla stemattor	-	-	-	-	-	2	3	-	2	2	-	-
Danaus chrysippus	-	-	-	-	-	13	17	21	23	9	29	-
Lampides boeticus	-	-	-	-	-	4	2	-	3	-	3	-
Vanessa annabela	-	-	-	-	-	2	3	4	4	2	5	-
V. cardui	-	-	-	-	-	-	-	-	-	-	-	-
Catopsilia pomona	-	-	-	-	-	2	1	1	1	1	3	-
Pieris edusa	-	-	-	-	-	-	2	1	2	2	-	-
Hesperilla ornata	-	-	-	-	-	10	8	11	12	13	12	-
Utetheisia pulchella	-	-	-	-	-	-	-	-	-	-	-	-
Pectinophora gossypiella	-	-	-	-	-	12	14	16	15	10	22	-
Agrotis ipsilon	-	-	-	-	-	-	-	-	-	-	-	-
Hymenia fascialis	-	-	-	-	-	52	48	53	50	57	57	-
Margaronia indica	-	-	-	-	-	10	9	11	10	12	12	-
Culex pipiens	-	-	-	-	-	-	-	-	-	-	-	-
Musca domestica	-	-	-	-	-	22	20	18	24	26	19	-
Eristalis sp.	-	-	-	-	-	11	14	6	12	17	6	-

Dacus cucurbitae	-	-	-	-	-	8	9	-	12	15	-	-
Tabanus sp.	-	-	-	-	-	-	42	41	40	45	-	-
Sarcophaga bravicornis	-	-	-	-	-	3	2	-	3	3	-	-
Coccinella septempunctata	-	-	-	-	-	-	-	-	-	-	-	-
Chrysopa sp.	-	-	-	-	-	-	-	-	-	-	-	-
Nezara viridula	-	-	-	-	-	-	-	-	-	-	-	-
Dysdercus cingulatus	-	-	-	-	-	5	2	6	-	6	-	-
D. koengii	-	-	-	-	-	-	-	-	-	-	-	-
Ochrilidia sp.	-	-	-	-	-	2	3	1	-	-	3	-
Chrotogonus sp.	-	-	-	-	-	-	-	-	-	-	-	-
Pantala flavescens	-	-	-	-	-	2	-	3	2	-	3	-
Agriocnemis femina	-	-	-	-	-	-	-	-	-	-	-	-

Table 6: Insect visitors (visits/m/h) of *Cucurbita maxima* as observed in *Vallabh Garden Agriculture Farm*, Bikaner, India (2008-2009)

	Dec	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Apis mellifera	-	-	-	-	-	-	-	-	-	-	-	17
Xylocopa fenestrata	-	-	-	-	-	-	-	-	-	-	-	-
X. virginica	-	-	-	-	-	-	-	-				
Polistes carolina	-	-	-	-	-	-	-	-	-	-	-	-
Polistes sp.	-	-	-	-	-	-	-	-	-	-	-	-
Coelioxys capitatus	-	-	-	-	-	-	-	-	-	-	-	-
Scolia specifica	6	-	-	-	-	-	-	-	-	-	-	2
Sphex sp.	-	-	-	-	-	-	-	-	-	-	-	-
Xanthopimpla stemattor	-	-	-	-	-	-	-	-	-	-	-	-
Danaus chrysippus	-	-	-	-	-	-	-	-	-	-	-	-
Lampides boeticus	-	-	-	-	-	-	-	-	-	-	-	-

Vanessa annabela	-	-	-	-	-	-	-	-	-	-	-	1
V. cardui	-	-	-	-	-	-	-	-	-	-	-	-
Catopsilia pomona	-	-	-	-	-	-	-	-	-	-	-	1
Pieris edusa	-	-	-	-	-	-	-	-	-	-	-	1
Hesperilla ornata	-	-	-	-	-	-	-	-	-	-	-	-
Utetheisia pulchella	-	-	-	-	-	-	-	-	-	-	-	-
Pectinophora gossypiella	-	-	-	-	-	-	-	-	-	-	-	-
Agrotis ipsilon	-	-	-	-	-	-	-	-	-	-	-	1
Hymenia fascialis	-	-	-	-	-	-	-	-	-	-	-	7
Margaronia indica	-	-	-	-	-	-	-	-	-	-	-	-
Culex pipiens	14	-	-	-	-	-	-	-	-	-	-	7
Musca domestica	-	-	-	-	-	-	-	-	-	-	-	-
Eristalis sp.	-	-	-	-	-	-	-	-	-	-	-	-
Dacus cucurbitae	-	-	-	-	-	-	-	-	-	-	-	-
Tabanus sp.	-	-	-	-	-	-	-	-	-	-	-	-
Sarcophaga bravicornis	-	-	-	-	-	-	-	-	-	-	-	-
Coccinella septempunctata	-	-	-	-	-	-	-	-	-	-	-	1
Chrysopa sp.	-	-	-	-	-	-	-	-	-	-	-	-
Nezara viridula	-	-	-	-	-	-	-	-	-	-	-	-
Dysdercus cingulatus	-	-	-	-	-	-	-	-	-	-	-	-
D. koengii	-	-	-	-	-	-	-	-	-	-	-	-
Ochrilidia sp.	-	-	-	-	-	-	-	-	-	-	-	1
Chrotogonus sp.	-	-	-	-	-	-	-	-	-	-	-	-
Pantala flavescens	-	-	-	-	-	-	-	-	-	-	-	-
Agriocnemis femina	-	-	-	-	-	-	-	-	-	-	-	-

Shaded area in Tables indicate flowering period

Table 7: Preferred time of visiting the flowers by different insects

Insect visitors	Forenoon	Afternoon
Apis mellifera Linnaeus		AN
Xylocopa fenestrata Fabricius		AN
X. virginica Linnaeus	FN	
Polistes carolina Linnaeus	FN	
Polistes sp.		AN
Coelioxys capitatus Fabricius	FN	AN
Scolia specifica Smith	FN	
Sphex sp.	FN	
Xanthopimpla stemattor Thunberg	FN	
Danaus chrysippus Linnaeus	FN	
Lampides boeticus Linnaeus		AN
Vanessa annabela Field	FN	
V. cardui Linnaeus	FN	
Catopsilia pomona Cramer	FN	
Pieris edusa Fabricius	FN	
Hesperilla ornata Leach	FN	
Utetheisia pulchella Linnaeus	FN	
Pectinophora gossypiella Saunders		AN
Hymenia fascialis Cramer	FN	
Margaronia indica Saunders		AN
Agrotis ipsilon Hufnagel	FN	
Culex pipiens Gemeine	FN	
Musca domestica Linnaeus	FN	
Eristalis sp.	FN	
Dacus cucurbitae Coquillett	FN	

Insect visitors	Forenoon	Afternoon
Tabanus sp.	FN	AN
Sarcophaga bravicornis Linnaeus	FN	
Coccinella septempunctata Linnaeus	FN	
Chrysopa sp.	FN	
Nezara viridula Linnaeus	FN	
Dysdercus cingulatus Fabricius	FN	
D. koengii Fabricius	FN	AN
Ochrilidia sp.	FN	
Chrotogonus sp.	FN	
Pantala flavescens Fabricius	FN	
Agriocnemis femina Brauer	FN	

Journal Academica Vol. 2(3), pp. 127-140, September 29 2012 - Condensed Matter Physics - ISSN 2161-3338
online edition www.journalacademica.org © 2012 Journal Academica Foundation

Full Length Research Paper

Chemical Mobility and Mineralogical Variability in the Mica Schists of Edough Massif (Annaba, Northeast Algeria)

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Accepted September 21 2012

ABSTRACT

Mineralogical as well as compositional changes are often due to changes in metamorphic grade. The insignificant changes of thermo-barometric conditions of the mica schists did not influence the mobility of the elements. The slight variation in bulk rock composition and the homogeneity of the alteration index allow to exclude alteration as major process for mass transfer and change of the phase assemblages encountered along the section. The mica schists however experienced strong tectonic constraints with increasing strain along the E-W transect. The isocons show that Si, Fe, Al and K where mobile during deformation and the transformation from garnet mica schists to andalusite mica schists. This transition leads to loss of Fe and gain of Al, Si and K. The element mobility correlates with deformation that favored fluid circulation and the growth of andalusite in the zone of strongest shear stress.

Key words: Isocons, Metamorphism, Mass transfer, *Edough Massif*, Algeria

1. INTRODUCTION

The *Edough Massif*, located in the oriental part of the Algerian coastline, is a dissymmetric "core complex" (Caby & Hammor 1992) oriented NE-SW with a length of about 50 km and a width of 20 km (Figure 1). The conditions of metamorphism, geochronology and geology studies of the massif have been the subject of several papers (Hilly, 1962; Gleizes et al. 1988; Ahmed-Said & Leake 1993; Laouar et al. 2002). The *Edough* metamorphic rocks consist of two tectonically superposed units composed of gneiss (the lower unit) and mica schists (the upper unit). The metamorphic assemblages indicate high temperatures for both units and show that the lower unit recorded medium pressure conditions, whereas the upper unit showed lower pressures. Characterization and quantification of mass transfer by fluids is based on research of mineralogical and chemical witnesses. The presence of metastable minerals indicates an incomplete re-equilibration to metamorphic conditions. Deformation and P-T condition are very important factors in the process of re-equilibration because they have the effect of accelerating or slowing down chemical processes and can influence the redistribution of fluids in the rocks. The studied zone is characterized by variations of mineralogical composition of the rocks, which may be related to variations of deformation (schistosity and

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foliation). This paper aims to evidence fluid rock interaction in the mica schists of the upper unit.

2. GEOLOGICAL BACKGROUND

The core of the *Edough Massif*, so-called "lower unit" is composed of biotite gneiss and two mica augen-gneiss of Neoproterozoic age (Hammor & Lancelot 1998). The gneisses are altered diatexites and have an arkosic origin (Hadj Zobir & Mocek 2012, Hadj Zobir 2012). They sometimes contain benches of leucogneisses and marbles (Hilly 1962; Gleizes et al. 1988; Ahmed-Said & Leake 1993) (Figure 1). Overlying the gneiss a so-called "intermediate unit" is composed of garnet mica schists with kyanite, sillimanite and andalusite mica schists and metric benches of marbles. The uppermost unit, "alternating series", is composed mainly by an alternation of feldspathic quartzite and aluminous *mica schist* with some andalusite levels.

The sedimentary envelope of the metamorphic massif is allochtone. It is represented by flysch facies: the Cretaceous flysch, composed mainly of dark blue schistose argillite, alternating with benches (20 to 50 cm) of sandy limestone, blue-grey micro-breccieted limestone of Maestrichtian age (Marignac & Zimmermann 1983) and the Numidian formation of Oligo-Miocene age (Lahondère et al. 1979) that corresponds to a quartzic sandstone formation with thin clayey levels (Hilly 1962). The metamorphic rocks and the sedimentary formations have been cut up during Miocene (Langhian) by magma of high to intermediate acidic composition and rhyolitic to microgranodioritic subvolcanic rocks (Figure 1).

The *Edough Massif* underwent a polycyclic metamorphism characterized by three major events (i) a high grade metamorphism (HT-HP) corresponding locally to conditions of the granulites facies, (ii) an intermediate degree of prograde metamorphism (MP-MT) and (iii) a low-pressure – high-temperature (Brunnel et al. 1988; Ahmed Said & Leake 1993; Caby et al. 2001). The different metamorphic units underwent first oblique deformation characterized by syn-metamorphic folds followed by flexural shear generating upright folds of N140° direction, anticlines with direction N50° to N60° and shear senses of N120° to N160° direction. The rocks of the *Edough Massif* present foliations and lineations that show deformation along gently dipping planes.

3. ANALYTICAL METHODS

A subset of 5 samples out of ten was chosen for analysis at the Center of Research and Development (CRD), SONATRACH (Boumerdes, Algeria). The major element compositions were determined by X-ray fluorescence (XRF).

4. RESULTS AND DISCUSSION

4.1. *Whole-rock and samples description*

Whole-rock samples have been systematically collected across the mica schists showing variable deformation and change in mineral composition. The sampling was done at 10 meters distances along an E-W section.

The studied area is characterized by monotone mica schists. In these biotite mica schists we note the successive apparition, from east to west, of new specific minerals, indicators of a metamorphic gradient such as garnet, staurolite, and andalusite. Foliation varies from NE-SW to E-W respectively from east to west. The eastern part of the studied zone with a NE-SW foliation is characterized by an abundance of white micas, some garnets and rare biotite. The coexistence of rare biotite and white micas indicates a relatively low degree of metamorphism. These rocks (sample

E36) are the least deformed and least metamorphosed of the whole section. The middle part of the studied section (samples E37'a, E37", E38) is characterized by the development of staurolite and small pockets of pink andalusite, associated with quartz, some biotite and rare muscovite. The western part showing E-W foliation (sample E41), is characterized by biotite and pockets of pink andalusite, associated with clear, transparent quartz (exudates ≥ 5cm in diameter) as well as feldspathic "nodules". Some lithologic levels carry indication of more intense deformation. Farther to the west of the study area, feldspar associated with andalusite is abundant and coexistence of sodic and potassic feldspar is observed.

Sample E36: is a garnet *mica schist* (Figure 2a) representing the protolith with the weakest deformation and thus metamorphic conditions representative for the area. Major phases found in this sample are garnet, white mica, biotite quartz and as accessory staurolithe. Garnet is only found in this sample (E36). It generally forms transparent; millimeter sized globular crystals that may comprise corroded rims: Rare biotite coexist with muscovite and form aureoles around garnet. Staurolithe s extremely rare in this samples and only one crystal was found in the thin section. This slightly deformed mineral is homogeneous.

Samples E37'a, E37" and E38: these samples stem from the central part of the section and are characterized by the growth of andalusite and feldspar while garnet disappears. Staurolithe and biotite are more abundant than in sample E36 (Figure 2b, 2c). Muscovite seems to be consumed by biotite. Andalusite forms small rose crystals, which are associated with quartz and potassic feldspar. The size of the staurolithe crystals augments.

Sample E41: this sample represents the zone with the strongest deformation and exhibits a mineralogical composition similar to samples E37'a, E37" and E38. The mica schists of this zone show andalusite phaenoblasts from 2 to 3cm, potassic feldspar and quartz. The difference to the other samples is obvious from the abundance of andalusite, staurolithe, potassic feldspar and biotite (Figure 2c). Twinned plagioclase is albitic and occurs as randomly distributed laths. Orthoclase dominates over plagioclase and the blasts are often broken. Biotite forms layers of various lengths which may attain 1cm.

4.2. whole-rock chemistry and chemical alteration

The successive petrographic samples contain variable element abundances (Figure 3). At the centre of the section a clear decrease of SiO_2 (62.08 – 66.89 wt%) is obvious. The highest values (69.12 wt%) can be found in sample E36 while E41, the sample with the strongest deformation contains less SiO_2 (67.46 wt%). This variation expresses the mobility of silica and explains the frequent formation of quartz exudates in the zone of strong deformation. The drop of Fe_2O_3 (7.88 – 4.82 wt%) and MgO (1.54 – 0.94 wt%) in the intermediate part goes along with disappearing of ferromagnesian minerals like garnet, while the drop of Al_2O_3 (17.70 – 16.64 wt%), CaO (0.44 – 0.41 wt%), K_2O (4.27 – 2.96 wt%), and Na_2O (1.37 – 1.08 wt%) correlates with the decrease of aluminous and alkaline minerals. The most deformed sample E41 is characterized by high values of Al_2O_3 (18.69 wt%) and K_2O (4.8%) corresponding to its mineralogy (large andalusite crystals and potassic feldspar).

The chemical evolution (Table.1) of the samples shows two rock groups (Figure 4): a first group that encloses samples E36, E37'a and E37", corresponds to weakly deformed rocks and low metamorphic grade. The second group with samples E38 and E41 corresponds to highly deformed rocks. The mica schists show a relatively homogenous chemical composition. The rocks are rich in Al_2O_3 (13.54 – 18.69%) and K_2O (3.02 – 4.8%), but show low contents of CaO (1.7 - 0.66) and Na_2O (1.5 – 1.54%). The distribution of major elements along the section, from little to strongly deformed rocks show a zigzag trend suggesting mass transfer due to chemical alteration, metamorphism or deformation. During chemical alteration Ca, Na and K are preferentially leached (Nesbitt & Young 1982). These elements are thus good indicators of alteration processes. The chemical alteration index (CIA) (CIA = Al_2O_3 / (Al_2O_3+CaO+Na_2O+K_2O) (Nesbitt & Young 1982) of the mica schists is elevated but shows only a low degree of variation: CIA_{E36} =0.69, $CIA_{E37'-E38}$ =0.74-0.79 and CIA_{E41} =0.74. These show that the weathering effect was insignificant and cannot be the cause of the mineral variations.

4.3. *Thermo-barometry*

P-T condition were calculated using the program THERIAK-DOMINO version 140205 of C. de Capitani (2005), using the database Jun92.bs (Berman et al. 1985; Perkins et al. 1986). The *mica schist* register temperatures in the range 500–600 °C (Figure 5). The least transformed sample (E36) containing garnet, white mica and biotite equilibrated at 500-550 °C and 0.15 – 0.25 GPa (Figure 5a). According to our model data the rocks from the middle part of the studied section registered temperatures from 500-525° C (samples E37'a) to 525- 575°C (sample E38). The most transformed sample E41 containing andalusite, staurolite and biotite points towards equilibration at T: 500-550°C, P: 0.15-2.5 GPa (Figure 5b). Thus calculations of stable assemblages using the bulk rock composition of the least and the most deformed *mica schist* and assuming equilibrium conditions indicate a homogenous P-T evolution, the effect of which was insignificant as far as mobility of the elements is regarded. The thermodynamics result shows that metamorphic conditions did not cause the mineralogical variability observed in the studied mica schists.

4.4. *Mass Transfer*

The chemical evolution from the less deformed rocks to a more deformed imprint expresses a transfer of matter evidenced by the appearance of biotite, andalusite or the disappearance of muscovite and garnet. The degree of deformation and mineralogical change of the rock is obvious from the enrichment or impoverishment of some elements and in the conservation of others. In the study area the deformation appears progressive and develops from East to West. Grants (1986) isocon method has been used to calculate mass transfer. Sample E36 has been taken as reference because it presents the lowest degree of metamorphism, deformation while bulk rock composition is similar to the deformed samples. The comparison is illustrated in figure 6. Al and Ti are considered as immobile and little soluble elements at conditions experienced during deformation and weathering (Tobisch et al. 1991, Erslevs & Ward 1994). However the *Edough* rocks show by their mineralogical changes that Al is mobile. Ti remains unchanged during the metamorphic changes (Gresens 1967; Fisher 1970; Ferry 1982). Since Ti is not involved in the phase transitions we

define the line crossing Ti as the isocon. The gains and the losses of elements in the mica schists are progressive as they can directly be linked to the variation in the degree of deformation. The variations in the Gresens diagrams show open fans suggesting significant amounts of mass transfer (Figure 6).

The most chemical elements are constantly washed away when there is an increase in the deformation gradient. Mg and Na show a very weak mobility and seem not affected by deformation processes. Fe behaves irregular; there is a tendency of loss of this element during the different stages of mineralogical transformation and deformation. The enrichment of K expresses the formation of biotite and potassic feldspar in highly deformed rocks.

Quantification of the constituents that have undergone gains and losses is done using the general equation proposed by Grant (1986).

$$C_i^A = (M^0 / M^A) * (C_i^0 + DC_i)$$

At constant mass, this equation becomes:

$$DC_i / C_i^0 = (C_i^A / C_i) - 1$$

DC_i / C_i^0: relative gain or loss of element "I" during transformation of the original rock;

M^0: original mass of the rock;

M^A: mass of the transformed rock;

C_i^0: mass or weight of the element in the original rock;

C_i^A: mass or weight of the element in the transformed rock

The balance of the gains and losses in chemical elements is summarized in Table 2. According to the Figure 4, the majority of elements are mobile. The Ti being immobile, the mass balance of the different samples can be calculated as:

1) 100g (E36) -19.75g SiO_2 + 0.79g Al_2O_3 +1.12g Fe_2O_3-1.40g CaO + 0.19g MgO +0.01g MnO + 0.45g K_2O - 0.41g Na_2O = 81g E37'a
2) 100g (E36) -13.15g SiO_2 + 2.02g Al_2O_3 + 0.81g Fe_2O_3-1.45g CaO + -0.09g MgO + 0.00g MnO+ 0.00g K_2O- 0.13g Na_2O = 88g E37''
3) 100g (E36) -11.93g SiO_2 + 0.84g Al_2O_3 -1.18g Fe_2O_3 -1.40g CaO - 0.26g MgO + 0.02g MnO - 0.49g K_2O - 0.59g Na_2O = 85g E38
4) 100g (E36) + 47.35g SiO_2 + 18.96g Al_2O_3 -1.86g Fe_2O_3 + 0.86g CaO + 0.9g MgO - 0.03g MnO + 5.34g K_2O + 0.45g Na_2O = 171.97g E41

During the increase of deformation (from sample E37"a to E38) (Figure 7), the loss in mass of SiO_2 is very important, suggesting the dissolution of quartz and white mica. The gain in mass of Al is continuous and increases until the sample E41, this variation can be correlated with the apparition and modal increase of aluminous minerals such andalusite.

5. CONLUSION

Mineralogical as well as compositional changes are often due to changes in metamorphic grade. The insignificant changes of thermo-barometric conditions of the mica schists did not influence the mobility of the elements. The slight variation in bulk rock composition and the homogeneity of the alteration index allow to exclude alteration as major process for mass transfer and change of the phase assemblages encountered along the section. The mica schists however experienced strong tectonic constraints with increasing strain along the E-W transect. The isocons show that Si, Fe, Al and K where mobile during deformation and the transformation

from garnet mica schists to andalusite mica schists. This transition leads to loss of Fe and gain of Al, Si and K. The element mobility correlates with deformation that favored fluid circulation and the growth of andalusite in the zone of strongest shear stress.

ACKNOWLEDGMENTS

The authors thank the staff of the department of Sedimentology in the Center of Research and Development (CRD), SONATRACH (Boumerdes, Algeria) to have facilitated us the access to the different services. S.HZ thanks DAAD for granting her stay at Potsdam University.

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FIGURE CAPTIONS

Figure 1: Schematic geologic map of the *Edough Massif* (according to Hilly, 1962; Caby and Hammor, 2001; Laouar et al., 2002).

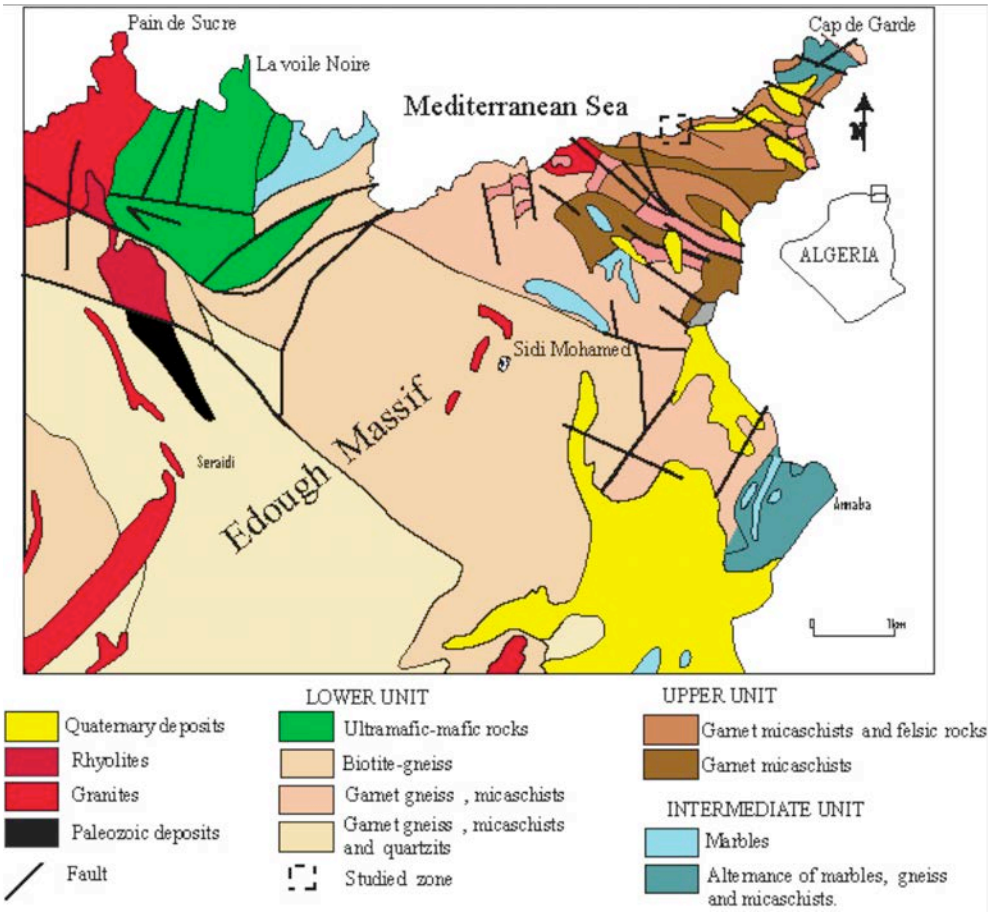
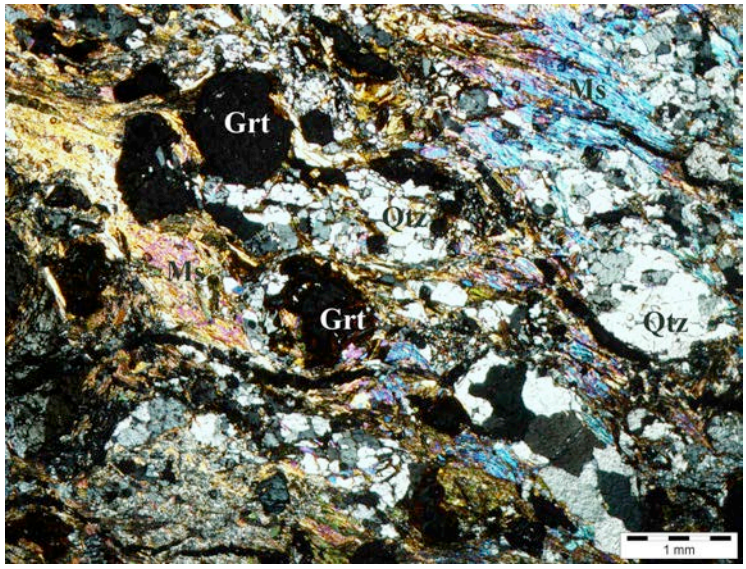


Figure 2: Mineralogical evolution and deformation of the « upper unit » in the *Edough Massif*. And: andalusite, Bt: biotite, Fsp: feldspar, St: Staurolite, Qtz: quartz (mineral abbreviations after Kretz, 1983)

a)



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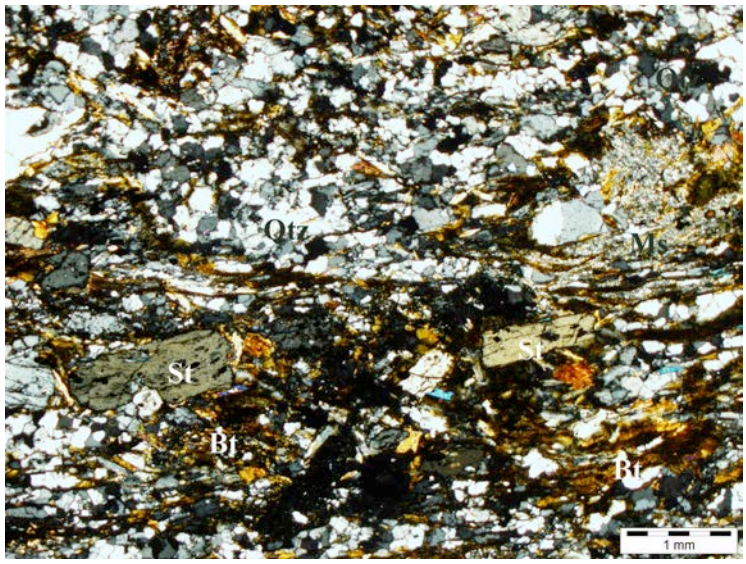

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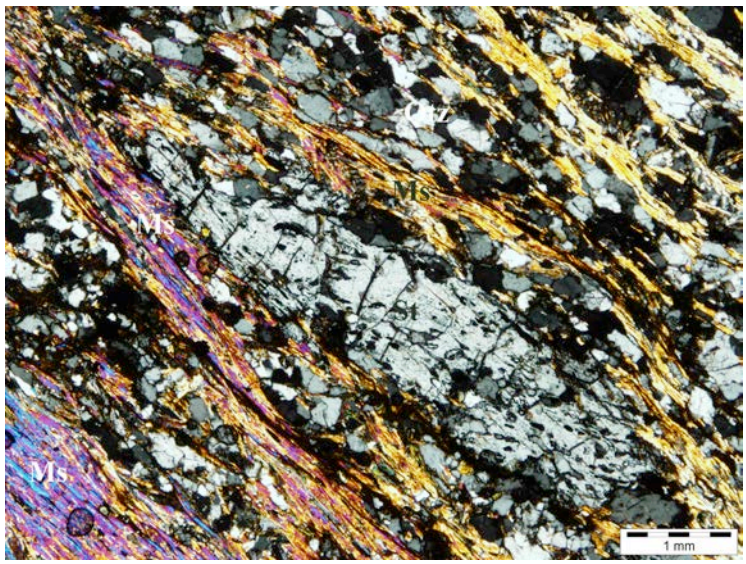

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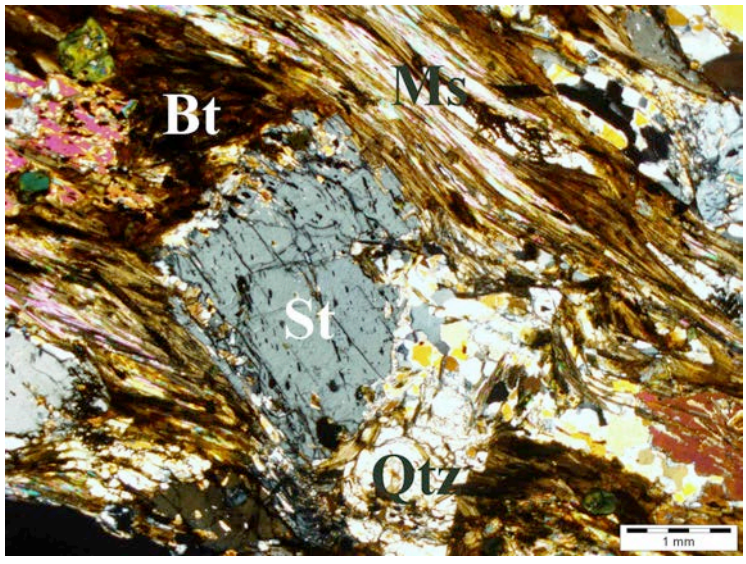


Figure 3: Harker diagrams showing major element variation along the transect

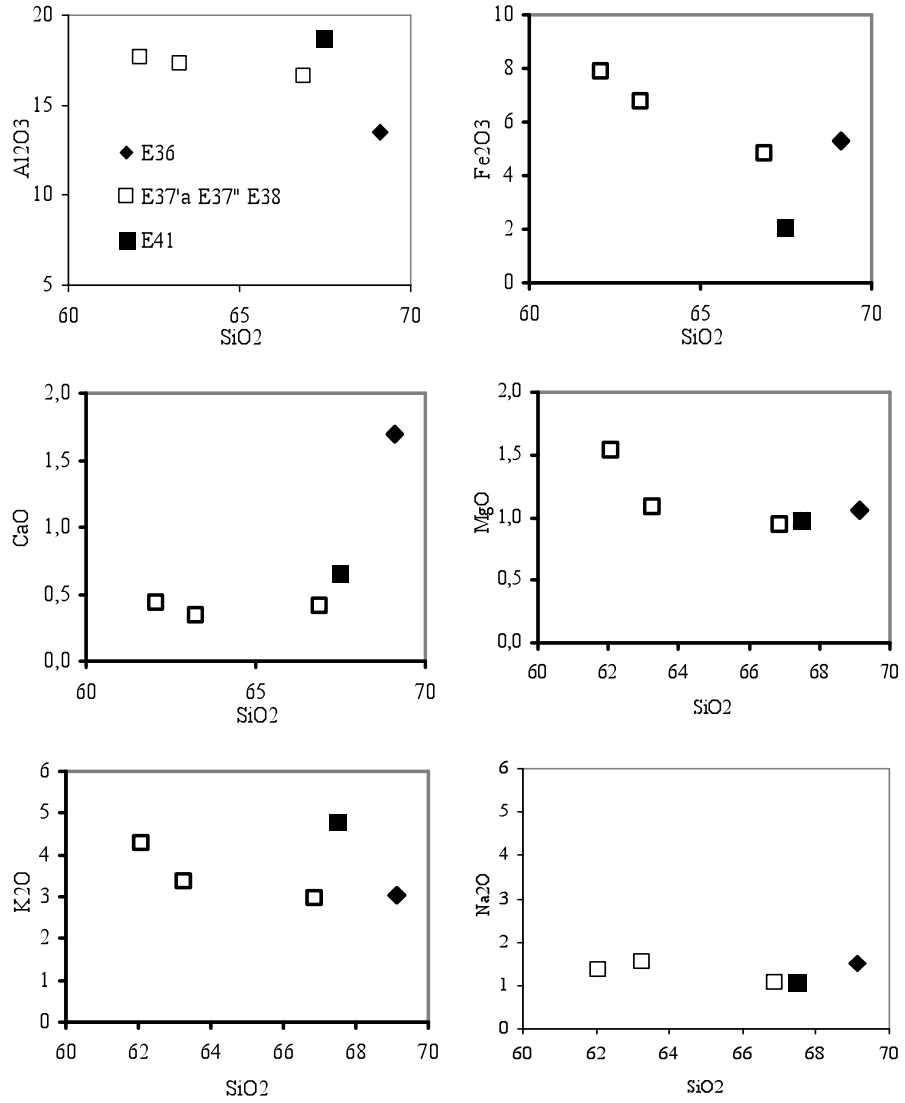


Figure 4: Fluctuations of the bulk chemical composition along the E-W transect

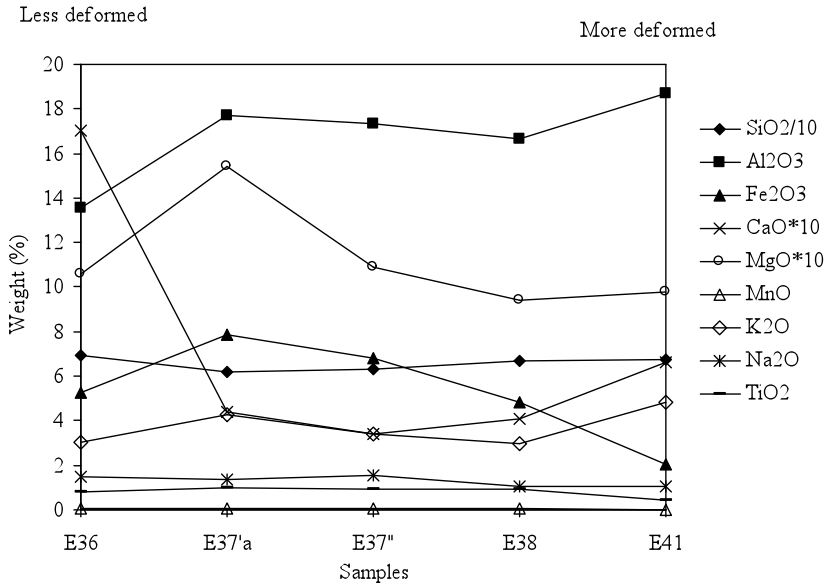
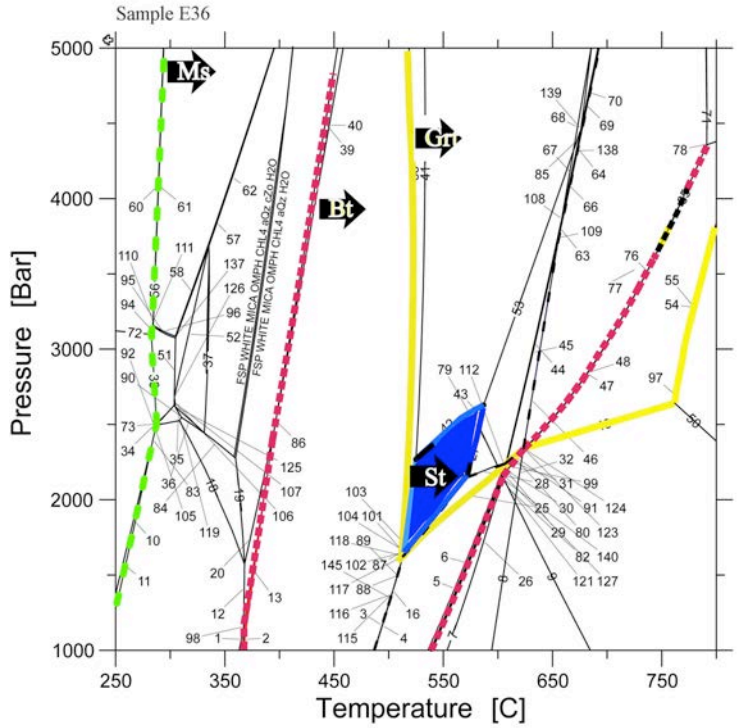
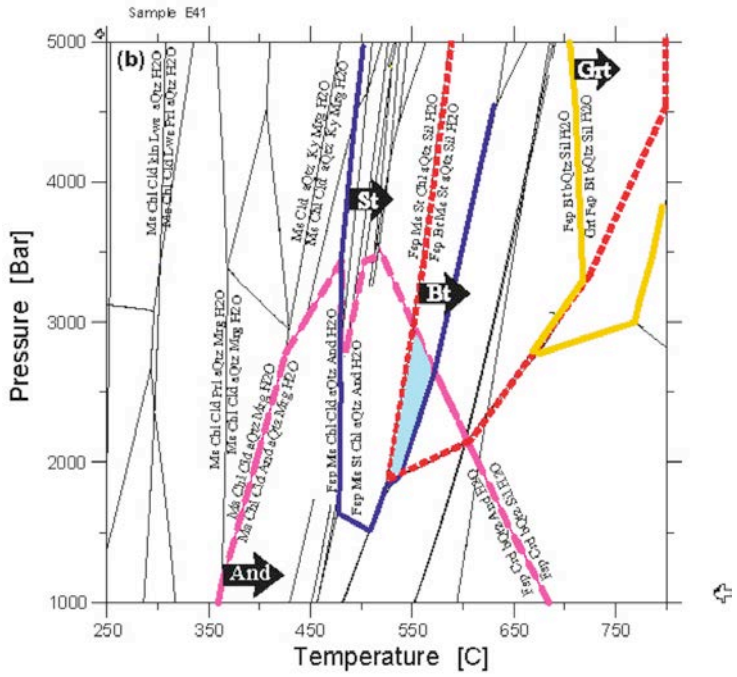


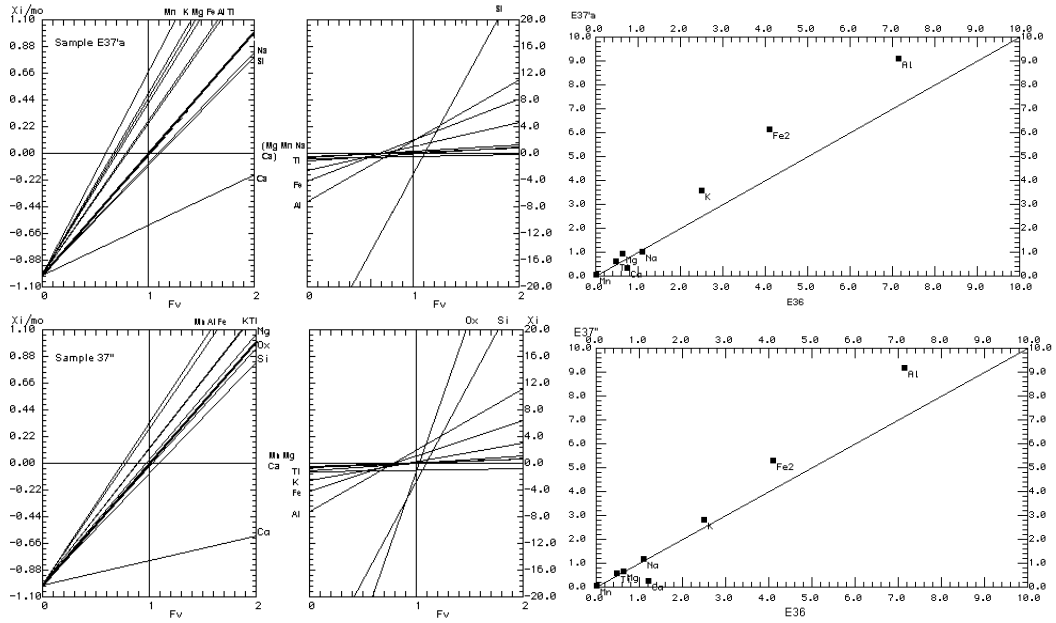
Figure 5: Thermobarometric conditions: a) for the less deformed rock (E36), b) for the most deformed (E41) made with Theriak-Domino. Mineral abbreviations (Kretz, 1983): And: andalusite, Bt: biotite, Chl: chlorite, Czo: clinozoisite, Crd: cordierite, Cld: chloritoid, Fsp: feldspar, Grt: garnet, H_2O: water, Ky: kyanite, Lws: lawsonite, Mrg: margarite, Ms: muscovite, Omp: omphacite, Prl: pyrophyllite, Qtz: quartz, Sil: sillimanite. Arrows indicate the appearance of a mineral





/ / / / = stability fields of minerals, ■P-T area of sample (E36), ■P-T area of sample (E41)

Figure 6: Composition–volume diagrams and isocons of the chemical transfers along the cross section in the mica schists



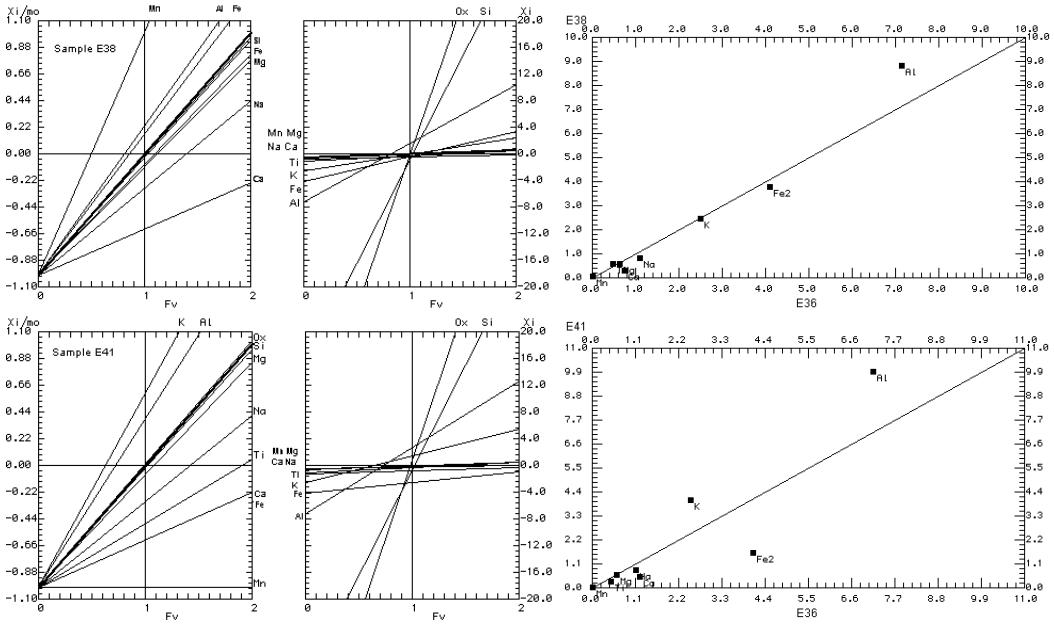


Figure 7: Histograms of the gains and relative losses during the transformation of the rock

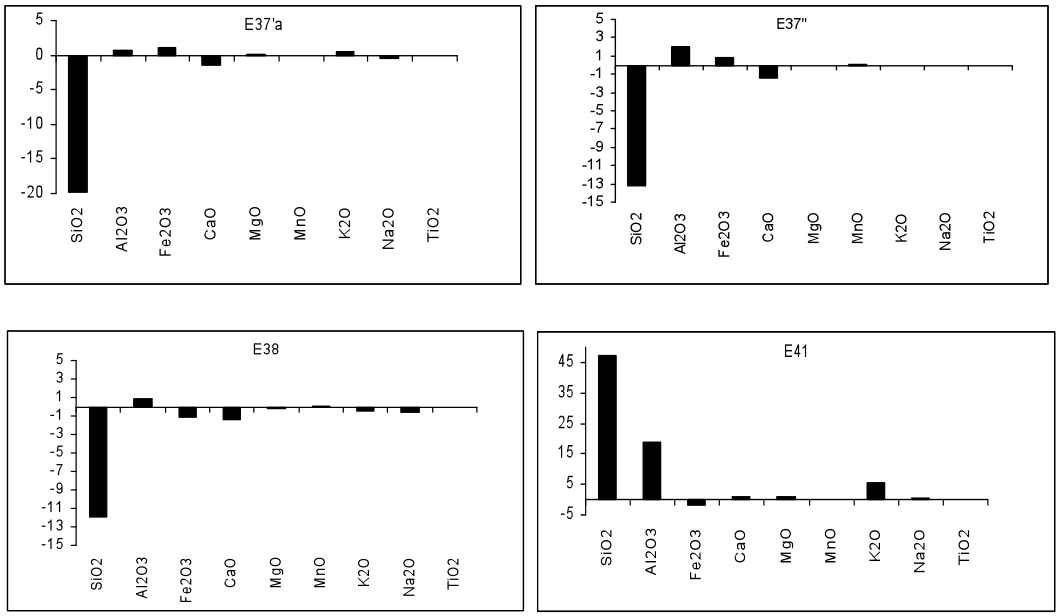


TABLE CAPTIONS

Table 1: Whole-rock geochemistry for the mica schists of the *Edough Massif*

Samples	E36	E37'a	E37"	E38	E41
SiO_2	69,12	62,08	63,25	66,89	67,46
Al_2O_3	13,54	17,70	17,33	16,64	18,69
Fe_2O_3	5,29	7,88	6,79	4,82	2,06
CaO	1,70	0,44	0,34	0,41	0,66
MgO	1,06	1,54	1,09	0,94	0,98
MnO	0,03	0,05	0,04	0,06	0,00
K_2O	3,02	4,27	3,38	2,96	4,80
Na_2O	1,50	1,37	1,54	1,08	1,06
TiO_2	0,82	1,02	0,92	0,95	0,43
L.O.I	3,65	4,25	4,00	3,90	3,40
Total	99,73	100,60	98,68	98,65	99,54

Table 2: Balance of the gains and relative losses during the transformation of the rocks subject to deformation

Sample	SiO2	Al2O3	Fe2O3	CaO	MgO	MnO	K2O	Na2O
E37'a	-19,75	0,79	1,12	-1,40	0,19	0,01	0,45	-0,41
E37"	-13,15	2,02	0,81	-1,45	-0,09	0,00	0,00	-0,13
E38	-11,93	0,84	-1,18	-1,40	-0,26	0,02	-0,49	-0,59
E41	47,35	18,96	-1,86	0,86	0,90	-0,03	5,34	0,45

Journal Academica Vol. 2(3), pp. 141-146, September 29 2012 - Analytical Chemistry - ISSN 2161-3338
online edition www.journalacademica.org © 2012 Journal Academica Foundation

Full Length Research Paper

Chemical Selective Sensors for Zinc Detection in Water

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Accepted September 24 2012

ABSTRACT

The aim of this work is to elaborate two selective chemical sensors for zinc detection applied to the control of water. In order to optimize the work pH of sensor, a Zeolite-self-assembled monolayer sensor was elaborated and studied by using voltametry cyclic in several solutions and at different pH. The zone of pH detection was located between pH 4 and 6. The cathodic limits of zinc deposition were identified and its electrode position was revealing in working sensor zone. Once the zone of working pH was located, a second type of Zeolite-PVC-membrane sensor was elaborated and studied by potentiomeric method for zinc detection. We show that the choice of plasticizer for membrane preparation was important. Optimal selectivity and better response of sensor can be obtained for a membrane composition: 80 mg of PVC, 160 mg of DOS and 5 mg of Zeolite. Sensor based on this membrane shows that Nernstian response to zinc ions over a wide concentration range (10^{-5}-10^{-2} M) with a slope of 24.2 mV / decade in pH work zone with a short response time (<20 s) and a good reproducibility. A detection limit of sensor reached is for about 10^{-5} M. We show that two chemical sensors can be elaborated in order to detect and control heavy metals in water.

Key words: Chemical sensors, selectivity, self-assembled monolayer, PVC membrane, potentiometry, voltammetry, heavy metal, zinc, zeolite

1. INTRODUCTION

The field of ion-selective electrodes has been growing fast since the past two decades. These have been the subject of interest for analytical chemists as they provide accurate, rapid and low cost method of analysis.

This technique is nondestructive, adaptable to very small sample volume and online monitoring is also possible by these devices. Some commercialized sensors for alkali and alkaline earth metals, halides, etc. are available; however, more efforts are required to develop ion-selective electrodes of commercial standards for heavy metal ions, which are toxic beyond a certain concentration level.

The determination of zinc is important as it is widely used in electroplating, fine chemicals, pharmaceuticals, paint industries and thus occurs widely in the environment. Also some biomedical and a number of wash steams process contain less activity of this metal and a zinc-selective electrode is specially needed to analyze them. Besides, zinc is also

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present in high protein foods and its large doses can cause fever, chills, pulmonary manifestation, gastro enteritis, vomiting, nausea, anemia and renal failure [V.K. Gupta et al. 2001, V.K. Gupta et al. 2005, A. M. Bond 1999, P. Kumar, N. Bachheti 2006, H. R. Pouretedal, M. Shamsipur 1998, H. A. Zamani et al. 2006, E. M. Rakhmanko et al. 2003, M. Shamsipur et al. 1999, V. K. Gupt et al. 2006].

Zeolites are crystalline aluminosilicates displaying in a single material both ion exchange capacity and size selectivity properties. This attractive feature was exploited in electrochemistry by designing a variety of zeolite-modified electrodes with, mediated electrocatalysis and electroanalysis [M. Giahi et al. 2005, M.L. Hamlaoui et al. 2002, S. Zougar et al. 2008].

In the present work, we have used Zeolite $Na_{12}(AlO_4)_{12}(SiO_2).27H_2O$ as an ionophore in polymeric membrane for the selective detection of zinc trace amounts in water.

2. EXPERIMENTAL

2.1 Reagents

All the reagents used for the preparation of metal salt solutions and the membranes, were of analytical reagent grade. Zeolite Na(A) was obtained from SOMEZ (Society Mediterranean of the Zeolites), O-Nitrophenyloctyl ether (O-NPOE) and Dodecyle sebacate (DOS) from Fluka Switzerland, high molecular weight polyvinyl chloride (PVC) and tetra hydro furan (THF) were from Aldrich. The solutions of metal salts were prepared in doubly distilled water and standardized by appropriate methods.

2.2 Apparatus

Potentiometric and Voltammetric measurements were carried out in a Potentiostat/ Galvanostat 273 A EG&G PAR, coupled to a personal computer with power suite software for data acquisition and potential control. These measurements are carried out using an electrochemical cell consisting of three electrodes; the reference electrode was a saturated calomel electrode (ECS); a platinum wire of 1 mm diameter as the auxiliary electrode and a graphite rod 30 mm long and 6 mm in diameter as the working electrode (Fig. 1). The experiments were performed in darkness and in a faraday box in order to eliminate electrical interferences.

Figure 1: Experimental device

2.3 Graphite electrodes pre-treatment

The graphite electrodes were previously treated with metallurgical papers at various ranks. The aim of this cleaning is to eliminate the impurities from the working graphite surface. This last is cleaned with acetone during 5 minutes under sonication, rinsed with distilled water and dried [J. Zhang et al. 1995].

2.4 Elaboration of Zeolite-SAM sensor

Once the cleaning of the electrode of graphite ended, a part of electrode is immersed in a solution of sulphuric acid 1M during 10 minutes, rinsed with distilled water and then dried. After then, the dried activated surface is immersed in a concentrated solution of sulphuric acid and appropriate amounts of Zeolite Na(A). After some hours, a molecular monolayer of Zeolite is formed on the surface of the graphite activated [A. Shabani et al., 2008].

2.5. Elaboration of Zeolite-membrane sensor

The PVC-based membrane was prepared by dissolving appropriate amounts of ionophore (Zeolite Na(A)), plasticizers DOS or o-NPOE and PVC in THF (5 mL). The homogeneous mixture was obtained during 5 minutes after complete dissolution of all the components by sonication in the ultrasounds. The polished graphite electrode was dipped into the membrane solutions (Dip-coating) and the solvent was evaporated. A membrane was formed on the graphite surface, and the electrode was allowed to stabilize overnight. The electrode was finally conditioned by soaking in a solution 10-2 M of zinc sulfate for 12 h [S. Sadeghi et al. 2006, S. Rouhani et al. 2009].

3. RESULTS AND DISCUSSION

3.1 Behavior of Zeolite-SAM sensor in zinc electrolyte

Fig. 2 presents the comparison between two voltammograms obtained from the behavior of the Zeolite-SAM sensor, in various solutions (a pure solvent (0.1M H3BO3 + 0.1M NaCl) and in zinc supporting electrolyte (0.1M Zn(SO4).7H2O + 0.1M H3BO3 + 0.1M NaCl)), covering the domain of potential between 500 mV / ECS and -1400 mV / ECS.

So, the cyclic voltammogram of the Zeolite-SAM sensor in zinc supporting electrolyte shows the reduction of the zinc from the potential -1000 mV / ECS. This last one followed by a very fine peak until reach a maximum about - 1300 mV / ECS according to the reaction of the following reduction: [K. D. Song et al. 2004, S. S. gamani, M. Pushpavanam 2009, Hsin-Yi et al., 2003]. But, the cyclic voltammogram of the same sensor in a pure solvent presents only the release of hydrogen. This comparison has shown that the reduction of the zinc appears clearly as an inhibitive effect to the release of hydrogen.

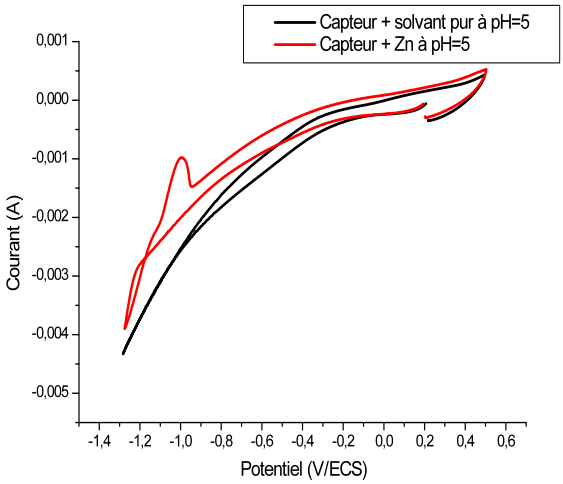

Figure 2: Voltammograms of Zeolite-SAM sensor in the absence and the presence of zinc supporting electrolyte, Scan rate 50 mV/S.

3.2 Effect of the pH on the reduction of the zinc

To study the influence of the pH on the reduction of the zinc and optimize the working pH of sensor, the pH of the solution of electrolysis was varied by 1.00 until 6.43. Then, Fig. 3 shows that only a release of hydrogen is observed in pH = 1, 2 and 3.

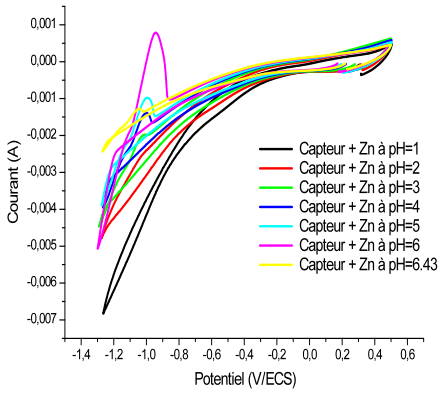

Figure 3: Voltammograms of Zeolite-SAM sensor at different pH of zinc supporting electrolyte, Scan rate 50 mV/S.

In the case of pH 4, 5 and 6 we observe that the obtained voltammograms are identical. Thus, the reduction of the zinc

is favor in this zone of pH [Hsin-Yi et al. 2003]. However, the cyclic voltammogram of sensor in pH 6.43 presents only the formation of the zinc hydroxide [$Zn(OH)_2$].
The obtained results show that in the zone of pH between 4 and 6, the electrolyte exercises an important role in the reduction of the zinc. Thus, it is very important to play on the pH of electrolyte to bring to light this phenomenon.

3.3 Influence of the composition of membrane on the characteristics of the selective zinc sensors

It is well understood that the sensitivity, linearity and selectivity obtained for a given ionophore depends significantly on the membrane composition [Y. A. Naik et al. 2002, A. Soleymanpour et al. 2008, M. R. Hassanzadeh et al. 2006, M. K. Amini et al. 2003, A. K. Sing et al. 2009, I. Isildak 2000, D. Nanda, et al. 2007, M. H. Arbab-Zavar et al. 2009, A. K. Singh et al. 2008] and nature of the plasticizer used. So, variations of potentiometric responses were measured at the concentration range 10^{-2}-10^{-6} M of buffer solutions of zinc. Thus, four membranes of varying plasticizer/PVC/ionophore were tested. Then, the results are summarized in Table 1.
It is obvious that a membrane N°1 composition of 80 mg, 160 mg O-NPOE and 5 mg Zeolite Na(A) gave a narrow working concentration range of 10^{-5}-10^{-3} M with a slope of 16 mV/decade. While, the membrane N°3 and N°4 without ionophore, did not show much improved response characteristics (range of concentration or slope).
It can be seen from Table 1, the best performance was exhibited by membrane N°2 containing DOS as solvent mediator with the composition I: DOS: PVC (5: 160: 80) (w/w; mg). This sensor N°2 (Fig. 4) displayed the widest working concentration range of 10^{-5}-10^{-2} M with a slope of 24 mV/decade.

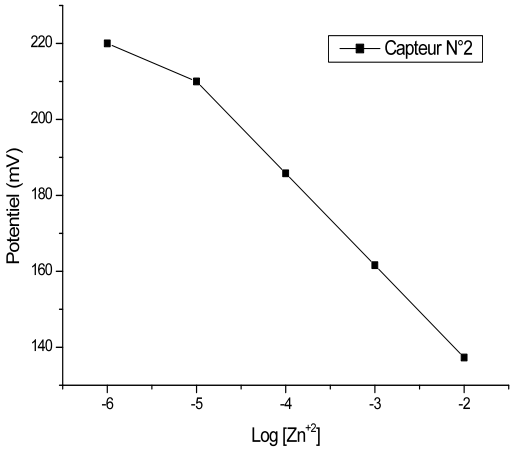

Figure.4: Calibration curve of the sensor N°2 with the optimum composition (80 mg PVC, 160 mg DOS and 5 mg Zeolite).

However, the limit of detection as determined 10^{-5} M from the intersection of two extrapolated segments of the calibration curve.

3.4. Effect of the pH on the response of selective sensor N°2 of the zinc

The pH dependence of the electrode potential for 10^{-4} M zinc ion was tested over the pH range 1.0–8.0 (adjusted with 0.1M HCl or 0.1M NaOH), the results are shown in Fig. 5.

Table. 1: Optimization of the membrane ingredients

Membrane	PVC (mg)	Plasticizer (mg)		Zeolite Na(A) (mg)	Concentration (M)	Slope (mV/decade)
		DOS	O-NPOE			
N°1	80		160	5	10^{-5}-10^{-3}	16
N°2	80	160		5	10^{-5}-10^{-2}	24.2
N°3	80		160		10^{-5}-10^{-3}	13.5
N°4	80	160			10^{-5}-10^{-3}	15

As can be seen, that the potentials are independent of pH in the range 4.0–6.0 and the same can be taken as the working pH range of the sensor N°2 of the zinc. Above and below these pH values, the sharp change in potential may be due to the hydrolysis of Zn^{2+} and H^{+} co-transport respectively.

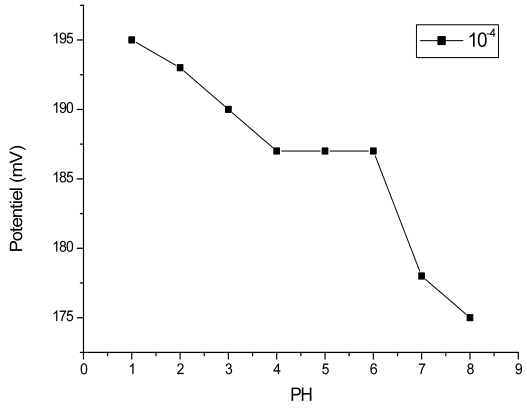

Figure 5: Potential response of the sensor N°2 at different pH of 10^{-4} M zinc ion.

3.5. Dynamic response of zinc selective sensor N°2

The study of the response of zinc selective sensor N°2 is realized by measuring the potential (mV) according to the time (s), in two levels of buffer solutions of zinc 10-4 M and 10-5 M. then, the results are shown in Fig. 6.

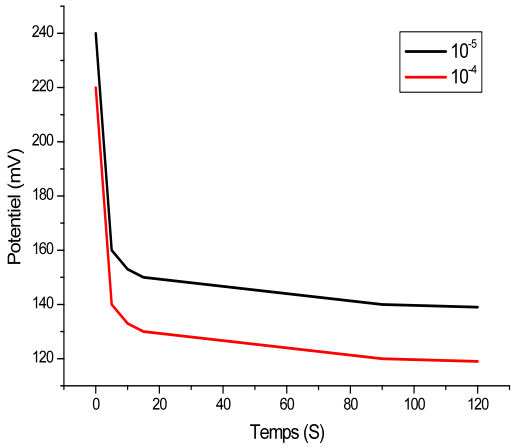

Figure 6: Dynamic response time of the sensor N°2.

As can be seen, the dynamic response time of sensor N°2 selective zinc in two levels (10^{-4} M and 10^{-5} M) is observed lower than 20 seconds.

4. CONCLUSION

In this work two chemical sensors can be elaborated in order to detect and control heavy metals in water.

We show that the optimum selectivity and responses of the sensor were obtained only for a membrane incorporing the mixture of PVC, DOS and Zéolite.

ACKNOWLEDGEMENTS

This work was partly supported by the Laboratory of Industrial Analysis and Materials Engineering (LAIGM), University 08 Mai, Guelma (Algeria).

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Journal Academica Vol. 2(3), pp. 147-151, September 29 2012 - Microbiology - ISSN 2161-3338
online edition www.journalacademica.org © 2012 Journal Academica Foundation

Full Length Research Paper

Biological Wastewater Denitrification by Thermophilic Bacteria

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Accepted September 24 2012

ABSTRACT

The biological denitrification of wastewater was studied by two thermophilic strains (Bacillus sp.) isolated from hot spring (Hammam Essalhine, Khenchela). The kinetics of denitrification was followed at 55°C anaerobically using (5g/l) of KNO_3 as final electron acceptor. The determination of NO_{3-} was performed by colorimetric method using sodium salicylate. The results showed the ability of the thermophilic strains to reduce NO_{3-} to NO_{2-} at much faster rate (14 to 17h) compared with a mesophilic strain Enterobacter cloacae (45h) isolated from activated sludge of a wastewater treatment plant. The study of the influence of temperature on nitrate reductase activity showed a maximum denitrification at 60 °C. These thermophilic denitrifying bacteria may be useful in processes of treatment of wastewater, to reduce the high concentrations of nitrates by a biological process.

Key words: Pollution, sewage treatment plants, denitrification, bacteria, thermophily

1. INTRODUCTION

Nitrate contamination of water is widespread in the region of Khenchela (eastern Algeria). Increased levels of nitrate have negative effects on health and environment. Biological denitrification has been shown to be one of the most advanced methods for removing nitrogen in low-cost way. (Rezaee A. *et al.*, 2008).

Denitrification by bacteria is generally regarded as being a result of anaerobic nitrate respiration (Payne W. J., 1973; Knowles R., 1982). Moreover, high temperatures promote more this process influencing the dissolved oxygen concentrations. Biological denitrification is inhibited when the dissolved O_2 is above 0.2 mg/l (Nozawa T. *et al*., 1988).

In this paper, we demonstrate the nitrate removal process by two thermophilic bacterial strains which thrive at high temperatures (Horiike T. *et al.*, 2002).

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2. MATERIALS AND METHODS

To study the biological denitrification kinetics, three batch cultures were performed in 500ml flasks containing a synthetic medium with similar composition of wastewaters. Containing (g L^{-1}): KNO_3, 5; KH_2PO_4, 1; NaCl, 1; $MgSO_4$, 0.2; $CaCl_2$, 0.02, trace elements solution, 1mL L^{-1}, the pH was adjusted to 7 ± 0.04. After sterilization at 120 °C for 30 min, glucose was added as carbon source (5 g L^{-1}) (Balch W.E. *et al.*, 1979; Mammeri L., 2007).

Each flask was inoculated with one of the selected bacterial strains. The three strains are characterized by their ability to reduce nitrate through bacterial enzyme, nitrate-reductase (Fig.1, Table 1).

Flasks were then incubated anaerobically in shaking water bath.

Samples were taken every 2 hours to determinate the growth rates by measuring the optical density at 600 nm using a UV/ VIS spectrophotometer (SHIMADZU). Nitrate rates were determinate by colorimetric method using salicylate sodium (Kariminiaae et *al*., 2004; Rodier, 2009).
The nitrate-reductase activity of *Bacillus sp. II* was tested at different temperatures (20-80°C) (Garcia J. L., 1977).

Figure 1: Microscopic appearance of the three nitrate-reductase strains. (a), *Bacillus sp. I*; (b), *Bacillus sp. II*; (c), *Enterobacter cloacae*.

Table 1: Characteristics of the three bacterial strains studied.

	Bacillus sp. I	***Bacillus sp. II***	***Enterobacter cloacae***
Growth T°	55 °C	60 °C	30°C
Gram stain	+	+	-
Nitrate-reductase	+	+	+
Isolation site	Thermal water (Hammam Essalhine) -Khenchela-	Thermal water (Hammam Essalhine) -Khenchela-	Activated sludge (Treatment plant) -Khenchela-
Incubation T°	55 °C	55 °C	30 °C

3. RESULTS AND DISCUSSION

The results show the ability of the three bacterial strains studied to reduce NO_{3-} to NO_{2-} at different rates. This is explained by decrease of nitrate rate over time of incubation, reaching minimum concentrations (Fig. 2, 3 and 4) (Jutharat *et al*., 2007).

The first two graphs (Fig. 3 and 4) show an excellent removal of nitrate by the thermophilic strains (*Bacillus sp. I, Bacillus sp. II)* in a very short interval time (14-17 h) compared to the mesophilic strain (*Enterobacter cloacae*) which was unable to remove full nitrates after 45h of incubation (Fig. 4).

The study of the influence of temperature on the nitrate-reductase activity showed a higher denitrification at 60 °C (Fig. 5).

These results confirm the ability of thermophilic bacteria, isolated from hot springs, to denitrify (Chen *et al*., 2002; Khelifi *et al*., 2010).

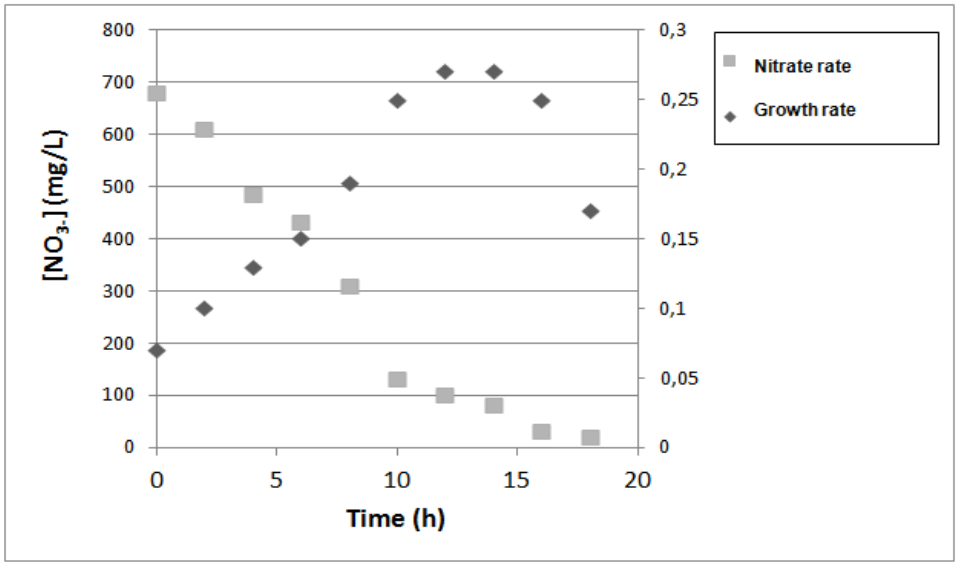

Figure 2: Kinetics growth and nitrate reduction by the thermophilic strain *Bacillus sp.I.*

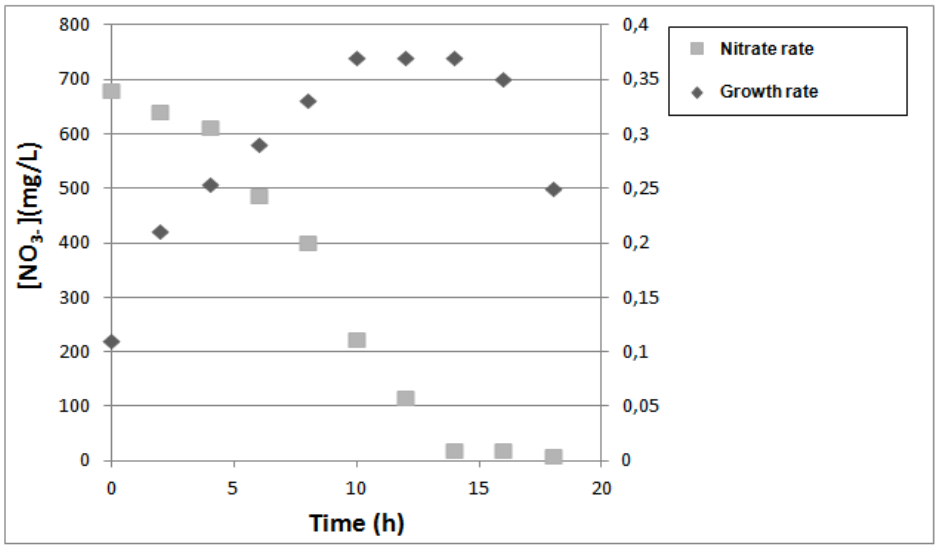

Figure 3: Kinetics of growth and nitrate reduction by the thermophilic strain *Bacillus sp.II.*

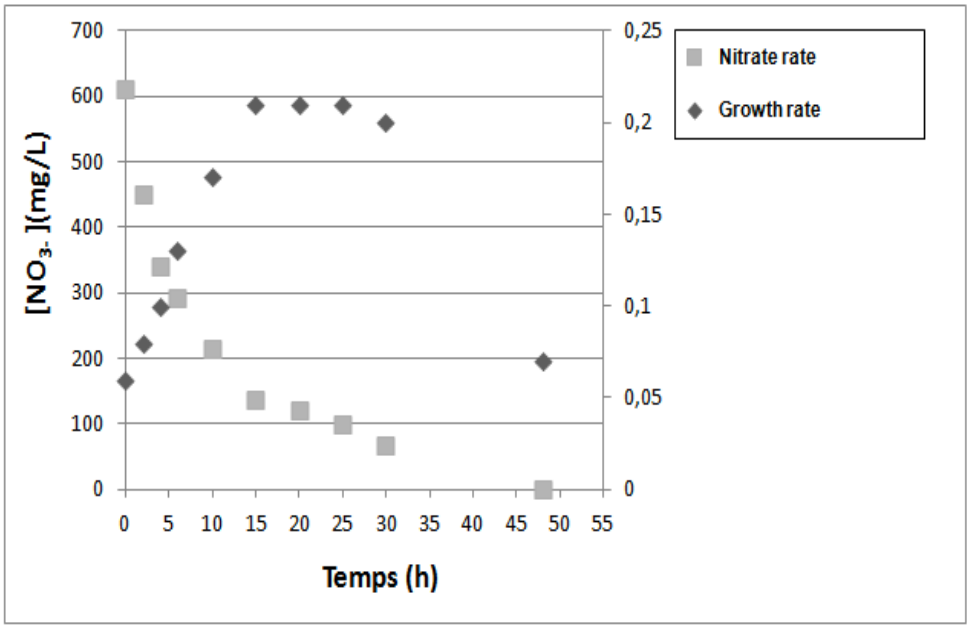

Figure: Kinetics of growth and nitrate reduction by the mesophilic strain *Enterobacter cloacae.*

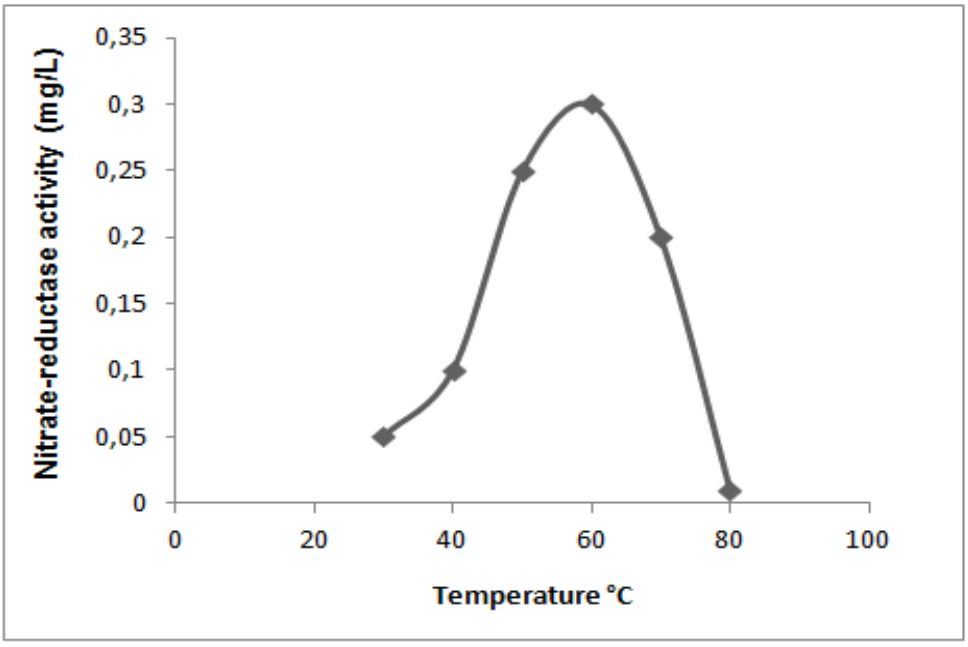

Figure: Dependence of the nitrate-reduction of *Bacillus sp. II* on the temperature.

4. CONCLUSION

Denitrification was studied at high temperatures using two bacterial thermophilic strains. The nitrate removal efficiency of this these isolates were faster than that of control mesophilic strain. These thermophilic bacterial strains can be very useful in processes of treatment of wastewater, by reducing the high concentrations of nitrates.

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Journal Academica Vol. 2(3), pp. 152-159, September 29 2012 - Particle Physics - ISSN 2161-3338
online edition www.journalacademica.org

Full Length Research Paper

The Symmetry of Matter and Antimatter

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Accepted July 30 2012

ABSTRACT

A formal and empirical review of matter and antimatter symmetry in QFT motivates a single particle reference hypothesis which is matched against recent observable data.

Key words: matter, antimatter, particle, antiparticle, relativistic quantum mechanics, quantum field theory, stability, annihilation, *baryogenesis*, standard model

1. INTRODUCTION

Physics is defined by the basic concept of matter (*viz.* energy) and the interactions thereof. As such, physics is categorized as a natural, empirical science.

On a rather phenomenological level, these interactions are successfully described in a more or less complex framework of space and time with quantitative notions about motion and force.

However, up until today the basic concept of matter remains a mystery, if not *the mystery* yet to be deciphered.

While day-to-day reason tends to define matter as something that has *mass* and occupies *space* with the property of a *volume*, modern physics work with a totally different concept, deeply rooted in its very formalism initiated by *Paul Adrien Maurice Dirac* (1902-1984), with his formal discovery of antimatter in his famous equation of 1928 [1].

Antimatter is a direct consequence of the theory of relativity and of quantum mechanics, i.e., of the quantum field theories (QFT) which underlie modern particle physics. Its theoretical prediction and experimental manifestation [2] are considered as one of the great successes of physics.

For every particle there is an antiparticle with quantum numbers and charges of the opposite sign.

Whether considering the relativistic wave equation for the electron that has both, positive and negative energy solutions, or current field theories with creation or annihilation operators acting on a field that create particles, destroy antiparticles or destroy particles and create antiparticles associated with the field, the properties and dynamics of particles and antiparticles are symmetrically correlated.

2. FORMAL SYMMETRY

The absolute symmetry between matter and antimatter is best demonstrated by briefly recapitulating the formalism of the free *Dirac-equation*, i.e., without any electromagnetic action potential:

$$(1) \qquad i\hbar\,\partial\psi(\vec{r},t)/\partial t = -i\hbar c\sum_{r=1}^{3}\alpha_r\,\partial\psi(\vec{r},t)/\partial x_r + \beta mc^2\psi(\vec{r},t)$$

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Since the functions $\psi\vec{p}(\vec{r},t)$ are eigenvalues of the impulse operator:

$$(2) \qquad \psi\vec{p}(\vec{r},t) = (2\pi\hbar)^{-3/2}\psi e^{i/\hbar(\vec{p}\vec{r}-Et)}$$

we need to determine the spinor

$$\psi = \begin{pmatrix} \psi_1 \\ \psi_2 \\ \psi_3 \\ \psi_4 \end{pmatrix}$$ in a way to solve (1) through the impulse operator (2). This yields the equation system for the energies E with $\vec{p} = (p_x, p_y, p_z)$ as

(3)

$$\begin{aligned}
(E - mc^2)\psi_1 - c(p_x - ip_y)\psi_4 - cp_z\psi_3 &= 0 \\
(E - mc^2)\psi_2 - c(p_x + ip_y)\psi_3 + cp_z\psi_4 &= 0 \\
(E + mc^2)\psi_3 - c(p_x - ip_y)\psi_2 - cp_z\psi_1 &= 0 \\
(E + mc^2)\psi_4 - c(p_x + ip_y)\psi_1 + cp_z\psi_2 &= 0
\end{aligned}$$

Now we choose the z-axis in the direction of the impulse $\vec{p}$ to get x and $y = 0$, i.e., $\vec{p} = (0,0,p)$ yields pairs to determine ψ_1 and ψ_3 ((4a) and (4c)) as well as ψ_2 and ψ_4 respectively ((4b) and (4d)):

$$\begin{aligned}
&(4a) \quad (E - mc^2)\psi_1 - cp\psi_3 = 0 \\
&(4b) \quad (E - mc^2)\psi_2 + cp\psi_4 = 0 \\
&(4c) \quad (E + mc^2)\psi_3 - cp\psi_1 = 0 \\
&(4d) \quad (E + mc^2)\psi_4 + cp\psi_2 = 0
\end{aligned}$$

With $E^2 = m^2c^4 + c^2p^2$ we have the relativistic expression for the energy of a *single*, free particle where the energy E represents *as well as both*, positive and negative values for the same impulse $\vec{p}$ of a single particle:

$$(5) \qquad \begin{aligned} E_+ &= +\sqrt{c^2p^2 + m^2c^4} \\ E_- &= -\sqrt{c^2p^2 + m^2c^4} \end{aligned}$$

Figure 1 illustrates the theoretical energy spectrum of (5) giving rise to a fundamental problem with the very existence of matter, hence, with the existence of *everything* at stake:

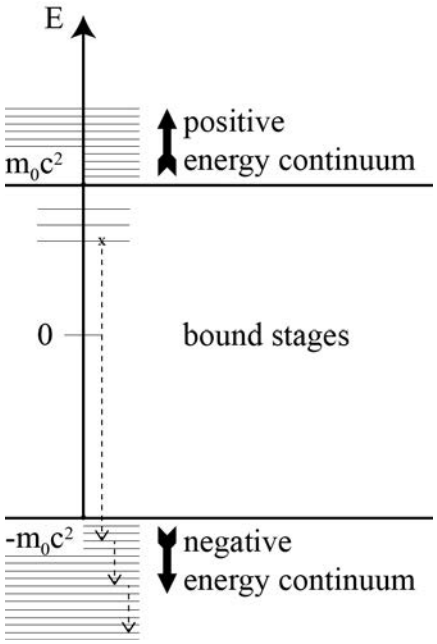

Figure 1: radiation catastrophe - an electron bound in an atom "falls" into the negative energy continuum with continuous emission of radiation.

How can matter exist? Taking the formal symmetry between matter and antimatter without any semantic reference hypothesis would physically imply atoms to be instable on principle. Matter would totally annihilate emitting pure energy in terms of light.
Obviously, just that is not observed. Nevertheless, considering

$$(5) \qquad E = \pm\sqrt{p^2c^2 + m_0^2c^4}$$

the fundamental problem of absolute symmetry of all points of matter (i.e., m_0) exists as well as both, on principle and in practice since the physical world exists.
The commonly accepted workaround is based on a semantic reference hypothesis originally proposed by *Dirac* himself [3].

For the purpose of providing an insight about the developed creativity to avoid negative energy properties, the general solutions for plane waves of the free *Dirac-equation* (6a and 6b) are further considered (cf. [4]):

$$\text{(6a)}\quad \psi(\vec{x},t)=\sum_{\pm s}\int d^3\vec{p}h^{-3/2}\sqrt{\frac{m_0c^2}{E_p}}\left[b(\vec{p},s)u(\vec{p},s)e^{(i/\hbar)(\vec{p}\vec{x}-E_pt)}+d^+(\vec{p},s)v(\vec{p},s)e^{(-i/\hbar)(\vec{p}\vec{x}-E_pt)}\right]$$

$$\text{(6b)}\quad \psi^+(\vec{x},t)=\sum_{\pm s}\int d^3\vec{p}h^{-3/2}\sqrt{\frac{m_0c^2}{E_p}}\left[b^+(\vec{p},s)\overline{u}(\vec{p},s)\gamma_0e^{(-i/\hbar)(\vec{p}\vec{x}-E_pt)}+d(\vec{p},s)\overline{v}(\vec{p},s)\gamma_0e^{(i/\hbar)(\vec{p}\vec{x}-E_pt)}\right].$$

The spinors $u(\vec{p},s),v(\vec{p},s)$ satisfy the *Dirac-equation* and constitute a complete orthogonal system.

$\psi^+(\vec{x},t)$ is hermitically conjoint to $\psi(\vec{x},t)$ where $b(\vec{p},s)$, $d(\vec{p},s)$, $b^+(\vec{p},s)$ and $d^+(\vec{p},s)$ are development-coefficients.

$E_p=c\sqrt{\vec{p}^2+m_0^2c^2}$. γ_0 is a constant matrix. The index s summarizes the spin-states.
The 2nd quantization of the *Dirac-field* now turns the development-coefficients b, d, b^+, d^+ into operators. The exchange-relations are chosen in a way that the *Pauli-principle* (exclusion principle) is satisfied. If the following anti-exchange relations apply $\left([A,\,B]_+=AB+BA\right)$, it guarantees formally that:

(7)

$$\left[b(\vec{p},s),b^+(\vec{p}\,',s')\right]_+=\delta_{ss'}\cdot\delta^3(\vec{p}-\vec{p}\,')$$
$$\left[d(\vec{p},s),d^+(\vec{p}\,',s')\right]_+=\delta_{ss'}\cdot\delta^3(\vec{p}-\vec{p}\,').$$

This yields to the anti-exchange relations for the fields

$$\left[\psi(\vec{x},t),\,\psi(\vec{x}\,',t)\right]_+=0$$
$$\left[\psi^+(\vec{x},t),\,\psi^+(\vec{x}\,',t)\right]_+=0.$$

In analogy to common procedures in QFT, (6b) b^+ and d are interpreted to be generation-operators for electrons. But now d generates a state with negative energy. In order to realize that, the energy-operator H (8) is expressed by b, d, b^+, d^+.

$$\text{(8)}\quad H=\sum_{\pm s}\int d^3\vec{p}E_p\left(b^+(\vec{p},s)b(\vec{p},s)-d(\vec{p},s)d^+(\vec{p},s)\right).$$

Interpreting the operator b^+ as generating a particle with positive energy $\left(E_p,\vec{p}\right)$ and transferring this interpretation formally to the second operator in (8) suggests the conclusion that d^+ generates a particle with negative energy $\left(-E_p,-\vec{p}\right)$.

The complete impulse-operator reads

$$\vec{p}=\sum_{\pm s}\int d^3\vec{p}\vec{p}\left(b^+(\vec{p},s)b(\vec{p},s)-d(\vec{p},s)d^+(\vec{p},s)\right).$$

Equation (8) shows that the continuum-solutions of the energy expression are not positive definite. But applying *Dirac's* semantic reference hypothesis (Fig. 2) according to which the vacuum is defined by all negative energy states being fully occupied with anti-electrons (positrons) and the positive energy states being completely empty, the energy and impulse operators are just rewritten as:

$$H = \sum_{\pm s} \int d^3\vec{p} E_p \left(b^+(\vec{p},s) b(\vec{p},s) + d^+(\vec{p},s) d(\vec{p},s) - - \left[d(\vec{p},s), d^+(\vec{p},s') \right]_+ \right)$$

$$\vec{p} = \sum_{\pm s} d^3\vec{p}\vec{p} \left(b^+(\vec{p},s) b(\vec{p},s) + d^+(\vec{p},s) d^+(\vec{p},s) - - \left[d(\vec{p},s), d^+(\vec{p},s') \right]_+ \right).$$

In anticipation of the desired creation- and annihilation operators, the energy is kept positive. For a vacuum, the first two terms cancel because there are neither positive energy states which could annihilate with $b(\vec{p},s)$ nor states of negative energy which could be filled by $d(\vec{p},s)$. The last term is supposedly just an infinite constant (the total negative energy of the vacuum) which will proof critical in furtherance of this presentation. For now, it is simply ignored (normalized).
Thus, an anti-electron (positron) is just a (positive) manifestation of a (negative) hole in the *Dirac-sea* (Figure 2):

3. EMPIRICAL SYMMETRY

The formally discussed, Lorentz-invariant QFT equations are the foundations of the "Standard Model" (SM) of particle physics. If we flip the signs of all charges we turn particles into antiparticles. If we perform a consecutive space reversal $\vec{x} \to -\vec{x}$ and then a time reversal $t \to -t$, we recover the original equations.
This symmetry is called "CPT" (Charge-Parity-Time reversal) symmetry. It fundamentally implies that particles and antiparticles have exactly the same mass and that antimatter is an exact mirror of matter with all physical phenomena so far observed being invariant under CPT conjugation.

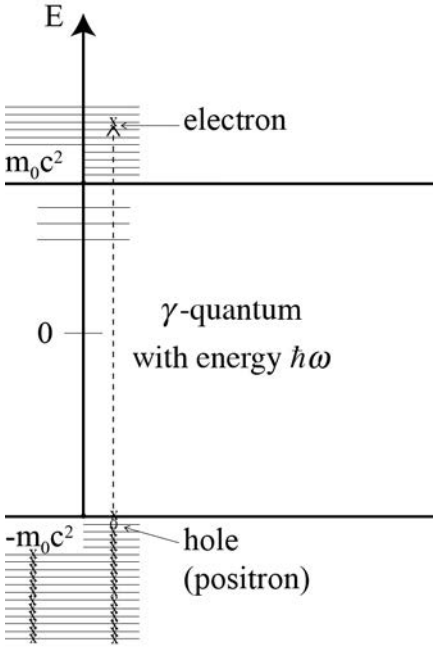

Figure 2: A photon with the energy $\hbar\omega \geq 2m_0c^2$ creates an electron-electron-hole-sate where the "hole" is interpreted as a positive electron (positron).

Hence, hydrogen atoms and their corresponding anti-hydrogen atoms should have exactly the same energy levels.
And just that has been empirically demonstrated at CERN [5].
Taking a look with the SM at the universe as a whole, matter is continuously transformed, e.g., in stars. Nuclear transformations such as the reaction *proton* → *neutron* + *positron* + *neutrino* change certain properties where, e.g., the number of protons decrease while neutrons increase.
Nevertheless, all empirical data gathered and analyzed so far strongly suggests that the more general class of particles called *baryons*, which includes protons and

neutrons, as well as *leptons* such as positrons and neutrinos, don't change but *remain absolute constant*.

4. GEDANKENEXPERIMENTS

To sum-up the formal and empirical situation of the well-tested SM, we set up simple *Gedankenexperiments*:

a) We imagine a dedicated region with absolutely no baryons nor leptons, neither matter nor antimatter, i.e., a total baryon and lepton number of zero.

Now we intend to introduce matter by interactions of high-energetic particles as actually done in particle accelerators and assumed by the SM in the early stage of the universe.

Since these interactions conserve the baryon and lepton number, they always result in pairs of baryons and antibaryons as well as leptons and antileptons created.

If we consider in line with the SM that baryons (B+) and antibaryons (B-) as well as leptons (L) and antileptons (L-) nullify each other by (almost) instant decay (B+/B- and L+/L- annihilation), the net number of B and L in our dedicated region would remain zero.

b) Now we imagine the opposite, i.e., a region with an equal amount of B+/B- and L+/L- where we intend to remove, e.g., the antimatter (B-/L-).

Since the SM prohibits spontaneous decay into particles *with less* net baryonic/leptonic content, the only process observable would be a B+/B- and L+/L- annihilation yielding again no net change in baryon and lepton number.

5. MATTER MYSTERY

Mysteriously, the so far presented properties of matter and antimatter seem to proof formally and empirically that the world of matter won't exist. This is why mainstream physics is still in the process of trying to decipher the relations of matter and antimatter by postulating an asymmetry resulting in an abundance of one over the other.

But the unsolved problems by assuming the existence of just a single region of our universe with a significant baryon number $\neq 0$ yield even more mysteries (cf. [6]), with two major implications:

As already laid out, standard particle physics only knows of formal and empirical processes which increase or decrease baryons and leptons *in pairs*, i.e., we don't know nor did we ever produce a change in the net number of B or L.

If now the inferred $B/L > 0$ (or just $B > 0$) shall be the case to have some starting point to physically explain the stability, hence, existence of matter as perceived, $B/L > 0$ must represent an initial condition of the SM.

Those however, who follow the formal and empirical symmetry of the universe with the universe having $B/L = 0$, thus equal amounts of matter and antimatter, postulate a spatial mechanism that needs to rearrange and separate matter from antimatter to treat it as distinct spatial domains.

A part of several attempts to formalize such domain separations [7], no consistent mechanism to prevent matter and antimatter domain interactions which would otherwise annihilate by either vanishing completely or lighting up the universe with annihilation gamma rays is known to-date.

Another alternative, although radical, was proposed by *Andrei Dmitrievich Sakharov* (1921-1989) [8] who just allows for baryon number violation declaring the SM as wrong at higher energies than currently available for empirical testing with accelerators. Unlike CPT symmetry, which follows from above discussed relativistic QFT and their implied Lorentz-invariance, baryon number variation is open to a variety of theoretical debate.

Sakharov himself set three conditions which could lead to a *baryogenesis*, i.e., to a dynamical generation of a baryon asymmetry from an initially symmetric universe:

1. The possibility of baryon number violation
2. CP symmetry violation
3. An initial thermal equilibrium

But because the underlying physics for *baryogenesis* is still completely unknown, there is a lot of speculation as to what spatial distribution of matter and antimatter is actually produced by *baryogenesis* (cf. [9]).

6. EPISTEMOLOGY

The description of *particles* with the language of physics, i.e., mathematics, constitutes both, its expressive power as well as its limits.
While the formalism of Lorentz-invariant QFT equations yields mathematical solutions which express more than their non-relativistic, non-quantum mechanical counterparts, i.e., positive *and* negative energy/mass properties, they also impose new limits with regard to their area of application.
Reviewing, e.g., the very mechanism of anticipating relativistic particles within QFT, the concept of a free particle is revised and limited by quantum mechanical measurement restrictions (*Heisenberg's Uncertainty principle*):

Because $\Delta x \sim \frac{\hbar}{\Delta p} \sim \frac{\hbar}{2m_0 c}$ limits our measurement process on principle to a wavelength (*Compton wavelength*) of $\lambda_c = \frac{\hbar}{m_0 c}$, any particle localization below λ_c yields to particle-antiparticle pair-creation with energies $> 2m_0 c^2$.

Accordingly, the concept of a single particle is absolutely limited to localizations above the *Compton wavelength* so that elementary particles such as electrons, quarks, or photons, and composite particles such as protons or neutrons have *no spatial localization.* And just as with the non-spatial localization of particles the same restriction is imposed on their localization in *time* where $\Delta x > \frac{\hbar}{2m_0 c}$ yields $\Delta t \sim \frac{\Delta x}{\Delta c} > \frac{\hbar}{2m_0 c}$ so that particles are rather described in probabilistic terms ϱ to localize them in (x, y, z, t).

6.1 Single particle hypothesis

Looking at free particles as entities with no spatial and temporal localization provides with evidence to investigate the possibility of a single particle reference hypothesis yet not considered:

Particle and antiparticle have exactly the same localization, i.e., are just one entity without any interaction.

Once such a particle (*bi-particle*) is localized below $\lambda_c = \frac{\hbar}{m_0 c}$ with $E \geq 2m_0 c^2$, the well-established QFT interactions between particles and antiparticles are observed, including but not limited to particle-antiparticle annihilation, i.e.:

Every particle above $\lambda_c = \frac{\hbar}{m_0 c}$ is a stable *bi-particle*.

6.2 Epistemological positioning

With this reference hypothesis being subject to our measurement restrictions imposed by quantum mechanical measurement properties, it essentially shifts the existential constraint of the

stability with a mere phenomenological reference hypothesis to an ontological one:
Instead of trying to alter a consistent and empirically successful formalism with well-understood and tested pair-creation and annihilation processes for presumably securing a physical explanation for the stability of matter, it leaves the valid question about stability and existence of matter for an ontological rather than phenomenological debate.

7. CONCLUSION

While there is widespread belief that the negative energies were once and for all understood in terms of antiparticles, they are not related to non-localized, non-temporal negative energy states whose quanta are by construction in QFT neither created nor annihilated above a localization of $\lambda_c = \frac{\hbar}{m_0 c}$, i.e., below energies of $2m_0c^2$.

As previously presented, the actual meaning of field negative frequency terms in QFT does not bypass the negative energies since the corresponding solutions were neglected from the beginning with phenomenological *ad hoc* reference hypothesis as initiated by *Dirac* himself.
The drawback for attenuating or totally neglecting negative energy solutions implies all those field vacuum divergences that formally arise after quantization along with all initiatives to cancel such infinities without reintroducing negative energy states (vacuum energy).
On a heuristic vein, the SM doesn't require any *ad hoc* modification in terms of *baryogenesis* nor are domain separation mechanisms required to prevent particle-antiparticle annihilation.
With cosmological observations of supernovae, WMAP [10] and COBE [11] satellite's data on Cosmic Microwave Background (CMB) as well as galaxy cluster distributions, the observational evidence is growing that our universe is presently in a state of accelerated expansion.
The majority of researchers is accounting for this empirical data with the reintroduction of a cosmological constant, *dark matter* with some kind of negative pressure, or with scalar fields with negative kinetic energy, i.e., *phantom fields* (cf. [12] [13] [14]).
But because all of these models are built on QFT they unavoidably yield a violation of positive energy conditions and are constraint by quantum instability of the vacuum where the common *trick* is to impose an *ultraviolet cutoff* to effectively restrict the theory to low energy and to keep the instability at an unobservable rate.
However, while stability is the main concern for any physical model trying to incorporate negative energy fields, it is only the *interaction* with positive energy fields which causes persistent theoretical failure.
The here presented, symmetric, bi-particle hypothesis may provide new insights to gravitational interaction and may derive rich phenomenological and theoretical perspectives.

ACKNOWLEDGEMENTS

Thanks to *Markus Porsche-Ludwig* for a mission-critical kitchen table discussion and to LION.

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