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ARROWS IN SCIENCE DIAGRAMS : HELP OR HINDRANCE FOR PUPILS?

Brendan Scholium

INTRODUCTION

The work of Ausubel (1968), Driver (1981) and others suggests strongly that children coming to science classrooms have already formed views about the natural and technological world around them. Similarly, one of the major outcomes of the Learning in Science Project (Osborne, et al., 1982) was that children do bring to science lessons strongly held views about why and how things behave as they do and that their views appear to them to be sensible and logical. Unless teachers identify the views that children hold and design their teaching accordingly, some children's ideas will not change, or will change in unanticipated ways as a result of formal science teaching.

Is the above situation true of children's views of science diagrams as well? From a colleague's study of textbooks commonly used at the Form 3 and Form 4 level (13-14 year olds) it was found that arrows are used in diagrams at an average rate of one every three pages. As well, arrows were used in these distinct ways:

(a) as labels;
(b) for measurement;
(c) as forces (other vector quantities were not used at this level);
(d) to illustrate relationships such as energy transfer or matter classification;
(e) to represent changes in chemical reactions;
(f) for sequence in time and/or space.

Sometimes arrows served two functions within one diagram.

The purpose of this study was to investigate and describe how the presence of arrows in science diagrams influences pupils' interpretations of these diagrams. In order to do this it was important to determine children's views of several different diagrams which did not contain arrows before introducing similar diagrams that did contain arrows. The latter group of diagrams were all taken from science textbooks.

SUBJECTS

The investigation took the form of a series of tape recorded interviews with individual children who were all in Form 4 classes. Fourth Form pupils (14 year olds)

were chosen because they should all have covered the topics from which the diagrams were chosen. All pupils were from average ability classes though one pupil was outstanding for the clarity of his expression and another pupil seemed bewildered by the experience. This may have been due to extreme shyness rather than a lack of an ability to verbalise the most straightforward of ideas or explanations. Of the fifteen pupils interviewed, eight were female. These have been given odd numbers 01 to 15 while males are coded using the even numbers 02 to 14. The pupils came from both single sex and co-educational schools in Auckland.

PROCEDURE

The pupils were withdrawn from science classrooms one at a time, and the interviewees were helped to relax by some initial conversation about his/her schooling and interests. The purpose of the interview was explained and this was that the interviewee had been chosen as one of a number of fourth formers from various schools to talk about several different science diagrams. It was their views that were wanted. Also, the purpose of having the tape recorder was explained.

Each diagram (see Appendix A) was presented one at a time, with a brief comment to help set the context of where the diagram had come from: e.g., for diagram 1, two comments such as 'Here is a diagram that you might have come across in a chapter on "Communities"'. Each pupil was asked "What does this diagram mean to you?' or 'When you see a diagram like this what does it mean to you?'. The pupils' meanings for words used or seen in the diagrams were explored as well as their overall view of each diagram.

Once the cards of diagrams without arrows (diagrams 1-5) had been completed, the five cards of diagrams with arrows (diagrams 6-10) were used with words such as 'Now let's look at this diagram, it's from a chapter on "Communities". What does this diagram mean to you?'. Thus each pupil made comments about ten diagrams. This procedure has been adapted from a method developed by Osborne and Gilbert (1980).

Each interview, which normally lasted about 20-30 minutes, was audio-taped and later transcribed.

DIAGRAMS OF FOOD CHAINS

(a) Without arrows

When the two diagrams of food chains (cards 1 and 2 in Appendix A) were presented to the pupils, every pupil except one (01) was able to explain clearly what each diagram showed. These examples indicate the views expressed:

'It's showing a food chain. The herbivore is living off the tree. The bird looks for food in the tree also (What sort of food?) I'm not sure. (And what about the cat?) It's a scavenger; it's looking for food. (Could it find its food from anything in this diagram?) No'. (01)

'It's really showing the life cycle of plants. The bugs eat the bush. The birds eat the bugs and the tiger eats the birds and they don't know it but they've got all these different things in them - in their system. That's not counting waste products of course ... The waste products contain seeds so more plants grow'. (09)

'I think the bird would eat all these insects. The caterpillar would eat the cabbage. I'm not sure if birds eat spiders but it looks as if they do'. (10)

(b) With arrows

However, when these diagrams were re-introduced (cards 6 and 7) there was a wider range of views expressed and less confidence in the views that were expressed. For half the pupils, the diagrams were outright puzzling:

'This looks like the cabbage is going to eat the caterpillar and the caterpillar is going to eat the bird. This diagram doesn't look right'. (02)

'It's telling me something that I wouldn't believe. It suggests that a spider eats a bird, or a caterpillar eats a bird which I think is impossible and a cabbage would hardly eat a caterpillar. Those arrows are around the wrong way for a food chain'. (05)

'It's showing the opposite of what really happens. It's showing that the producer provides for everything. The insects get bigger and they provide food for the birds'. (12)

The other pupils gave various meanings for the relationships between species in the food chain. Words such as 'lives off', 'produces', 'depends on', and 'is eaten by' were used to explain the diagrams whereas in the earlier cards nearly every pupil used the term 'eats'.

One pupil (01) continued to be confused:

> 'This one's about the sun's energy ... The plant and the herbivore are somehow connected. I'm not sure how. The scavenger is up here looking for food. (In the diagrams or pictures here or somewhere else?). Somewhere else'. (01)

Other than the obscure comment from pupil 01 above, no pupil spoke about energy flow in a food chain in the direction of the arrows. For half the pupils the presence of arrows introduced a confusing element into their understanding of the diagrams of food chains.

MATTER CLASSIFICATION DIAGRAMS

(a) Without arrows

Diagram three (see Appendix A) was introduced with words such as 'This is a diagram from a chapter on "Substances"' or 'What Matter is made of'. A few pupils expressed their views clearly and readily but the majority of the pupils found some difficulty with the diagram probably because it was less familiar as an example than the previous diagrams discussed. The following views were expressed:

VIEW 1 These pupils (02, 03 and 09) held the view that the diagram was a method of showing that examples of matter were <u>partly</u> living <u>partly</u> non-living, and that these parts were composed or made up of molecules and atoms.

> 'Matter is made up of living cells and non living crystals and both of them are made up of molecules which in turn are made up of atoms. (What are examples of matter?) Insect - an insect is made up of living cells and non living cells and part of us - probably the waste products are the non living part, the things we don't use. The living cells are the part that help us to breathe and see. (Would paper be an example of matter?) No because it doesn't have living cells.' (09)

VIEW 2 Seven pupils (05, 06, 07, 08, 10, 13, 15) had the view that the diagram was a way of showing that examples of matter are <u>either</u> living <u>or</u> non living and both of these types or categories of matter are made up of molecules and atoms.

'Matter is, ... can either be non living which is crystals or it can be living which has cells, and they both have molecules made up of atoms'. (07)

VIEW 3 Two pupils (04 and 11) had the view that the diagram represented a life cycle for matter.

'It's what matter turns into when it changes. It's like a cycle. Matter changes into living things. (What are some examples of matter?) Therefore the air. Things that are in the air are matter (Tell me more.) There are living cells in the air (Carry on.) other things that are in the air are as small as atoms (What is in the air then?). Lots of things, some of them are as small as atoms. Others are living cells. (What about this other part of the diagram?) This shows what they go to when they die. They go to crystals, they evaporate; go to nothing'. (04)

OTHER VIEWS The other three pupils, (01, 12, 14) were not sure really what the diagram meant. They had difficulties in verbalising any relationships between parts of the diagram and definitely had no clear idea of what the whole of the diagram meant. There were parts of the diagram explained but no clear view emerged. For example, pupil 14 said among other things:

'Molecules are little parts of substances in science. Living things are in cells, things like bacteria. Nothing lives in crystals. There's no connection between crystals and molecules. (What does this word matter mean to you?) Matter refers to things that are living. (For example?) The sun and heat'.

(b) With arrows

When the discussion focussed on the diagram with arrows (diagram 8) the views expressed were generally similar to those expressed earlier. Most of the pupils explained their view more easily and this may have been because of the presence of the arrows or just the fact that they were more relaxed by that stage of the interview. For the purpose of comparison consider what each of the pupils whose comments were used in the section above said about the diagram with arrows.

VIEW 1 'This diagram is the same one as we saw before'. (09)

VIEW 2 'Matter can either be non living which are crystal, which are made up of molecules and molecules are made up of atoms. Or matter can be living which is made up of cells which are also made up of molecules'. (07)

VIEW 3 'It's sort of like a life chain but it involves things you can't see, the micro-organisms. You can't really see them but this shows the cycle they go through. (Tell me about it.) This is matter living in little cells ... they all go down to molecules and atoms. These become non living crystals when they die. It depends what you are talking about. You can't say a tree is living in the sense that it's living in its own world. It is living in that it has living cells which are made up of molecules. Once the cells die, you get crystallisation, you have non-living crystals formed'. (04)

OTHER VIEWS With arrows present pupil 01 held a view consistent with category 2 above; she explained that matter is made up of living cells or non living crystals, and that cells and crystals are made up of molecules and atoms.

Pupil 12 held a view that the matter is in both living cells and non living crystals and when these break down 'later on' molecules and atoms are formed. The arrows were seen as expressing sequence in time.

The third pupil, 14, held a different view from that expressed earlier, but still an idiosyncratic view related to energy flow and time.

> 'All the matter, all the energy goes that way (pointing in direction of arrows). The living cells get energy from matter and they form into atoms. The non living things get energy too. They form into crystals which then form into molecules when they break down'.

CAR DIAGRAM

(a) Without arrows

Card number 4 was introduced with words such as 'This diagram might be found in a chapter on Forces. What does it mean to you?'

Most pupils immediately began talking about a specific section of the diagram, often merely saying out loud the words shown on the diagram with little explanation. Only one pupil used the term 'force' in describing the diagram. The majority of pupils had the view that the terms shown were labels to help show how the car works, or properties of the car. The function or purpose of the labels varied as follows:

VIEW 1 Six pupils regarded the diagram as showing how the car works. Other expressions used were 'how the car reacts' or 'how fast the car goes'.

> 'It's showing how a car works. Friction and the weight keeps the car on the road. The driving force is what keeps the car moving. The reaction is that when the car is going it's the exhaust gases'. (14)

VIEW 2 Four pupils mentioned that the diagram showed properties or characteristics of a car.

> 'It shows what the different science points are on a car. Things relating to science. (Where is the wind resistance you spoke about earlier?) Round the back - near the driving force. (How are the wind resistance and the driving force connected?) The driving force is the wind pushing out of the way and wind resistance comes from round the back of the car and makes it go a bit slower ... (What about wind resistance and friction. How do you think about those?) Friction is more to do with tyres. But the wind isn't'. (04)

OTHER VIEWS Another pupil (08) explained that the labels represented forces present when a car is moving and was scientifically correct in explaining three of the four forces. He was not clear about the reaction force.

A further pupil (10) considered that the terms shown were all to do with gravity and he supported his view with the observation that gravity acts in all directions around the car.

Another pupil focussed on the word reaction and explained the diagram represented what would happen if a potential collision was to be avoided.

'This shows the reaction that would happen if you saw a car coming towards you. There'd be friction because of the car's movement. The driving force is the speed the car is going and the weight is how heavy it is. You have these things happening and you react to them. That's the reaction'. (12)

Two pupils' views were not easy to describe.

(b) With arrows

When diagram 9 was used six pupils gave basically the same view previously. Another four of the pupils were able to give more information about the diagram, even though their views were not necessarily scientifically correct.

'This one looks a bit different. Yes, it's got arrows now. It shows the car is going ahead and the friction is coming towards it. The reaction is from the top and the weight is below it. (What do you mean by weight?) It's showing that the mass of the car is on the road. The weight of the car is felt by the road. (laughs) I know that sounds stupid. It's showing that the weight is not upwards. The car is not lifted. (What about the term reaction?) It's just the wind. The wind goes up and over the car'. (09)

'This isn't like the others (cards 1 and 2). This is a science one. (What are the others like?) They are more human ones. This one is science technology. The car is man made. (Tell me about this.) This shows all the forces on the car. (What do you mean by 'forces'?) The strains on the car. Not really how the car works but the reaction points ... the friction is to do with the tyres and the wind resistance goes over the car. It depends on the driving force. (And what about the driving force?) The wind might come over the car then come round and push like in little circles ... gravity holds the car to the ground so it reacts to the ground. (04)

Three pupils were confused by the presence of the arrows. One (08) had previously been the one pupil who had clearly explained the correct function of the labels as forces. But with this diagram he was not happy.

'Basically the arrows are all in the wrong place. The driving force is pointing towards the car whereas it should be coming away from

> the car repelling it. Friction is just blindly pointed at the vehicle, it should be pointing downwards at the point of contact of the vehicle and the road. The weight is right. The reaction is wrong too it should be pointing towards the vehicle because the reaction is when the driving force is overcome ... This diagram is explaining that the car is stationary. The other shows the forces when the car is moving. This one just leaves you to make up your own mind. (08)

The other pupil was still not clear about this diagram.

With both cards (4 and 9) the pupils were asked if the car was moving. Their answers are tabulated.

Diagram	Is the car moving? Yes	No
4. Without arrows	12	3
9. With arrows	11	4

Pupil 08 was the only pupil whose view changed and his reason is given above.

EARTH'S GRAVITATIONAL FIELD DIAGRAM

(a) Without arrows

This diagram was introduced with a comment such as 'this diagram has "Fig. 18.1 The Earth's Gravitational Field" written under it and might be found in a chapter on Gravity, or Earth's Gravitational Attraction'. The diagram was initially confusing to most of the pupils interviewed because of its similarity to diagrams depicting the sun. Thirteen of the pupils made comments that the diagram looked like a diagram of the sun. Five of these pupils then spoke about what the diagram meant if it was the earth shown. These five pupils and the other two (08, 12) who spoke only about the earth's gravitational field had various ways of explaining what the diagram meant to them. Three quotes are given to illustrate this variation:

'In a way it just looks like the sun ... Otherwise it could be the earth and it just gravitates out from the middle. The gravity goes out and pulls in. (What do you mean by gravity?) I always think that gravity comes from the middle of the earth and pulls in so we can stand rather than float up and around. It pulls things towards the surface but not right in'. (11)

'This one is explaining the strengths of the earth's gravitational field. The lines that are longest and most spread out show where the gravitional field is strongest. The others show where the gravitational field is weaker ... The earth's gravitational field is its gravity, the pull in towards the centre of the earth'. (08)

'Those lines show that gravity is all around the earth. Like when you jump up and come down'. (10)

(b) With arrows

All fifteen pupils spoke about the earth's gravitional field or gravity. The presence of arrows was a clear indicator, along with the introductory comments from the interviewer, that the earth was obviously represented by the circle on the page. The arrows represented gravity pushing or pulling, or staying on the earth's surface because of the spin of the earth. These views were expressed:

'That suggests to me that something from the inside is pulling something from the outside. (What is the something?) It's shown by the arrows. It's gravity whatever that is ... (What is meant by this term "earth's gravitational field"?) How much can be pulled in over a certain area. The arrows show that things come in from a wide range'. (05)

'This is the gravity pulling into the earth. As it's spinning round it's got things pulling into it. (What sorts of things?) It's not really things being pulled in, it's just that things stay on the earth and don't float away. (Things like what?) Oxygen, us. Gravity is the spinning rotation which holds us. If the spinning stops we'd all float away'. (04)

'That's explaining the gravitational field. The force that pulls everything in towards the centre of the earth. It's showing the

longer and more widely distributed arrows are the areas of greatest gravity and the smaller ones show the less. This one has arrowheads and that's helpful'. (08)

As well two questions were asked to each pupil as part of this section of the interview.

Question \ Answers given	Yes or Yes, but less than on earth	No	Not sure
Is there gravity in space?	7	7	1
Is there gravity on the moon?	10	4	1

These questions were used to help clarify pupils' views about gravity (or earth's gravitational field) extending to places not shown by the arrows in the diagram.

DISCUSSION

The description of pupil's views for the paired diagrams has highlighted some significant differences. However, in over 10 per cent of the responses given for diagrams containing arrows, pupils clearly indicated that the diagram itself was the same as the earlier equivalent diagram discussed. In these instances the pupils considered that there had been arrows in the earlier diagram. For example:

'There isn't anything different from before. The arrows are still pointing the same way'. (03, Diagram 8)

Several of the terms found in the diagrams have been investigated in greater depth in other studies. Stead (1982) and Brumby (1982) have investigated children's understanding of the concept 'living'. Thus it was not surprising to find children in this study who gave air, oxygen, heat, water or the sun, as examples of matter that was living for these views and others were also found in the two studies referred to. Stead and Osborne (1981a) explored children's views of gravity. They found that children's views of gravity being caused by the air pushing down, or the earth spinning are by no means uncommon. These views were also expressed by pupils in this study. Stead and Osborne (1981b) also investigated children's views of friction and Schollum (1982) found there was variation in the way the term reaction was understood and

used, in a study of children's views of chemical changes. A similar range of views occurred when pupils focussed on the term 'reaction' in diagrams 4 and 9. The five meanings obtained for the term 'reaction' were:

- movement upwards
- response to a physical stimulus
- the mixing of two substances causing change
- waste products (the exhaust gases)
- another way to tell that the car is moving.

Thus the range of views was similar even though the stimuli for eliciting views varied throughout the investigations referred to.

In instances when pupils' views changed once the arrows were introduced to diagrams (cards 6-10) some pupils interpreted the arrows in ways not intended by the textbook authors. This is not surprising where there are six distinct uses for the arrows, commonly found in science textbook diagrams at this level. For example, several pupils had the view that the arrow upwards in diagram 9, showing the reaction force, actually denoted movement upwards. Similarly the arrows in diagram 10 denoted movement of substances towards the earth's surface. As one pupil said:

> 'It shows that the gravity is going in. Everything is going down because of gravity. (What sorts of things?) Everything. When you let something go, it drops down'. (07)

Finally, the emphasis in this study has been on the presence or existence of arrows in science diagrams, and not on their sizes, shape or position. Isolating these factors would require further investigation. However, as has been seen (above) pupils were distracted by the position of arrows in some of the diagrams.

IMPLICATIONS FOR TEACHERS

Osborne et al. (1982) found that some of the views held by pupils seem to be particularly resistent to change, or be influenced in unanticipated ways, by science teaching. In a related study Schollum (1981) found that children often interpreted science diagrams to fit the views they held about the particular concepts or topics involved in the diagrams. For example, 80% of 12-14 year olds (N = 416 total) do not hold the view that there is nothing between the particles of gas in air. When a diagram of a gas is drawn showing particles spread wide apart, then many children rationalise the diagram and their own views by thinking that 'the teacher (or writer) has not bothered to draw in everything'. Teachers must respond to this possibility if

explaining diagrams carefully and to do this they must be aware of the views that children hold.

In a similar way, to prevent confusion arising or being reinforced when diagrams containing arrows are used, teachers need to be aware not only of the variation in the ways arrows are used but also of pupils' views about these types of diagrams.

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APPENDIX A

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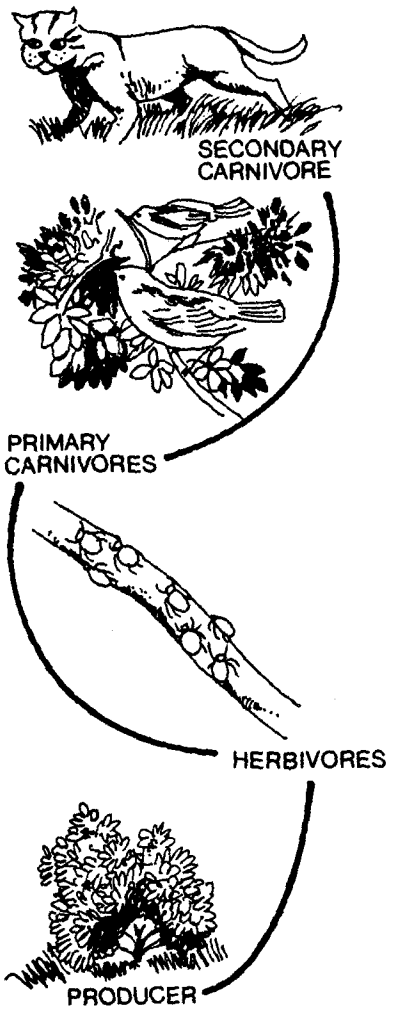

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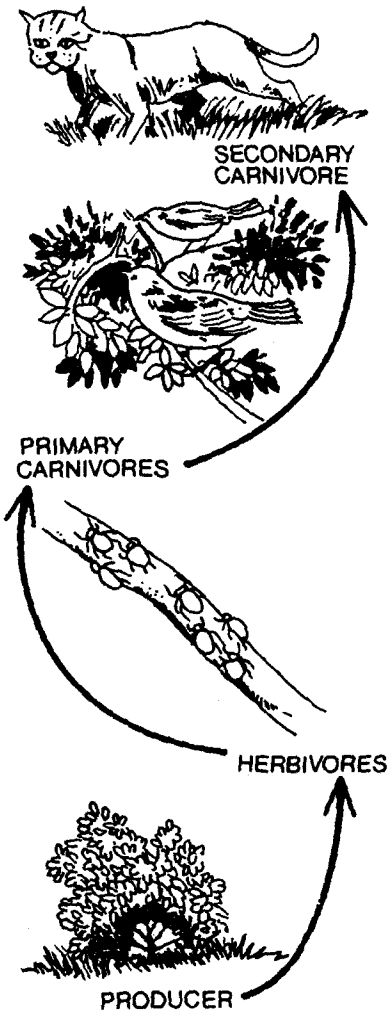

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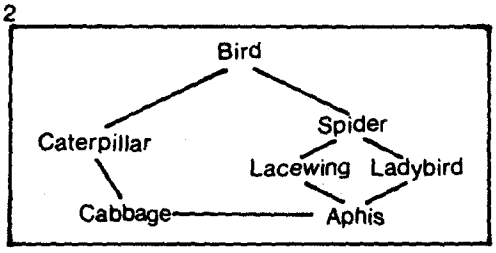

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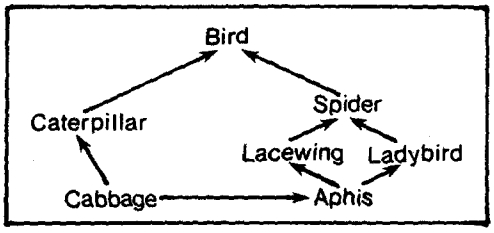

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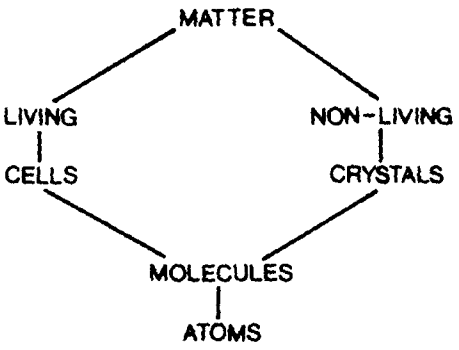

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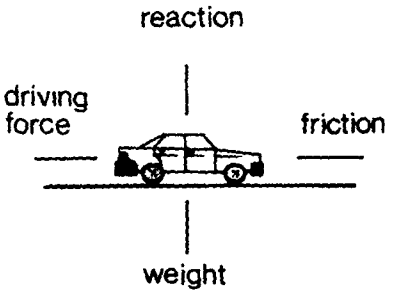

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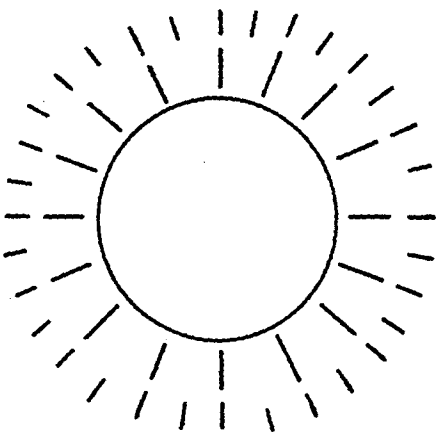

Fig.18 1 The earth's gravitational field

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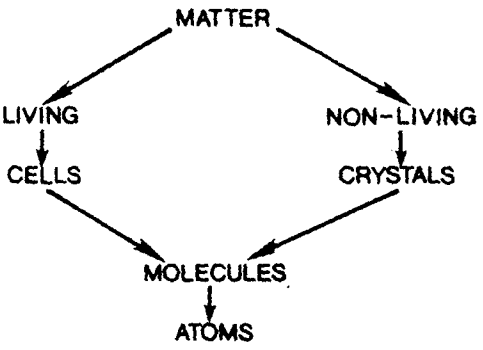

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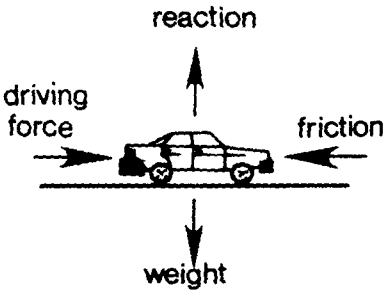

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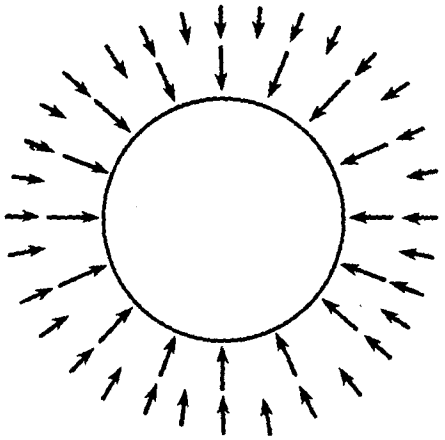

Fig.18·1 The earth's gravitational field