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Paper Title: **CARIBBEAN HIGH SCHOOL STUDENT'S CONCEPTIONS OF THE KINETIC MODEL OF MATTER**

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1 INTRODUCTION

This study investigated the ideas of Caribbean high school physics students regarding the particle (kinetic) model of matter.

11 THE PROBLEM

a) Student difficulties with scientific concepts

Research on students' conceptions in science has occupied part of the research agenda in recent years, perhaps prompted and guided by Driver and Easley's (1978) summary of previous work. In the Caribbean, however, there is no data base on the conceptions of students and thus a need for the development of such a base exists. Recognition of this need, as well as the author's experiences while teaching and examining Caribbean high school students, led to the particular focus of the study which forms part of a larger research project.

b) Particle theory of matter

The particle (kinetic) theory of matter is a model which may be used to explain a wide range of physical phenomena. These include the differences in the structure and properties of solids, liquids and gases, the pressure exerted by a gas and the relation between this pressure and the volume and temperature of the gas, and the expansion of matter on heating. This model was developed with reference to, and is supported by, the observed phenomena and properties of matter but no single observed property would be adequate to justify its adoption.

The kinetic model makes the basic assumptions that matter is composed of large numbers of very small, discrete particles (atoms, molecules or ions) and that those particles are in continuous motion. In the model of a gas further simplifying assumptions are made including the stipulation that there are no forces between particles except during collisions, and that the the volume of the particles is neglible compared with the volume of the container. Both these assumptions are linked with the idea that the particles are relatively far apart. The particles will thus move at essentially a constant velocity between collisions. The model also assumes Newton's Laws of Motion and demands that concepts such as momentum, velocity, force, energy and pressure be clearly distinguished.

The density of a substance is a function of both the mass of the individual particles and their arrangement - for a given substance the density depends only on the number of particle per unit volume. Thus gas <u>particles</u> do not have a low density (in fact, the average density of an oxygen atom is about
6×10^4 kgm^{-3}) but there is a relatively low number of particles per unit volume and thus a gas has a low density. The pressure on any surface in a gas is due to the collisions of the gas particles with the surface and thus varies with temperature, which affects the speed of the particles, and the volume, which affects the rate of collisions independently of the speed of the particles. The temperature of a gas is a measure of the average kinetic energy of its particles and, conversely, the average kinetic energy of the particles depends only on the temperature of the gas. Most solids expand when heated because the particles move further apart (while also vibrating with a greater amplitude and greater average speed).

The user of the kinetic model must, therefore, be able to distinguish between the macroscopic, observable properties of matter and the inferred microscopic model of explanation. Here the term microscopic is being used to refer to the particles in the kinetic model although it might be argued that sub-microscopic would be a more accurate term. Particles which are actually visible under a microscope, for example the small pollen grains or smoke particles of

Brownian motion demonstrations, are clearly not the particles in the theory. The particles in these demonstrations are legitimately described as macroscopic - that is, observable.

c) Previous Research

Ben-Zvi et al (1988) note that the maintenance of the distinction between the macroscopic and microscopic perspectives is not always easy - students may view an atom of copper as a very small piece of solid metal or an atom of mercury as a very small drop of the liquid. Andersson (1990) notes that Swedish text books do not always maintain a clear distinction between substances and atoms/molecules and Selley (1978) gives examples in the chemistry literature where microscopic particles are given macroscopic properties in an inappropriate manner, for example, "The settling time of a suspension of the polymer is very slow, as even giant molecules are very light" (p 144).

Students have been found to ascribe macroscopic properties to the particles themselves in a range of contexts. This is illustrated by such expressed ideas as - change of particle size with change in temperature; attributing the property of being a good heat conductor to each molecule of a metal and the property of `softness' to candle wax molecules as it is a soft substance; attributing the colour yellow to atoms of phosphorus as phosphorus is yellow and suggesting that the particles themselves melt when a substance changes from solid to liquid (Brook et al, 1983, deVos and Verdonk, 1987).

Several workers have found evidence that learners of the particle theory do not easily relinquish a continuous theory of matter (Januik, 1991, Stavy, 1988, Renstrom, 1988, Brook et al, 1983, Novick and Nussbaum, 1981). A problem for some with the particle theory appears to be the idea that the particles are moving, or `set', in a vacuum. Brook et al (1983) found widespread belief that air fills the space between the particles. The movement of the particles is also a source of difficulty, as the type of motion is often confused among the phases of matter, and its temperature dependence may be conceived as leading to no motion on cooling, or on reaching 0°C (Brook et al, 1983). The temperature of a gas is also often believed to affect the `forces between the particles of a gas' (actually zero in the model gas) and hence the pressure exerted by the gas on its container (Mitchell and Kellington, 1982, Brook et al, 1983). In this context non-Newtonian conceptions of force and the effects of forces are in evidence in students' responses.

The distribution of the particles in a gas has been found to be considered non-uniform by many students up to senior high school level (Novick and Nussbaum, 1981). Januik (1991) found that between one in four to one in six of his sample of Polish students, depending on format of the question, felt that considerably greater numbers of particles are near the surface of a balloon than in the centre of the balloon. Gabel et al (1987) found similar ideas in a sample of pre-service teachers.

Research has also shown the willingness of some students to attribute living characteristics to the particles such as "wanting" to get out of a container (deVos and Verdonk, 1987, Brook et al, 1983). The research surveyed indicates some of the possible difficulties in comprehending and accepting the particle theory of matter. No published research in the Caribbean on this topic has been found.

111 METHODOLOGY

The main purpose of the study, that of the gathering of information for a Caribbean data base on children's conceptions in science, led to the selection of a cross-sectional survey design. As Mouly (1963) comments, this may "establish the status of the phenomenon under investigation" (p 231) and in such a survey the sample is selected to describe some larger population (Babbie, 1973).

THE DEVELOPMENT OF THE INSTRUMENT

The stages in the development of the instrument and the samples used at each stage are displayed in Appendix 2. The purpose of the final instrument was to determine the concepts and ideas relating to the particle model of matter. The different stages contributed in differing ways to the validity of the final instrument. The interviews and open-ended written instruments were used primarily as sources of the concepts held by the students. The more common of these concepts along with evidence from the research, were then used to develop the options in the first draft of the multiple choice instrument. Further ideas were elicited in the explanations to the multiple choice answers in a pilot testing which used both students and teachers. The teachers were also asked to comment on the language level and general suitability of the instrument for the stated purpose. The piloting of the multiple choice instruments also determined that all responses were being utilised and that adequate time was provided for the completion of the instrument.

The clinical interview has been used extensively to identify conceptions held by young people eg. Brook et al (1989), Bliss (1989), Watts (1983), Clement (1982), Gilbert et al (1982), Nussbaum (1979), Novick and Nussbaum (1978). Interviews allow follow-up questions to clarify the respondent's meaning and to obtain the reasons for responses. This technique has the drawback of being (i) very time consuming and (ii) lacking the potential for generalisation due to the relatively small numbers of respondents involved.

Interviews were undertaken with a group of ten Jamaican high school students from the fourth form (Grade 10) and lower sixth form (Grade 12). Along with evidence from previous research and the author's teaching and examining experience, the interview data was utilised to create an instrument with open ended (short essay) items - (see appendix 4).

Open ended (short essay) written instruments allow the collection of data from somewhat larger numbers. The interpretation of the responses and their subsequent coding is, however, often problematic and a reasonably large proportion of such responses may not be classifiable (Brook et al, 1983).

The open ended instrument was piloted using samples of 21 Trinidadian fourth form students and 22 Jamaican fourth form students. From the ideas and conceptions evident in the responses to this instrument a multiple choice instrument was developed.

Multiple choice questions permit much greater numbers of subjects to be surveyed. Further, the marking of such items is objective although the drafting of questions and responses is a subjective process (Kempa, 1986). The options should reflect the ideas that the respondents might be expected to possess. The choices of responses may, however, be the result of (i) `irrelevant' clues within the question or option or (ii) inappropriate application of a physical principle. Also, the chosen option may not be believed but the question-type demands a selection and thus one is chosen.

The multiple choice instrument developed was piloted using 23 Trinidadian fourth form students, 15 Jamaican fourth form students, 21 Jamaican sixth form students and 17 Caribbean physics teachers, from several territories, who were temporarily employed to the Caribbean Examinations Council as markers of the Caribbean Examinations Council's physics examination. The results of the first pilot testing led to modifications and a second pilot testing in Jamaica with 23 fourth/fifth form students and 31 sixth form students. The results of this exercise were the multiple choice items for the final instrument.

Tamir (1989) points to the gains when explanations are requested to multiple choice questions - they can `help identify misconceptions, missing links and teleological reasoning among students who choose the correct option' (p 286). They also can lead to a better understanding of the ideas of those who choose distractors. Amir et al (1988) also note the lower performance on justifications of the choices made compared with the performance on multiple choice questions and the facility of the justifications to point to cases where partial knowledge leads to the selection of a response.

In the light of these considerations the decision was made to use a mainly multiple-choice-with-explanation format in the final instrument and "explain your answer" was added at the end of each question. A true/false question with five parts utilised in the first pilot suggested that the lack of cues to guide responses led to somewhat surprising and contradictory choices compared with the selections on related multiple choice items. A second true/false question was developed as question twelve. The final instrument is presented in Appendix 1 - a summary of the format and content is shown below in Table 1.

Table 1

Item Content - Particle Theory of Matter Instrument

ITEMS M.C.	T/F	CONTENT FOCUS
1	12(i)	Vacuum between particles
2	12(ii)	Reasons for particles' distribution in container
3	12(iii)	Variation of pressure with temperature
4		Variation of pressure with mass of gas
5	12(iv)	Effect on particles - block heated
6		Effect on particles - balloon and air heated
7		Effect on particles - tin and air cooled
8	11(i)	Continuing movement of gas particles
9	12(v)	Particle speed - no temperature change - volume decreases
10		Distribution of gas particles when heated
	11 (i)-(v)	Forces and gas particles

M.C. - Multiple Choice Item   T/F - True/False item

1V CHOICE OF SAMPLE AND ITS CHARACTERISTICS

The Caribbean Examinations Council (C.X.C.) was set up in 1972 by regional governments with a mandate to develop syllabuses for candidates in secondary schools and conduct the examination of these candidates at the end of grade eleven (age 16+). There are currently sixteen English-speaking countries in the Caribbean that enter candidates for these examinations. Candidates who obtain a Grade 1 or 11 in these examinations are considered suitable to progress to further academic study in the particular discipline. One course of further study is provided by preparation for the Advanced Level (A-Level) certificate of British Examination Boards. These courses prepare the students for entry to university.

The sample used in the investigation reported in this paper were all students of Jamaica or Trinidad and Tobago who had obtained a Grade 1 or 11 in the June 1991 C.X.C. General Level physics examination and were now enrolled in the first year of the two year course which leads to the A-level examination in physics. All candidates had been exposed to the concepts explored on the instrument in their C.X.C. course. The intent of the researcher was to obtain samples from schools which were representative of those in the two territories and which would also reasonably reflect the male/female distribution of the candidates for these examinations in physics. Generally about twice as many males as females are entered for A-level physics in Trinidad and Tobago, and over three times as many males as females in Jamaica. A deliberate decision was taken to select more females than warranted by the ratio to ensure that the female sample did not become too small for comparative purposes. The great majority of A-Level physics candidates in Trinidad and Tobago attend single-sex schools which are distributed throughout the island. In Jamaica most of the single sex high schools are situated in Kingston with reasonable numbers of candidates also being drawn from urban and rural coeducational schools. The composition of the sample (Table 2) reflects these differences in the demography of the school population and the information is arranged according to school type. A total of six schools were used in Jamaica and five in Trinidad and Tobago.

Table 2 - Sample

Territory	School Type	Boys	Girls	Totals
Jamaica	All girls, Urban		14	
	All boys, Urban	19		
	Coeducational, Rural	26	12	
	Coeducational, Urban	20	2	
		65	28	93
Trinidad and Tobago	All girls, Rural		29	
	All boys, Rural	28		
	All boys, Urban	19		
	Coeducational Urban	11	2	
		58	31	89
	Totals	123	59	182
		Grand Total		182

The total sample of 182 was about 20% of the population. Twelve of the instruments were returned incomplete, ten from Trinidad and Tobago and two from Jamaica and were not further analysed and the table represents the final sample as analysed.

ADMINISTRATION OF INSTRUMENT

The researcher personally administered the final instrument to the subjects in the urban schools in Jamaica. For rural schools in Jamaica and the schools in Trinidad and Tobago administration was carried out by the physics teacher.

All these schools were visited by the researcher, the administration of the instruments discussed with the physics teacher and written instructions provided to guide the administration. All the data was collected in October 1991.

V RESULTS

The choices made on the items by the complete sample are presented, in percentages, in Table 3, with the key indicated by underlining.

Table 3

Item	a %	b %	c %	d %
1	27	9	<u>46</u>	18
2	6	<u>72</u>	16	6
3	17	<u>72</u>	8	3
4	9	6	<u>79</u>	6
5	2	<u>71</u>	24	3
6	4	1	<u>94</u>	1
7	<u>84</u>	3	2	11
8	<u>14</u>	53	<u>30</u>	3
9	40	20	<u>31</u>	9
10	26	16	<u>52</u>	6

Item	True %	False %	Item	True %	False %
11 i	67	<u>33</u>	12 i	<u>56</u>	44
ii	50	<u>50</u>	ii	43	<u>57</u>
iii	51	<u>49</u>	iii	61	<u>39</u>
iv	<u>45</u>	55	iv	28	<u>72</u>
v	42	<u>58</u>	v	58	<u>42</u>

Selections of Total Sample

The percentages for Jamaica and Trinidad and Tobago separately had great similarity and are presented in Appendix 3. The slight differences noted did not warrant further analysis. An integrated summary of the data in Table 3 is outlined below along with relevant data extracted from the students' responses to the `explanation' parts of the items.

(i) `What is in between the air particles in a closed container?'(Q1). Thirty six percent of the sample felt that air or other gases were present between air particles and 18% `nothing because there is no room between the particles'. In the true/false item on the same concept (Q12a) 44% believed it was false to say that a vacuum was between the particles.

It was evident from the responses to the explanation that the students had a poor appreciation of the ratio of material to empty space in a gas (usually over 1 to 1000). Also several suggestions which would obviate the need to believe in a vacuum were found:

"they move so fast that the vacuum is filled up" (Trinidad, male),

"particles spread out to occupy any space in which it is placed" (Trinidad, female).

The logical consequence of a `full' container of air (as stated in the question) was frequently cited to support the choice of 1d `Nothing because there is no room between the particles'.

(ii) In question two `why do the particles of air not fall to the bottom of the flask?' 16% felt that the particles had low density and hence did not fall - the true/false item investigating the same concept elicited 43% agreeing with the statement that the particles had low density.

There was evidence that some respondents were searching for an explanation of a perceived potential `equilibrium':

"the air will have the tendency to rise until its density is equal to the external density" (Trinidad, female).

"the particles are floating on other particles of equal weight" (Trinidad, male).

Alternatively, the particles' low mass was cited:

"Particles are very light and able to float around" (Jamaica, male).

"they have neglible mass and are always floating, they also have low density" (Trinidad, female).

(iii) `Why does the pressure in a closed tin of air increase when it is heated?' (Q3). Seventeen percent selected the option that particles hitting each other harder and more often led to an increase in pressure whereas in the true/false equivalent item sixty one percent supported a similar statement.

Pressure as the result of `collisions' was cited as explanation with a rise in temperature leading to greater speeds -the imprecision of the use of the word collision (with what?) appeared to lead to some of the problems in this context.

(iv) `Why does the pressure in a tyre increase when more air is pumped in?' (Q4). The dependence of the pressure of a gas on the mass of gas present was apparently understood by the substantial majority of the sample - 79%.

(v) In question five `What change occurs in the particles when a block of metal is heated?' about a quarter of the sample suggested that the particles in a solid both vibrated more and expanded. In the true/false equivalent question (12iv) 28% suggested that particles in a solid expand on heating. These figures contrast with the very low proportion (4%) suggesting that air particles expand on heating in question six and three percent in question three.

(vi) `A student suggests that the particles in a gas will eventually slow down and stop moving - which of the following statements is true?'(Q8). Only 30% of the sample recognised that the particles in a model gas have no forces acting on them except during collisions. Fifty three percent of the sample attributed the continued motion to collisions with each other with a further 14% suggesting `outside forces'. In the true/false item two thirds of the sample felt that the statement `Forces keep the particles moving' was a true statement (Q11i). Fifty five percent felt that `there are no forces between the particles except when they collide' was a false statement. There was a common idea that when particles collide they give a `force' or energy to each other to create and maintain motion:

"as they are hitting each other they create a force which sends the other particle moving" (Jamaica, male).

"collisions create forces on them that keep them moving" (Jamaica, female). Outside forces were also cited to maintain the motion.

(vii) `When a gas is compressed at a constant temperature what happens to the average speed of the air particles?' (Q 9). Only 31% of the sample selected the option that the average speed of the air particles remains constant when compressed at a constant temperature. Forty percent felt that the speed increases because of the greater number of inter-particle collisions (which would indeed increase in frequency) and 20% felt the speed increases as the particles have less space to move in. It was clear that these two statements were seen by many as different aspects of the same idea i.e. less space to move in (9b) "therefore they collide more often" (Jamaica, male) or hit more often (9a) "as there is less space to move about" (Trinidad, male).

There were several instances of explanations which would, in a scientific framework, lead to contradictions; for instance, although the constancy of the temperature was acknowledged and Boyle's law cited, it was suggested that as the volume was less the frequency of collision would be greater and thus the speed would increase.

(viii) `How are the gas particles in a container distributed after heating'? (Q 10). The distribution of the gas particles in a heated container was considered uneven by a substantial proportion of the sample with 26% considering that most particles would be at the sides and 16% selecting a distribution with most particles at the top of the container. The increase in pressure was cited to explain the former choice and convection for the latter:

10(a) "The forces on the sides will be greater" (Trinidad, Male).

and for 10(b) "Hot air will tend to rise" (Jamaica, Male) and "Convectional movement of the particles" (Jamaica, Male).

DISCUSSION

The conceptions and ideas concerning the particle theory of matter of Caribbean high school students that have been outlined have similarities with those found in previous research. Common conceptions which do not fit the currently accepted scientific model are now discussed.

A VACUUM DOES NOT EXIST AND MATTER IS CONTINUOUS

Up to half of the sample had not internalised the idea that gas particles move through empty space. Novick and Nussbaum's (1981) work at a similar level found similar difficulties and the work of Brook et al (1983), and Stavy (1988) indicate that this is a widespread difficulty. A conflict between an \`everyday' use of a common word and its meaning in a scientific context was identified regarding the phrase \`full of air'. Other researchers have pointed to the problems inherent in the language demands of science [see, for example, White (1988), Cassels and Johnstone (1983), Carre, (1981) and Richards (1978)].

GASES ARE \`LIGHT'

The true/false item 12(ii) showed that nearly half the sample supported the statement that the density of gas particles is low -a considerably greater proportion than in the multiple choice item 2. The value of investigating the same concept with items of different formats is clear. A lack of distinction between mass and density was noticeable and also the inappropriate use of the word float similar to that found by Stavy (1988). In certain contexts the mass of the gas particles might well be neglible (say, the mass of air in a tin compared with the mass of the metal tin) but a non-scientific transfer of this concept was found in attempts to explain why gas particles do not fall.

PRESSURE IN A GAS RESULTS FROM INTERPARTICLE COLLISIONS

A perhaps too casual use of the word collision (in teaching?) might partly explain the agreement of a large proportion of students with the idea that interparticle collisions lead to the pressure of a gas - a conception also found by Brook et al (1983). Again the responses to the true/false item on this concept (61% agreement) suggested considerably greater in security with the concept than suggested by the multiple choice item (17% choosing the option).

PARTICLES POSSESS MACROSCOPIC PROPERTIES

About a quarter of the sample attributed expansion of the particles to heated solid particles, a finding similar to those of Brook et al (1983). Ben-Zvi et al (1988) note that scientists, and teachers, often shift between the macroscopic and microscopic in ways which learners may find hard to follow and Kruger and Summers (1989) found British Primary School teachers generally unable to maintain these distinctions.

MOTION OF PARTICLES IS MAINTAINED BY FORCES

The majority of the sample believed that the constant motion of the particles was maintained by a force or forces. A second instrument investigating the respondents conceptions of the relation between force and motion was administered to the sample at the same time, although the results are not reported in detail here. The results from this second instrument showed that over 85% of the sample supported a connection between constant motion and a force in the direction of motion in one or more contexts. The particle theory demands an appreciation and acceptance of the concepts inherent in a Newtonian perspective - such an understanding or acceptance was absent in this sample of Caribbean high school students. Much work has been done which has shown the widespread occurrence of these non-Newtonian ideas, see, for example, Gunstone and Watts (1985), McDermott (1984), Gardner (1984), Watts (1983) and Clement (1982).

SPEED OF PARTICLES DEPENDS ON VOLUME OR PRESSURE

A greater frequency of collision between particles due to a smaller volume was linked with the idea that pressure is due to such collisions and with a rise in the average speed of the particles. This led some students to infer that the speed depended on the volume or pressure of a gas or both. The transfer of energy from one particle to another or the `force' of one particle on another were concepts utlised which link with the motion-implies-a-force concept and thus no force would imply no, or reducing, motion.

DISTRIBUTION OF GAS PARTICLES IS NON-UNIFORM

Macroscopic properties such as convection and increased pressure were cited to justify a non-uniform distribution of gas particles - Novick and Nussbaum (1981) found similar ideas in their sample of Israeli students.

V1 IMPLICATIONS AND CONCLUSION

The above results suggest that even for more able and successful Caribbean students of physics the particle theory of matter is not a model that is easily assimilated and accepted. In the Caribbean at present there appears relatively low awareness among teachers and teacher educators of research of this nature and thus, perhaps, an even lower appreciation by teachers of the need to consider the learners' conceptions - before, during and after instruction - as one means of guiding modifications to instructional practice that might lead to better teaching of some of the concepts and models in physics. The regional nature of the

Caribbean Examinations Council may allow it to be a vehicle for the dissemination of information of this kind through its annual reports on the work of candidates. The Faculty of Education of the University of the West Indies, also a regional institution with a campus in each of Jamaica, Barbados and Trinidad and Tobago, may also act as a centre for information and, hopefully, a centre for further research. The work of George and Glasgow (1989) which highlights the cultural `roots' of some of Caribbean childrens' ideas may give some pointers as to the direction of that research.

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APPENDIX 1

THE PARTICLE THEORY OF MATTER

Scientists believe that all matter is made up of particles. Use ideas about particles to help answer the following questions.

Indicate the best answer to each question by CIRCLING THE LETTER of your answer. Also please explain your answer where requested.

1. A closed container is full of air. What is in between the air particles?

a] More air
b] Other gases
c] A vacuum
d] Nothing because there is no room between the particles.

Explain your answer.

2. Why do the particles of air not fall to the bottom of the container?

a] The particles of air are floating.
b] The particles are always moving.
c] The particles have low density.
d] Forces keep the particles from falling.

Explain your answer.

3. When a closed tin full of air is heated the pressure rises. Why does the pressure increase?

a] The air particles hit each other harder and more often.
b] The air particles hit the tin harder and more often.
c] The forces between the air particles increase.
d] The air particles expand and fill the container more.

Explain your answer.

4. An inflated bicycle tyre has more air pumped in but its volume does not change. The pressure in the tyre goes up - why does the pressure increase? Because the particles

a] collide with each other more and start to move faster.
b] are in a confined space so they start to move faster.
c] make more collisions with the tyre walls.
d] hit the walls harder.

Explain your answer.

5. A block of metal is heated by putting it into hot water.

What is the change in the particles in the metal as a result of the block being heated? The particles

a] expand.
b] vibrate more rapidly
c] expand and vibrate more rapidly.
d] begin to move around more freely.

Explain your answer.

6. A balloon full of air is warmed by pouring warm water over it. What happens to the particles of the air?

a] The particles expand.
b] The particles move more slowly.
c] The particles move more quickly.
d] The forces between the particles decrease.

Explain your answer.

7. A tin, full of air, is placed in the freezer of a refrigerator. What is the effect on the particles of air?
The particles

a] move more slowly.
b] stop moving.
c] contract.
d] condense.

Explain your answer.

8. Scientists have suggested that the particles in a gas are in constant motion. A student says that eventually the particles will slow down and stop moving. Which of the following statement is true?

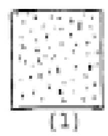
a] The student is incorrect as the particles have outside forces acting which keeps them moving.
b] The student is incorrect as the particles are hitting each other which keeps them moving.
c] The students is incorrect as no forces are acting on the particles except when they collide so the particles keep moving.
d] The student is correct as there are no forces acting on the particles so the particles will eventually stop.

Explain your answer.

9. A gas is compressed to a smaller volume at a CONSTANT temperature. Which of the following statements about the particles in the gas is true? The particles speed, on average,

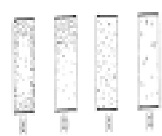
a] increases as they hit each other more often.
b] increases as they have less space to move in.
c] remains the same as the temperature does not change.
d] decreases as they have less space to move in.

Explain your answer.



(1)

10. A tightly sealed tin of air is heated to 50^{o}C. Diagram (1) above shows the particles of air before heating. Which of the following diagrams shows the distribution of the particles of air after heating?



(a) (b) (c) (d)

Explain your answer.

11. Consider the forces that may be between the particles in a gas. Which of the following statements is/are true/false? Please circle your choice in each case.

True T/False F

i] Forces keep the particles moving. T/F

ii] Attractive forces hold the particles together. T/F

iii] Repulsive forces keep the particles apart. T/F

iv] There are no forces between the particles except when they collide. T/F

v] There are frictional forces which oppose the motion of the particles. T/F

12. Which of the following statements is/are true/false? Please circle your choice in each case.

True

T/False F

i] In a container of oxygen gas there is a vacuum between the particles of oxygen. T/F

ii] Gas particles have a low density and so they do not fall to the bottom of the container. T/F

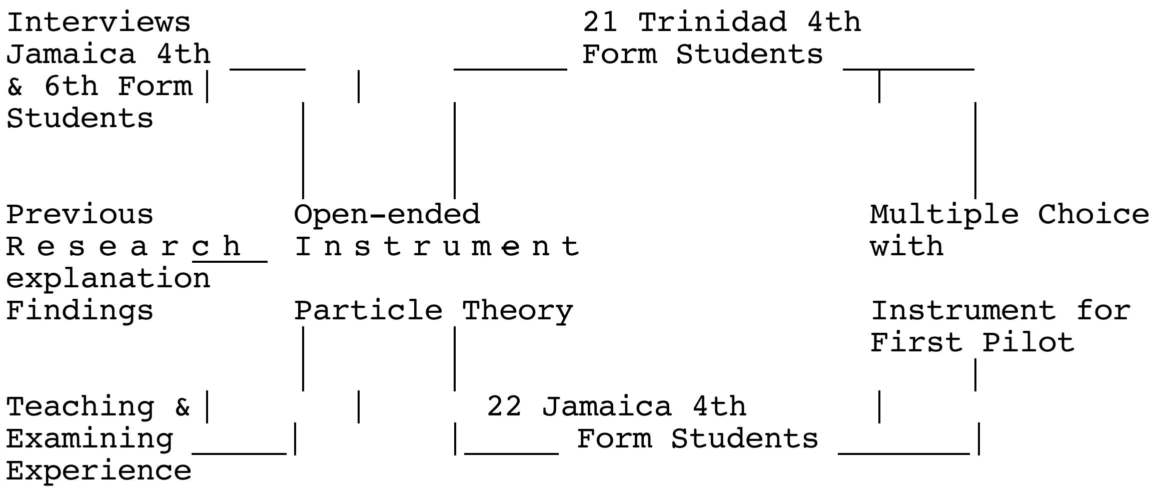
iii] When a gas is heated the particles hit each other harder and so the pressure rises. T/F

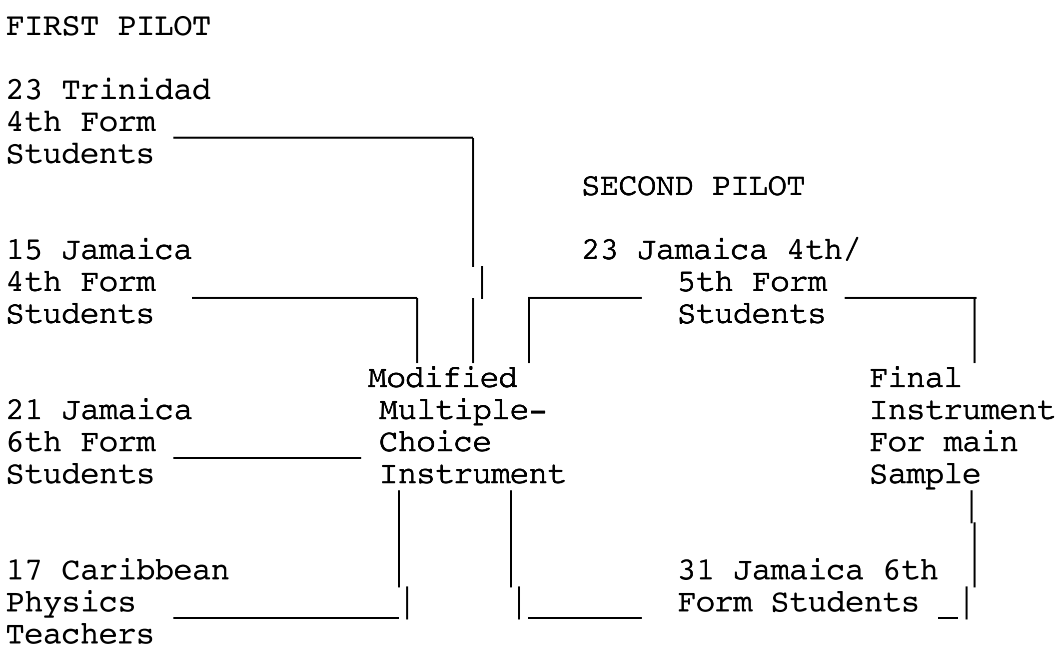
iv] When a block of metal is heated the particles expand. T/F

v] When a gas is compressed to a smaller volume at a constant temperature the average speed of the particles increases. T/F

APPENDIX 2

DEVELOPMENT OF INSTRUMENT





APPENDIX 3

Choices of options of items, by territory

Item	Territory	a	b	c	d
		%	%	%	%
1	J	31	5	46	18
	T	25	14	41	20
2	J	9	67	16	8
	T	3	77	15	5
3	J	12	73	13	2
	T	21	73	2	4
4	J	12	7	75	6
	T	6	5	83	6
5	J	4	70	21	5
	T	0	72	27	1
6	J	5	1	93	1
	T	3	1	95	1
7	J	80	3	2	15
	T	90	3	1	6
8	J	18	51	26	5
	T	9	55	36	0
9	J	35	17	33	15
	T	46	23	29	2
10	J	20	21	51	8
	T	34	10	53	3

Item		True	False	Item		True	False
		% %	% %			% %%	%
		J/T	J/T			J/T	J/T
11	i	65/68	35/32	12	i	61/50	39/50
	ii	44/57	56/43		ii	43/42	57/58
	iii	57/44	43/46		iii	59/63	41/37
	iv	43/46	57/54		iv	32/25	68/75
	v	34/52	66/48		v	54/61	46/39

J - Jamaica   T - Trinidad and Tobago

APPENDIX 4

OPEN ENDED INSTRUMENT

THE PARTICLE THEORY OF MATTER

1. A closed container is full of air. Air is believed to be made of particles. What is in between the air particles?

2. Why do the particles of air in a container not all fall to the bottom of the container?

3. When a closed tin full of air is heated the pressure increases. Why does the pressure increase?

4. A bicycle tyre has more air pumped in but its volume does not change. The pressure in the tyre goes up-why does the pressure increase?

5. Scientists have suggested that the particles in a gas are in constant motion. A student says that eventually the particles will slow down and stop moving. Do you think the student is correct? Explain your answer.

6. A block of metal is heated by putting it into hot water. What, if any, are the changes in the particles which make up the metal?

7. A balloon full of air is cooled by pouring ice-cold water over it. What happens to the particles of the air?

8. A tin full of air is placed in the freezer of a refrigerator. What is the effect on the particles of air?