The Limitations of Standardized Science Tests as Benchmarks for Artificial Intelligence Research: Position Paper

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Abstract

In this position paper, I argue that standardized tests for elementary science such as SAT or Regents tests are not very good benchmarks for measuring the progress of artificial intelligence systems in understanding basic science. The primary problem is that these tests are designed to test aspects of knowledge and ability that are challenging for people; the aspects that are challenging for AI systems are very different. In particular, standardized tests do not test knowledge that is obvious for people; none of this knowledge can be assumed in AI systems. Individual standardized tests also have specific features that are not necessarily appropriate for an AI benchmark. I analyze the Physics subject SAT in some detail and the New York State Regents Science test more briefly. I also argue that the apparent advantages offered by using standardized tests are mostly either minor or illusory. The one major real advantage is that the significance is easily explained to the public; but we argue that even this is a somewhat mixed blessing. I conclude by arguing that, first, more appropriate collections of exam style problems could be assembled, and second, that there are better kinds of benchmarks than exam-style problems. In an appendix I present a collection of sample exam-style problems that test kinds of knowledge missing from the standardized tests.

It has often been proposed that a standardized tests constitute useful goals for AI systems doing automated scientific reasoning and informative benchmarks for progress. For example Brachman et al. (2005) suggest developing a program that can pass the SATs. Clark, Harrison, and Balasubramanian (2013) propose a project of passing the New York State Regents Science Test for 4th graders. Strickland (2013) proposes developing an AI that can pass the entrance exams for the University of Tokyo. Ohlsson et al. (2013) evaluated the performance ConceptNet system (Havasi, Speer, and Alonso 2007) on a preprocessed form of the Wechsler Preschool and Primary Scale of Intelligence test. Barker et al. (2004) describes the construction of a knowledge-based system that (more or less) scored a 3 (passing) on two section of the high school chemistry Advanced Placement test.

In this position paper, I want to discuss specifically the project of developing AI programs to pass standardized science tests, as a step toward developing AI programs with powerful abilities to reason about science; and I will argue that focusing narrowly on this goal is not the best way of advancing AI understanding of basic science, and that this benchmark is not the best way of measuring progress.

The dangers of focusing on too narrow and idiosyncratic a target are well illustrated by Watson. IBM set itself the goal of winning at Jeopardy, and with huge labors, in an extraordinary tour de force, succeeded. However, it is not at all clear what contribution this has made to AI technology; and it
seems to have made no contribution whatever to AI theory. Having succeeded on Jeopardy, IBM is making a huge effort to find a retrospective application for it in terms of some other applications; what has been published to date on this effort is not especially impressive.

(Since I have been involved in the Winograd Schema Challenge (Levesque, Davis, and Morgenstern 2012), let me parenthetically clarify a related point there. The Winograd Schema Challenge is intended as a challenge; eventually, if natural language abilities and the inference mechanisms they require advance sufficiently, some program will pass it. But there is no point in working on the Winograd Schema Challenge. Winograd schemas are not a subject matter; they are not even a natural category. They are a collection of disambiguation problems — mostly coreference resolution though not all — designed to be difficult, that conform to a very specific structure in order to make sure that they are not easily solved by statistical techniques over surface features. The relevant field to work on is natural language understanding generally or disambiguation specifically.)

Certainly, a standardized science test is a more meaningful and useful goal for AI than Jeopardy. The questions that make up these tests involve much more fundamental knowledge and much deeper forms of reasoning than the trivia about actors, geography, and so on that make up Jeopardy. So I would certainly expect that an effort to pass a standardized science test would be very much more fruitful for AI than Watson, except, of course, in terms of publicity. The problems cannot be solved using statistics over surface features. Solving them will almost certainly require major advances in knowledge representation, reasoning, and diagram interpretation and significant advances in natural language interpretation. Indeed Barker et al. (2004) were able to draw some interesting and fruitful conclusions for knowledge representation and knowledge engineering from their project aimed at passing the chemistry AP test. Nonetheless, I will argue that, if we focus our research too narrowly on passing standardized tests, we will miss critical fundamental issues that will come back to bite us later; and that if we make too much of these tests as benchmarks, it will not be helpful to the field in the long run. I think there are much better ways to formulate goals and benchmarks.

1 Testing science that any fool knows

Standardized tests were written as tests for human students, and therefore emphasize aspects of the subject that human students find difficult. In humans, successful mastery of these aspects reasonably reliably indicates mastery of the subject matter. In many case, however, what is difficult for humans is easy for AI systems, and vice versa; so mastery of these subjects by an AI system does not at all indicate mastery of the subject matter.

In particular, standardized tests generally omit aspects of the subject that “any [human] fool knows” because these are not worth testing. But of course, the computer does not necessarily know them. Nor can it be assumed that progress in encoding formal science will necessarily bring with it this basic knowledge. One can easily envision an AI program that knows and can manipulate the equations of general relativity and quantum electrodynamics, but has no idea how things work in the ordinary world. The kind of knowledge I have in mind are things like

- You can’t fit a watermelon into a sandwich bag. Moreover, you can’t make the watermelon fit by folding it. However, you could cut off a piece that will fit in the sandwich bag.
- You can’t see anything if your eyes are closed. You can’t see anything if there is no light. You can feel things even if there is no light.
- If it’s warm in your room and cold outside, and you open the window, the room will get colder.

Many more examples are given in appendix A.1.
The importance of having general knowledge that “any fool knows” does not generally diminish as the sophistication of the science involved increases, except in some cases where the entire subject matter become so recondite that there is only a remote connection to anything within the scope of ordinary knowledge. This is particularly true in reasoning about scientific experiments. For example, understanding a chemical experiment with test tubes and beakers requires basic knowledge about containers and liquids — you can pour liquid from the test tube into the beaker, and so on — which is nowhere explicit in the chemistry textbook, and may not be tested even implicitly on the chemistry SATs. Certainly it is unlikely that non-standard variants of these — e.g. if I hold the test tube upside down over the table, the contents will spill out — are tested implicitly on the SATs.

One might argue that this kind of knowledge will needed as background in order to answer the questions that arise on the standardized tests; and therefore a project to pass the standardized tests will necessarily address this kind of knowledge. As far as I can judge from my examination of the standardized tests, this is not the case; a program could pass standardized tests with very little of this basic knowledge. On the other hand, for scientific understanding generally, this basic knowledge is critical. In separate unpublished projects I have analyzed some of the commonsense reasoning needed to understand short passages from a biology textbook and from a description of a high-school chemistry experiment; these basic issues arise again and again.

2 Gaps in specific standardized tests

The gap discussed in section 1 of questions aimed at very basic knowledge, is presumably common to all standardized tests except possibly tests addressed to cognitive impairment. There is no point in asking questions that all test takers will get right. Beyond that, though, each standardized test has its own gaps, from the point of view of an AI benchmark, reflecting primarily the fact that the test was not written with the objective of serving as an AI benchmark. Here, of course, one has to consider each test individually; different tests have different strengths and weaknesses. In general, if an AI researcher wants to use a particular test as a benchmark, she should examine it carefully to determine which of the aims of her research are met by the test and which are not. I have examined and will discuss below two particular tests: the SAT subject test in Physics, and the New York State Regents 4th grade Science test.

First a general caveat: In the world of education, there is a great deal of expertise on these standardized tests, which I do not share; and there is an immense, often rancorous, literature on the strengths, weaknesses, biases and so on of these tests, which I have not read. (Not the least of my reservations about using these tests as benchmarks is the danger that the AI community will be seen as taking one side or another in these debates; or, conversely, that the politics of these debates will distort the analysis in the AI community.) However, all of this literature addresses the question of the merits of these tests in educating humans, not their merits as AI benchmarks. I do not want to touch the question of educating and testing people with a ten-foot pole. None of my analysis below should in any way be viewed as expressing an opinion on the merits of the tests in the educational system, except for the opinion, I hope uncontroversial, that it is best to avoid wrongly-posed questions even in the human setting.

2.1 The SAT Subject test in Physics

Since the actual tests are not available (more about this in section 4), I have used as a proxy Sample Test 1 in (Kaplan, 2014 pp. 291-305) on the presumption that the Kaplan people know what they’re doing. I have analyzed the 75 questions on this test along 5 dimensions: Type of problem, mode of mathematical calculation, physical domain, type of geometry involved, and use of real-world
Types of problems:
Prediction (34). Calculate/compare numeric features (10). Graph reading/manipulation (7). Identify physical law (5). Diagnosis (5). Identify process (4). Planning (2). Taxonomy (2). Terminology (2). Other (4).

Mode of calculation
Arithmetic (13). Comparative analysis/Sign calculus (8). Symbolic algebra (5). Qualitative behavior of functions presented graphically (5). Identify geometric feature matching physical law (3). Trivial symbolic algebra (3). Add curves presented graphically (2). Other (8). No calculations involved (28).

Three of the problems listed above under “Symbolic algebra” can be solved by dimensional analysis and the process of elimination, and one can be solved by qualitative reasoning and the process of elimination.

Physical domain:
Newtonian mechanics (15). Electromagnetism (10). Wave theory (10). Kinematics (9). Nuclear physics and elementary particles (7). Thermodynamics (6). Circuit analysis (6). Optics (5). Gravity. & EM (3). Radioactivity (2). Tension (1). Celestial mechanics (1).

Geometric reasoning. 28 problems involved geometric reasoning of various kinds. I did not find a useful way of dividing these into categories.

Real world knowledge: 8 problems involved the integration of real-world knowledge, as discussed in the text.

Table 1: Categorization of problems in a sample SAT physics test

knowledge. A summary is shown in table. Details are available on request.

In some respects, this meets the objectives of an AI benchmark strikingly well. The range of types of problems is particularly impressive; certainly prediction takes the lion’s share, but there is a good case to be made that that is reasonable. Also noteworthy is the comparatively slight dependence on exact arithmetic, and the large role played by qualitative reasoning of one kind and another.

Still, it is hardly an ideal test for our purposes. The most important gap is the small number of problems that draw on real world knowledge. I should say that I am setting the bar on “real world knowledge” rather high here. (Also, of course, the term is not actually apt — electrons and so on are certainly part of the real world — but I can’t think of a better one.) I exclude references to real objects that might as well be perfectly abstract; for instance, problem 47 refers to “a car”, but it could just as well be “a mass”. I also exclude uses of the standard denizens of physics problems being used in standard ways: pulleys, blocks, strings, glass as a venue for reflection and refraction, and so on. I likewise exclude electronic components such as resistors, capacitors, batteries, and so on, being used in a standard way. If there were a problem in which the mass of a pulley or a resistor or the thickness of a string were important, that would count as “real world” (there aren’t any).

Those excluded, there are in fact eight problems that invoke real world knowledge, mostly in very minor ways. The issue is important enough that we illustrate with four examples; of the rest, one
is very similar to problem 33, and the other three involve real world knowledge only slightly, at the level of problem 9.

**Problem 9:** Which of the physical principles below might be used to solve the following problem: A new soft drink bottle is opened, allowing gas to escape into the atmosphere. As the gas escapes, how does its degree of disorder change?

(A) first law of thermodynamics (conservation of energy)
(B) second law of thermodynamics (law of entropy)
(C) ideal gas law
(D) heat of fusion and heat of vaporization equation
(E) heat engine efficiency

[I have slightly rearranged the statement of the question for clarity.]

The real world scenario is not actually critical here — one can solve the problem just by pattern matching on the phrase “degree of disorder”, and to some extent one actually does — but the reference to the soft drink is certainly helpful to the human student in grounding what would otherwise be rather obscure. It is not clear that this reference would be of any help to an AI.

**Problem 16:** You are sitting on a seat facing forward on an airplane with its wings parallel to the ground. The window shades of the airplane are closed, and the vibration of the plane is negligible. When you place your class ring on the end of a necklace chain and hold the other end in front of you, you notice that the chain and ring hang vertically and point directly to the floor of the airplane. Which of the following could be true of the airplane?

I. The airplane is at rest.
II. The airplane is moving with a constant velocity.
III. The airplane is increasing its speed.
IV. The airplane is decreasing its speed.

(A) I only
(B) III only
(C) I or II, but not III or IV.
(D) III or IV, but not I or II.
(E) IV only

This problem relies on a number of elements of real world knowledge; the test taker has to realize that the floor of an airplane is parallel to the wings and that the ground is perpendicular to the force of gravity. He also has to understand what it means to put a ring on one end of a chain and hold the other end. However, none of the 74 other problems draw on world knowledge in such a rich way, or anywhere close to it.
Problem 27: A neutral electroscope is shown above. If a positively charged rod is brought near the knobs of the electroscope, which of the following statements is true?

(A) The electroscope can be charged negatively without the positively charged rod throughout the knob and using only a grounding wire.
(B) The electroscope can be charged positively without the positively charged rod throughout the knob and using only a grounding wire.
(C) The leaves of the electroscope are negatively charged.
(D) The knob of the electroscope is positively charged.
(E) The electroscope has a net positive charge.

Answering the question requires some understanding of the internal structure of the electroscope; it does not suffice to think of the device as a black box.

The wording of the question seems a little problematic to me. The intended answer is clearly (A); however, in scenario (A), the entire device, including the leaves, will be negatively charged, so (C) would also be true. Presumably the point is that (C) will not be true if the device is not grounded; however, this condition is not stated.

Question …33 relate[s] to the positive charge following a circular path in a region of magnetic field in the figure below.

Problem 33: The direction of the magnetic field in the region shown is

(A) out of the page and perpendicular to it.
(B) into the page and perpendicular to it.
(C) toward the top of the page.
(D) toward the top of the page.
(E) to the right.
Problem 75 is of a similar flavor.

The need for world knowledge here is in interpreting the phrase “out of the page”. In itself, this would pose an extraordinarily difficult problem of interpretation. (One can imagine the poor AI, mulling over the PDF input, with no $\hat{z}$ dimension, let alone an outward direction associated with the content, wondering what on earth the phrase could mean.) However, since the phrase is common in this kind of test (and, in fact, apparently associated only with electromagnetic theory on the SAT exam) and since there do not seem to be any other references to the exam page as a physical object, presumably the interpretation of this in terms of three dimensional geometry would be hard-coded.

Thus, the integration of real-world knowledge is rare and mostly shallow. It seems to me that for an AI benchmark one would wish to see a great deal more such problems, and problems that require deeper levels of integration. I give some examples in appendix A.2.

Another category of problem that is underrepresented is problems that require integrating knowledge from multiple physical domains. In this sample exam, there is only one example.

**Question . . . 38** relate[s] to the two masses $M_1$ and $M_2$ which have a charge $Q_1$ and $Q_2$ respectively. The masses are initially separated by a distance $r$.

If the two charged masses are placed in space so that no other forces affect them, and they remain at a distance $r$ apart indefinitely, which of the following must be true?

(A) Both charges are positive.
(B) $Q_1$ is positive and $Q_2$ is negative.
(C) $Q_1$ is negative and $Q_2$ is positive.
(D) $Q_1 = Q_2$.
(E) $M_1 = M_2$.

This is one of a collection of questions that discuss electric repulsion and gravitational attraction, so it is clear to the student here that the point is that these two forces are exactly balanced in the proposed scenario. The intended answer is thus (A); this is another mistake, since it is equally possible that both charges are negative.

Again one would wish to see more problems of this kind; there are quite a few examples in appendix A.2.

The inclusion of two questionable problems out of seventy-five is somewhat disturbing. However, it is possible that this would only happen in the Kaplan practice exams, and that the actual SATs are more carefully vetted.

### 3 Regents’ fourth-grade science test

No one could accuse the Regents’ fourth-grade science test of neglecting real world knowledge; practically all the problems on the test involve real world knowledge.

The Regents science test ranges over a number of subject but gives particular emphasis to biology. Of the 45 questions on the 2014 exam, 23 were in biology, 13 in physics, 7 in earth sciences, and

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1. It would be interesting to know whether human students have any trouble with this. It is certainly a remarkable example of shifting the level of abstraction.
2. There may be good reasons for this, in terms of the human test. Including problems with real-world knowledge can make it harder to be sure that the physical analysis is correct (we will see an example in section 3); it can introduce unfair biases (e.g. does problem 16 give an unfair advantage to students who have flown in an airplane?) and so on.
3. There are two other problems that require knowledge of both gravity and electromagnetism. However these do not require *integrating* this knowledge; they appear in separate answers of the multiple choice.
2 in astronomy (all these terms being broadly construed). The biology questions do address quite fundamental issues; the gap in “what any fool knows” questions discuss in section 1 is significantly less acute there, though not entirely gone. Appendix A.1 includes some biology questions that are more basic than any in the test. The coverage of basic physics, on the other hand, is not adequate for AI purposes, though it may be suitable for the fourth grade curriculum. Few physics problems are included, and those few are rather random (e.g. the fact that a black object gets hotter in the sun than a white object) and somewhat error-prone (see below).

The Regents test also occasionally includes problems that are seriously badly formulated. I will give two examples:

**Question 32, 2014 test:**

The data table shows the air temperature at noon for a city in New York State on five Wednesdays during the month of March. The temperature for March 31 has been left blank.

| Date       | Air Temperature at Noon |
|------------|-------------------------|
| March 3    | 42                      |
| March 10   | 45                      |
| March 17   | 48                      |
| March 24   | 51                      |
| March 31   | ?                       |

Based on the pattern shown in the data table, predict the air temperature at noon on Wednesday, March 31.

I must say, I find it appalling that the Regents’ exam would include a question of this kind. It is simply teaching children that what they learn in school bears no relation to the actual world as they know it.

The problem with this from the AI perspective is that it is much easier to write an AI program that gets the intended answer of 54 here than to write one that realizes that the question is nonsense. All the program needs is a rule that, if it sees an arithmetic sequence followed by a blank, it should fill in the next term of the sequence. It does not have to understand anything else about the question. If our benchmarks include a lot of problems of this kind, the strong temptation will be to develop programs that are good test-takers, rather than good physical reasoners. These kinds of test-taking tricks have nothing more to do with physical reasoning than the array of techniques that were programmed into Watson to deal with Jeopardy puns have to do with natural language understanding.

**Question 13, 2011 Regents exam**

A student riding a bicycle observes that it moves faster on a smooth road than on a rough road. This happens because the smooth road has

A. less gravity  
B. more gravity  
C. less friction  
D. more friction

The physics here is wrong. A bicycle can hardly be ridden at all if there is very little friction with the road (on ice, for instance). Once the friction is sufficient that the bicycle does not slip, increasing it further should hardly matter, since the bicycle wheel rolls without sliding along the road. At the
contact point, the horizontal velocity of the wheel is zero. The fact that it is hard to ride on a rough surface must have to do with there being too much up and down. Both a student and an AI system would be penalized for knowing too much physics.

Finally, this test to a rather surprising extent uses very similar problems from one year to the next. If a training corpus and a test corpus are extracted from a corpus collected over several years, the degree of success is likely to be unrealistically high.

4 Apparent advantages of standardized tests

It seems to me that the apparent advantages of using standardized tests as benchmarks instead of creating our own tests for the purpose and using those are mostly either minor or illusory. The advantages that I aware of are the following:

1. Standardized tests exist, in large number; they do not have to be created. This “argument from laziness” is not entirely to be sneezed at. The experience of the computational linguistics community shows that, if you take evaluation seriously, developing adequate evaluation metrics and test materials requires a very substantial effort. On the other hand, the experience of the computational linguistic community also suggests if you take evaluation seriously, this effort cannot be avoided by using preexisting materials. I cannot imagine anyone in the computational linguistics community proposing that NLP programs of any kind should be evaluated in terms of their scores on the SATs.

2. Entrusting the issue of evaluation measures and benchmarks to the same physical reasoning community that is developing the programs to be evaluated is putting the foxes in charge of the chicken coops. The AI researchers will develop problems that fit their own ideas of how the problems should be solved. This is certainly a legitimate concern; but I expect in practice much less distortion will be introduced this way than by taking tests developed for testing people and applying them to AI. Again, the computational linguistic community has not generally been much troubled by this issue. (I have heard it argued that the near universal use of the BLEU measure for machine translation has distorted research in that area.)

3. The standardized tests have been carefully vetted and the performance of the human population on them is very extensively documented. On the first point, as we have seen, the vetting does not seem to be completely air-tight; a number of questions with bugs have gotten through. On the second point, there is no great value to the AI community in knowing how well humans of different ages, training and so on do on this problem. It hardly matters which questions can be solved by 5 year olds, which by 12 year olds, and which by 17 year olds, since, for the foreseeable future, all AI programs of this kind will be idiot savants (when they are not simply idiots); capable of superhuman calculations at one minute, and subhuman confusions at the next. There is no such thing as the mental age of an AI program; the abilities and disabilities of an AI program do not correspond to those of any human being who has ever existed or could ever exist.

4. Success on standardized tests is easily accepted by the public (in the broad sense, meaning everyone except researchers in the area), whereas success on metrics we have defined ourselves requires explanation, and will necessarily be suspect. This, it seems to me, is the one serious advantage of using standardized tests. Certainly the public is likely to take more interest in the claim that your program has passed the SAT, or even the fourth-grade Regents test, than in the claim that it has passed a set of questions that you yourself designed and whose most conspicuous feature is that they are spectacularly easy.

However, this is a double-edged sword. The public can understandably jump to the conclusion that, since an AI program can pass the physics SAT, it understands physics at the level of a human high
school senior; the AI researcher, much less excusably, can make the same mistake. For example, Ohlsson et al. (2013) entitled their paper “Verbal IQ of a Four-Year Old Achieved by an AI System.” The statement, of course, is not even close to being true. A four-year old can make up stories, chat, occasionally follow directions, invent words, learn language at an incredible pace; ConceptNet (the AI system in question) can do none of these. Nonetheless, this absurd claim got taken up and repeated in headlines in gizmag.com, kurzweilai.net, extremetech.com, smartplanet.com, and so on. One article (Gaudin 2013) in ComputerWorld took the claim even further, with the headline “Top Artificial Intelligence System is as smart as a 4-year-old.”

Finally, some standardized tests, including the SAT’s, are not published and are available to researchers only under stringent non-disclosure agreements. It seems to me that AI researchers should under no circumstances use such a test with such an agreement. The loss from the inability to discuss the program’s behavior on specific example far outweights the gain from using a test with the imprimatur of the official test designer.

5 What benchmarks would be better than the standardized tests?

What benchmarks should be used instead of the standardized tests? If we want to stick to short answer test formats, which does have advantages, then certainly the standardized tests are a starting point (once we have edited out the bad apples.) However, we should supplement those with many more problems that require real world knowledge; problems that combine knowledge from different theories; and problems that use forms of reasoning and forms of geometric knowledge that are overlooked or underutilized.

More importantly, however, we should not confine ourselves to exam-style benchmarks and goals. Rather, we should consider a variety of tasks such as:

- Understanding texts of various kinds: Textbooks, equipment manuals, text in narrative that draws on physical knowledge (Davis 2013) and so on.
- Exam questions with essay style answers.
- Reasoning about variants of physical situations (Davis 1998).
- Integration with planners in situations that involve complex physical reasoning.
- Integration with design programs (Klenk et al. 2014).
- Guidance for robots.

Each of these tasks will require dealing with new aspects of physical reasoning. The result will be a much richer theory and much more powerful programs than just looking at answering tests. Of course, designing benchmarks and metrics for these tasks is harder and less well defined than for short answer tests. But in general it is better to be working on the right problem with an imperfect metric than to be working on the wrong problem with a perfect one.

4 Of course, what this paragraph really amounts to is yet another clear demonstration of the benefits of making inflated claims. The authors have gotten publicity all over creation for this minor piece of work; that they have been taken to task in this obscure, unpublished paper is a small price to pay. Overall, they have come out way ahead.
6 Final observation

Standardized tests carry an immense societal burden and must meet a wide variety of very stringent constraints. They are taken by millions of students annually under very plain testing circumstances (no use of calculators, let alone Internet). They must therefore be gradable either automatically or by not very expert human graders. They bear a disproportionate (and at the current date, ever-increasing) role in determining the future of those students. They must be fair across a wide range of students. They must conform to existing curricula. They must maintain a constant level of difficulty, both across the variants offered in any one year, and from one year to the next. They are subject to intense scrutiny by large numbers of critics, many of them unfriendly. These constraints impose serious limitations on what can be asked and how exams can be structured.

In developing benchmarks for AI physical reasoning, we are subject to none of these constraints. Why tie our own hands, by confining ourselves to standardized tests? Why not take advantage of our freedom?

References

K. Barker et al. (2004). “A Question=Answering System for AP Chemistry: Assessing KR&R Technologies,” KR-2004.
R. Brachman et al. (2005). “Selected Grand Challenges in Cognitive Science,” MITRE Technical Report 05-1218.
T.L. Brown, H.E. LeMay, and B. Bursten. 2003. Chemistry: The Central Science, (9th edn.) Upper Saddle River, NJ: Prentice Hall.
P. Clark, P. Harrison, N. Balasubramanian, (2013) “A Study of the Knowledge Base Requirements for Passing and Elementary Science Test,” AKBC-13,
E. Davis (1998). “The Naive Physics Perplex,” AI Magazine, vol. 19, no. 4, Winter 1998, pp. 51-79.
E. Davis (2013). “Qualitative Spatial Reasoning in Interpreting Text and Narrative.” Spatial Cognition and Computation, 13:4, 2013, 264-294.
S. Gaudin (2013). “Top Artificial Intelligent system is as smart as a 4-year old”, Computerworld, July 15, 2013.
C. Havasi, R. Speer, J. Alonso (2007), “Conceptnet 3: A flexible multilingual semantic network for common sense knowledge”, Recent Advances in Natural Language Processing, 27-29.
Kaplan (2013). Kaplan SAT Subject Test: Physics. 2013-2014. Kaplan Publishing.
M. Klenk, D. Bobrow, J. de Kleer, and B. Janssen (2014). “Making Modelica Applicable for Formal Methods.” Proceedings of the 10th International Modelica Conference.
H. Levesque, E. Davis, L. Morgenstern, (2012). “The Winograd Schema Challenge,” AAAI-12.
S. Ohlsson, R.H. Sloan, G. Turán, A. Urasky (2013), “Verbal IQ of a Four-Year Old Achieved by an AI System.” Commonsense-2013.
NYSED (2013 and 2014) “The Grade-4 Elementary-Level Science Test”, http://www.nysedregents.org/Grade4/Science/home.html
Appendix: Collection of problems

Appendix A.1 is a collection of problems, mostly physics, some biology, intended to be easily solved by fourth-graders. (I am no expert on what realistically to expect from students of various ages.) Appendix A.2 is a collection of problems that high school physics students should find easy; they run from problems whose answer should be immediate to some that might well require a few minutes’ thought.

The large number of problems about containers reflects the fact that I have been working for several years about reasoning about containers. The large number of problems about astronomy reflects the fact that I like astronomy; I am rather surprised that it is not part of the material on the physics SATs. There are no questions about electric circuits because they bore me; plus they don’t lend themselves to common sense reasoning.

Groups of related problems are bracketed with lines of asterisks.

Please note: The point of this is to give examples of the kinds of features of problems that I discuss in the main text. It is not intended in itself as a benchmark collection for AI research, and I do not endorse its use as such. Still less do I intend it for use with human students.

Appendix A.1: Easy problems

Problem 1.1: You have a bag with some groceries. If you now put a sack of potatoes into the bag, what will happen?
A. The bag will now be lighter.
B. The bag will be the same weight.
C. The bag will be heavier.

Problem 1.2: You are packing food for a picnic. You have a big watermelon which is a foot long and eight inches thick. You have a little plastic sandwich bag which is four inches wide. Will the watermelon fit in the sandwich bag?

Problem 1.3: Can you make the watermelon fit in the bag by folding the watermelon?

Problem 1.4: If you have a sharp knife, could you cut a piece of the watermelon small enough to fit in the bag?

Problem 1.5: If you cut the watermelon into lots of pieces, could you fit all of them into the bag?

Problem 1.6: Can you put the bag next to the watermelon?

Problem 1.7: There is a jar right-side up on a table, with a lid tightly fastened. There are a few peanuts in the jar. Joe picks up the jar and shakes it up and down, then puts it back on the table. At the end, where, probably, are the peanuts?
A. In the jar.
B. On the table, outside the jar.
C. In the middle of the air.

Problem 1.8: There is a jar right-side up on a table, with a lid tightly fastened. There are a few peanuts on the table. Joe picks up the jar and shakes it up and down, then puts it back on the table. At the end, where, probably, are the peanuts?
A. In the jar.
Problem 1.9: You are in your room with the door open. Some music is playing in the next room. You shut the door. Which of the following is true?
A. The sound of music in your room will get softer.
B. The sound of music in your room will get louder.
C. It won’t make any difference.

Problem 1.10: You are in your room with the door to the rest of the house open and the window shut. The whole house is the same temperature, a comfortable 70°F. Outside it is 40°F. If you open the window, what will happen to the temperature in the room?
A. The room will get a lot warmer.
B. The room will get a lot colder.
C. It won’t make any difference.

Problem 1.11: In the same circumstances as problem 10, what will happen to the temperature outside?
A. It will get a lot warmer outside.
B. It will get a lot colder outside.
C. It won’t make any difference to the temperature outside.

Problem 1.12: The situation is the same as problem 10, only this time, instead of opening the window, you close the door to the rest of the house. What will happen to the temperature in the room?
A. The room will get a lot warmer.
B. The room will get a lot colder.
C. It won’t make any difference to the temperature.

Problem 1.13: You and your sister are looking at the moon, and then you shut your eyes. Your sister leaves her eyes open. Can you still see the moon?

Problem 1.14: Can your sister still see the moon?

Problem 1.15: Can you see your hand if you hold it in front of your face?

Problem 1.16: Can you see your hand if you hold it behind your head?

Problem 1.17: Can you see your hand if it’s inside a pocket?

Problem 1.18: If you are at home, and you left your jacket at school, a mile away, can you see your jacket?

Problem 1.19: If you are at home, during the day, and your jacket is on a chair right next to you, and you look in its direction, can you see it?

Problem 1.20: Suppose you are at home and your jacket is on a chair right next to you and it’s nighttime and there’s no light at all in your room. Can you see your jacket, if you look straight at it?
Problem 1.21: Can you feel it, if you touch it?

Problem 1.22: Can you feel it, if you hold your hand close to it without touching it?

Problem 1.23: If it has some kind of smell, could you smell it, if you put your nose up to it?

Problem 1.24: After a cat eats a mouse, the mouse is:
A. Alive inside the cat’s belly.
B. Pretty sick.
C. Dead.

Problem 1.25: When a cat eats a mouse, it uses its
A. Mouth
B. Fur
C. Eyes
D. Nose

Problem 1.26: If a seagull lays eggs that hatch, what will the babies be when they grow up?
A. Eggs.
B. Chickens
C. Seagulls.
D. Snakes.

Problem 1.27: If a cow dies, how long will it be until the cow is alive again?
A. The cow will be alive again next day.
B. The cow will be alive again in a year.
C. The cow will be alive again after her children die.
D. The cow will never be alive again.

Problem 1.28: If a female eagle and a male alligator have a child, what would it be?
A. Definitely an eagle.
B. Definitely an alligator.
C. Either an eagle or an alligator.
D. A creature that is half an eagle and half an alligator.
E. An eagle and an alligator cannot have a child.

Problem 1.29: Wolves live in packs. If a wolf gets separated from its pack, and cannot rejoin the pack then
A. It will die within a few hours.
B. It will turn into some different kind of animal.
C. It will go to sleep until its pack comes back.
D. None of the above.

Problem 1.30: Sam is a squirrel and Ted and Wendy are his parents. Ted and Wendy are
A. Younger than Sam.
B. Exactly the same age as Sam.
C. Older than Sam.
D. They might be older, or younger, or the same age.

Problem 1.31: Fish can only breathe in water. If you are fishing from a boat and you pull the fish into the boat, then
A. It will turn into an animal that can breathe outside of water.
B. The boat will fill up with water, so that the fish can breathe.
C. The fish will stop breathing but otherwise be OK.
D. The fish will die.

Problem 1.32: Many birds travel long distances back and forth every year from their winter home to the summer home and back. If you have one of these birds in a zoo, then:
A. The bird will stay in the zoo.
B. The bird will carry the zoo back and forth from its winter home to its summer home.
C. The bird will escape from the zoo.
D. The bird will stay in the zoo.
E. The bird will die.

Problem 1.33: If a person has a cold, then he will probably get well,
A. In a few minutes.
B. In a few days or a couple of weeks.
C. In a few years.
D. He will never get well.

Problem 1.34: If a person cuts off one of his fingers, then he will probably grow a new finger
A. In a few minutes.
B. In a few days or a couple of weeks.
C. In a few years.
D. He will never grow a new finger.

Problem 1.35: If a person hurts himself by stubbing his toe, it should feel better
A. In a few minutes.
B. In a few days or a couple of weeks.
C. In a few years.
D. It will never feel better.

Problem 1.36: Does it hurt to cut your hair?

Problem 1.37: Does it hurt if you fall down and scrape your knee?

Problem 1.38: Does it hurt if you bang your head against a wall?

Problem 1.39: Does it hurt if you lay your head on a pillow?

Problem 1.40: Does it hurt if a cat scratches you?

Problem 1.41: Suppose that you have two books a blue book and a red book. The pages are the same size and are made out of the same kind of paper, but the blue book is much thicker than the red book. Which, probably, has more pages, the blue book or the red book?

Problem 1.42: Which is probably heavier, the blue book or the red book?
Problem 1.43: Could you put the red book on top of the blue book?

Problem 1.44: Could you put the red book inside the blue book?

Problem 1.45: Is it possible that there is a page that are both in the blue book and in the red book?

Problem 1.46: Is it possible that there is a page in the red book that has exactly the same words as some page in the blue book?

Problem 1.47: Suppose you tear a page out of the blue book, then tear a page out of the red book, then out of the blue book, then out of the red book, and so on. What will eventually happen?
   A. The blue book will run out of pages, but there will still be pages in the red book.
   B. The red book will run out of pages, but there will still be pages in the blue book.
   C. Eventually, you will tear the last page out of the blue book, and then you will tear the last page out of the red book.
   D. You can keep tearing pages forever.

Problem 1.48: Suppose you have two copies of the same book. One has a white cover and the other has a black cover, but otherwise they are identical. Which weighs more?
   A. The white book weighs more.
   B. The black book weighs more.
   C. They weigh the same.

Problem 1.49: If you tear a page out of the white book what will happen?
   A. The same page will fall out of the black book.
   B. Another page will grow in the black book.
   C. The page will grow back in the white book.
   D. The white book will tear a page out of the black book.
   E. None of the above.

Problem 1.50: If the white book and the black book have a child, what would it be?
   A. A black book.
   B. A white book.
   C. Either a black or a white book.
   D. A book that is half black and half white,
   E. A grey book.
   F. Books cannot have children.

Problem 1.51 Sara has a bucket half full of water. She carefully puts a couple of stones into the bucket. What happens?
   A. The stones will float at the top of the water.
   B. The stones will sink to the bottom of the bucket.
   C. The stones will sink halfway down.
   D. The water will all turn into stone.
   E. The stones will dissolve in the water.

Problem 1.52 What happens to the level of water in the bucket?
   A. It gets higher.
   B. It gets lower.
   C. It stays the same.
Problem 1.53 George accidentally poured a little bleach into his milk. Is it OK for him to drink the milk, if he’s careful not to swallow any of the bleach?

Problem 1.54 When Ed was born, his father was in Boston and his mother was in Los Angeles. Where was Ed born?
A. In Boston.
B. In Los Angeles.
C. Either in Boston or in Los Angeles.
D. Somewhere between Boston and Los Angeles.

Appendix A.2: Physics/astronomy problems that should be easy for high-school physics students

Problem 2.1: You have packed some objects into a 6" × 4" × 8" box. You have an empty box which is 12" × 6" × 12". Will the same objects fit into empty box?
A. Yes, they will fit.
B. No, they will not fit.
C. Impossible to tell from the information given.

Problem 2.2: You have packed some objects into a 6" × 4" × 8" box. You have an empty box which is 6" × 6" × 6". Will the same objects fit into empty box?
A. Yes, they will fit.
B. No, they will not fit.
C. Impossible to tell from the information given.

Problem 2.3: Suppose that you have a large closed barrel. Empty, the barrel weighs 1 kg. You put into the barrel 10 gm of water and 1 gm of salt, and you dissolve the salt in the water. Then you seal the barrel tightly. Over time, the water evaporates into the air in the barrel, leaving the salt at the bottom. If you put the barrel on a scales after everything has evaporated, the weight will be
A. 1000 gm
B. 1001 gm
C. 1010 gm
D. 1011 gm
E. Water cannot evaporate inside a closed barrel.

Problem 2.4: Does it ever happen that there is an eclipse of the sun one day and an eclipse of the moon the next?

Problem 2.5: Does it ever happen that someone on earth sees an eclipse of the moon shortly after sunset?

Problem 2.6: Does it ever happen that someone on earth sees an eclipse of the moon at midnight?

Problem 2.7: Does it ever happen that someone on earth sees an eclipse of the moon at noon?

Problem 2.8: Does it ever happen that one person on earth sees a total eclipse of the moon, and
at exactly the same time another person sees the moon uneclipsed?

**Problem 2.9:** Does it ever happen that one person on earth sees a total eclipse of the sun, and at exactly the same time another person sees the sun uneclipsed?

Problem 2.10: Suppose that you are standing on the moon, and the earth is directly overhead. How soon will the earth set?
A. In about a week.
B. In about two weeks.
C. In about a month.
D. The earth never sets.

**Problem 2.11:** Suppose that you are standing on the moon, and the sun is directly overhead. How soon will the sun set?
A. In about a week.
B. In about two weeks.
C. In about a month.
D. The sun never sets.

Problem 2.12: You are looking in the direction of a particular star on a clear night. The planet Mars is on a direct line between you and the star. Can you see the star?

Problem 2.13: You are looking in the direction of a particular star on a clear night. A small planet orbiting the star is on a direct line between you and the star. Can you see the star?

**Problem 2.14:** Suppose you were standing on one of the moons of Jupiter. Ignoring the objects in the solar system, which of the following is true:
A. The pattern of stars in the sky looks almost identical to the way it looks on earth.
B. The pattern of stars in the sky looks very different from the way it looks on earth.

**Problem 2.15:** Suppose you are in a room where the temperature is initially $62^\circ$. You turn on a heater, and after half an hour, the temperature throughout the room is now $75^\circ$, so you turn off the heater. The door to the room is closed; however there is a gap between the door and the frame, so air can go in and out. Assume that the temperature and pressure outside the room remain constant over the time period. Comparing the air in the room at the start to the air in the room at the end, which of the following is true:
A. The pressure of the air in the room has increased.
B. The air in the room at the end occupies a larger volume than the air in the room at the beginning.
C. There is a net flow of air into the room during the half hour period.
D. There is a net flow of air out of the room during the half hour period.
E. Impossible to tell from the information given.

**Problem 2.16:** The situation is the same as in problem 65, except that this time the room is sealed, so that no air can pass in or out. Which of the following is true:
A. The pressure of the air in the room has increased.
B. The pressure of the air in the room has decreased.
C. The air in the room at the end occupies a larger volume than the air in the room at the beginning.
D. The air in the room at the end occupies a smaller volume than the air in the room at the beginning.
E. The ideal gas constant is larger at the end than at the beginning.
F. The ideal gas constant is smaller at the end than at the beginning.

Problem 2.17: You blow up a toy balloon, and tie the end shut. The air pressure in the balloon is:
A. Lower than the air pressure outside.
B. Equal to the air pressure outside.
C. Higher than the air pressure outside.

![Diagram of a cylinder with a piston and a nozzle](image)

Problem 2.18: You have a piston inside a cylinder with a open nozzle at the other end, as in the above picture. The cylinder is vertical, with the piston at the bottom and the nozzle at the top. The cylinder is 20 cm high; its cross section is a circle of radius 3 cm. The radius of the nozzle is 1/4 cm. You now push upward on the cylinder hard enough so that, after a fraction of second, it moves upward at a constant speed of 5 cm/sec. At the moment when the piston is 10 cm from the top, how fast is the water moving when it comes out of the nozzle?

Problem 2.19: In the situation described in problem 68, how high does the fountain of water go? (Ignore air resistance.)

Problem 2.20: As the piston approaches the top of the cylinder, does the speed of the water
coming out increase, decrease, or stay the same?

**Problem 2.21:** Let \( w_p \) be the weight of the piston and let \( w_w(t) \) be the weight of the water that remains in the piston at time \( t \). Once the piston has reached the speed of 5 cm/sec, let \( f(t) \) be the force on the piston needed at time \( t \) to keep it moving at a constant upward speed. Which of the following is true:
A. \( f(t) = 0 \), because the piston is not accelerating.
B. \( f(t) = w_p \).
C. \( w_p < f(t) < w_p + w_w(t) \).
D. \( f(t) = w_p + w_w(t) \).
E. \( f(t) > w_p + w_w(t) \).

**Problem 2.22:** Suppose you replace the water by a heavier liquid, like mercury, but otherwise left the problem the same (the piston still moves at 5 cm/sec). Which of the following would change:
A. The speed of the liquid leaving the piston.
B. The height of the fountain of liquid.
C. The force needed on the piston.

**Problem 2.23:** In the Millikan oil-drop experiment, a tiny oil drop charged with a single electron was suspended between two charged plates. The charge on the plates was adjusted until the electric force on the drop exactly balanced its weight. How were the plates charged?
A. Both plates had a positive charge.
B. Both plates had a negative charge.
C. The top plate had a positive charge, and the bottom plate had a negative charge.
D. The top plate had a negative charge, and the bottom plate had a positive charge.
E. The experiment would work the same, no matter how the plates were charged.

**Problem 2.24:** If the oil drop started moving upward, Millikan would
A. Increase the charge on the plates
B. Reduce the charge on the plates.
C. Increase the charge on the drop.
D. Reduce the charge on the drop.
E. Make the drop heavier.
F. Make the drop lighter.
G. Lift the bottom plate.

**Problem 2.25:** If the oil drop fell onto the bottom plate, Millikan would
A. Increase the charge on the plates

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Charged Plate

\[ \text{Oil drop} \]

Charged Plate

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B. Reduce the charge on the plates.
C. Increase the charge on the drop.
D. Reduce the charge on the drop.
E. Start over with a new oil drop.

**Problem 2.26:** The experiment demonstrated that charge is quantized; that is, the charge on an object is always an integer multiple of the charge of the electron, not a fractional or other non-integer multiple. To establish this, Millikan had to measure the charge on
A. One oil drop.
B. Two oil drops.
C. Many oil drops.

Read the following description of a chemistry experiment illustrated below. A small quantity of potassium chlorate (KClO₃) is heated in a test tube, and decomposes into potassium chloride (KCl) and oxygen (O₂). The gaseous oxygen expands out of the test tube, goes through the tubing, bubbles up through the water in the beaker, and collects in the inverted beaker over the the water. Once the bubbling has stopped, the experimenter raises or lowers the beaker until the level of the top of water inside and outside the beaker are equal. At this point, the pressure in the beaker is equal to atmospheric pressure. Measuring the volume of the gas collected over the water, and correcting for the water vapor which is mixed in with the oxygen, the experimenter can thus measure the amount of oxygen released in the decomposition.

![Chemistry Experiment Diagram]

From (Brown, LeMay, and Bursten, 2003) fig. 10.15, p. 372.

**Problem 2.27:** If the right end of the U-shaped tube were outside the beaker rather than inside, how would that change things?
A. The chemical decomposition would not occur.
B. The oxygen would remain in the test tube.

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5Do not attempt to carry out this experiment based on the description here. Potassium chlorate is explosive, and safety precautions, not described here, must be taken.
C. The oxygen would bubble up through the water in the basin to the open air and would not be
collected in the beaker.
D. Nothing would change. The oxygen would still collect in the beaker, as shown.

**Problem 2.28:** If the beaker had a hole in the base (on top when inverted as shown), how would
that change things?
A. The oxygen would bubble up through the beaker and out through the hole.
B. Nothing would change. The oxygen would still collect in the beaker, as shown.
C. The water would immediately flow out from the inverted beaker into the basin and the beaker
would fill with air coming in through the hole.

**Problem 2.29** If the test tube, the beaker, and the U-tube were all made of stainless steel rather
than glass, how would that change things?
A. The chemical decomposition would not occur.
B. The oxygen would seep through the stainless steel beaker.
C. Physically it would make no difference, but it would be impossible to see and therefore impossible
to measure.

**Problem 2.30** Suppose the stopper in the test tube were removed, but that the U-tube has some
other support that keeps it in its current position. How would that change things?
A. The oxygen would stay in the test tube.
B. All of the oxygen would escape to the outside air.
C. Some of the oxygen would escape to the outside air, and some would go through the U-shaped
tube and bubble up to the beaker. So the beaker would get some oxygen but not all the oxygen.

**Problem 2.31** The experiment description says, “The experimenter raises or lowers the beaker until
the level of the top of water inside and outside the beaker are equal. At this point, the pressure in
the beaker is equal to atmospheric pressure.” More specifically: Suppose that after the bubbling
has stopped, the level of water in the beaker is higher than the level in the basin (as seems to be
shown in the right hand picture). Which of the following is true:
A. The pressure in the beaker is lower than atmospheric pressure, and the beaker should be lowered.
B. The pressure in the beaker is lower than atmospheric pressure, and the beaker should be raised.
C. The pressure in the beaker is higher than atmospheric pressure, and the beaker should be lowered.
D. The pressure in the beaker is higher than atmospheric pressure, and the beaker should be raised.

**Problem 2.32** Suppose that instead of using a small amount of potassium chlorate, as shown, you
put in enough to nearly fill the test tube. How will that change things?
A. The chemical decomposition will not occur.
B. You will generate more oxygen than the beaker can hold.
C. You will generate so little oxygen that it will be difficult to measure.

**Problem 2.33** In addition to the volume of the gas in the beaker, which of the following are
important to measure accurately?
A. The initial mass of the potassium chlorate.
B. The weight of the beaker.
C. The diameter of the beaker.
D. The number and size of the bubbles.
E. The amount of liquid in the beaker.

**Problem 2.34** The illustration shows a graduated beaker. Suppose instead you use an ungraduated
glass beaker. How will that change things?
A. The oxygen will not collect properly in the beaker.
B. The experimenter will not know whether to raise or lower the beaker.
C. The experimenter will not be able to measure the volume of gas.
Problem 2.35 The illustration shows two separate basins and beakers. What is the significance of that?
A. These are two separate basins and beakers.
B. The left hand picture (a) shows the state of things at the very start of the experiment; the right hand picture (b) shows the state of things at the very end of the experiment.
C. The left hand picture (a) shows the state of things toward the beginning of the experiment, after some gas has been evolved and collected; the right hand picture (b) shows the state of things toward the end, after the bubbling has stopped but before the levels have been equalized.
D. The right hand picture illustrates safety procedures.

Problem 2.36 Both pictures (a) and (b) show the mouth of the beaker below the level of the water in the basin. Suppose that instead the mouth of the beaker is above the level of water in the basin. What would happen?
A. The water would flow out of the beaker into the basin.
B. The water will stay in the beaker, but the oxygen would escape into the open air in the gap between the mouth of the beaker and the surface of water in the basin.
C. The oxygen will collect in the beaker, but it will be impossible to carry out the procedure of balancing the pressures by raising and lowering the beaker.

Problem 2.37 At the start of the experiment, the beaker needs to be full of water, with its mouth in the basin below the surface of the water in the basin. How is this state achieved?
A. Fill the beaker with water right side up, turn it upside down, and lower it upside down into the basin.
B. Put the beaker rightside up into the basin below the surface of the water; let it fill with water; turn it upside down keeping it underneath the water; and then lift it upward, so that the base is out of the water, but keeping the mouth always below the water.
C. Put the beaker upside down into the basin below the surface of the water; and then lift it back upward, so that the base is out of the water, but keeping the mouth always below the water.
D. Put the beaker in the proper position, and then splash water upward from the basin into it.

Problem 2.38 From the time that you first bring the heat to the test tube to the time that you finish measuring the volume of gas, how much time would you think elapses?
A. A fraction of a second.
B. Several minutes to an hour.
C. Several days.
D. A year or more.

Problem 2.39 Nearby stars exhibit parallax due to the annual motion of the earth. If a star is nearby, and is in the plane of the earth’s revolution, and you track its relative motion against the background of very distant stars over the course of a year, what figure does it trace?

Problem 2.40 If a star is nearby, and the line from the earth to the star is perpendicular to the plane of the earth’s revolution, and you track its relative motion against the background of very distant stars over the course of a year, what figure does it trace?

Problem 2.41 A star exhibits the following unusual behavior: Every 20 days, it grows gradually dimmer for an hour, stays dim for three hours, and then over the next hour returns to its usual brightness.

The following explanation is conjectured: The star has a dark twin which rotates around it. The dim time corresponds to the time that the dark twin is partially occluding the bright star, from the point of view of earth.
It is further observed that the cycle time is not quite constant; it is slightly shorter in the spring and slightly longer in the fall.

Which of the following explanations of this variance in the cycle time is most plausible?
A. The earth is closer in the spring and further in the fall, so the light takes less time to travel in the spring.
B. The earth is moving toward the star in the spring and moving away in the fall, so in the spring it is closer at each successive observation.
C. The earth is closer in the spring and further in the fall. The earth’s gravity is affecting the star’s revolution, so that it moves faster in the spring and slower in the fall.
D. There is a third invisible star that is affecting the dark star’s behavior.

**Problem 2.42:** This change in cycle time will be largest if
A. The star is in the plane of the earth’s revolution.
B. The star is on the line from the earth perpendicular to the plane of the earth’s revolution.
C. The position of the star in the sky makes no difference.

**Problem 2.43:** Suppose that the star is in the plane of the earth’s revolution and 20 light years away. What is the difference between the cycle time at its shortest and the cycle time at its longest? Note: the earth’s orbital velocity is about 30 km/sec; the speed of light is about 300,000 km/sec.

**Problem 2.44:** This effect is analogous to:
A. Precesssion of the equinoxes.
B. Doppler effect/red shift.
C. Motion of a mass on a spring.
D. Foucault’s pendulum.