VIRGINIA BOARD OF EDUCATION
AGENDA ITEM

Agenda Item: **K**

Date: **October 20, 2022**

Title: **First Review of the Advisory Board on Teacher Education and Licensure's Recommendation for a Passing Score for the Praxis® Physics (5266) Test for the Science – Physics Endorsement**

Presenter: **Dr. Joan B. Johnson, Assistant Superintendent for Teacher Education and Licensure**

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Purpose of Presentation:
Action required by state or federal law or regulation.

Executive Summary:
The proposed recommendation from the Advisory Board on Teacher Education and Licensure (ABTEL) is to set a passing score for the **Praxis® Physics (5266) Test** for the Physics endorsement. The Praxis® Physics (5266) test will replace the Praxis® Physics: Content Knowledge (5265) test. This **new** assessment was designed and developed through work with practicing physics teachers, teacher educators, and higher education physics specialists to reflect the science knowledge teachers need to teach the physics curriculum and to reflect state and national standards, including the National Science Teaching Association Preparation Standards for physics. This test will be required for individuals seeking initial licensure unless exempted by holding a full, clear out-of-state license with no deficiencies and can be taken and passed to add an endorsement in Physics by individuals holding a valid renewable teaching license.

Educational Testing Service (ETS) provides a recommended passing score from the multistate standard-setting study to help education agencies determine an appropriate operational passing score. For the Praxis Physics test, the recommended passing score is 56 out of a possible 100 raw-score points. The scale score associated with a raw score of 56 is **145** on a 100–200 scale.

The current Praxis® Physics: Content Knowledge (5265) Test has a Board prescribed passing score of 147 on a 100-200 scale. The Praxis® Physics (5266) test is a **new** assessment and the previous passing score was not a consideration of ETS or ABTEL when establishing this test's passing score. Because this is a **new** assessment, ABTEL is also recommending that a data review be conducted after one year to determine if the passing score is providing for the greatest opportunity of teachers entering the profession while maintaining rigor.

On September 19, 2022 information regarding the multistate standard-setting process was presented to ABTEL members by Malik K. McKinley, Sr., Director of Client Relations, Professional Educator Programs, Office for Teacher Licensure and Certification, Student and Teacher Assessment Division, Educational Testing Service. ABTEL members reviewed the standard-setting report and recommended that the Board approve the passing score of 145 (the standard setting panel's recommendation).

Attached are the Multistate Standard-Setting Technical Report - Praxis® Physics (5266) Test and the Praxis® Study Companion. Also attached is a literature review and analysis of licensure assessment and student outcomes that was provided to the Virginia Board of Education (Board) in January 2022 that might provide useful information regarding the predictive value of teacher licensure assessments on student outcomes.

This item supports Priority 2 of the Board's Comprehensive Plan: 2018-2023.

Action Requested:
Action will be requested at a future meeting. Specify anticipated date below:
November 17, 2022.

Superintendent's Recommendation
The Superintendent of Public Instruction recommends that the Board receive for first review the recommendation of the Advisory Board on Teacher Education and Licensure to establish a passing score of 145 for the Praxis® Physics (5266) Test.

Previous Review or Action:
No previous review or action.

Background Information and Statutory Authority:
Currently, the Board requires the following assessments for initial licensure:

- Virginia Communication and Literacy Assessment (VCLA);
- Praxis Subject Assessments; and
- Praxis® Teaching Reading: Elementary (5205) for specified endorsements.

The Board prescribes the Praxis Subject Assessments as a professional teacher's assessment requirement for initial licensure in Virginia. The current Board of Education's prescribed assessment for physics is the Praxis® Physics: Content Knowledge (5265).

The Praxis® Physics (5266) test will replace the Praxis® Physics: Content Knowledge (5265) test. This **new** assessment is designed and developed through work with practicing physics teachers, teacher educators, and higher education physics specialists to reflect the science knowledge teachers need to teach the physics curriculum and to reflect state and national standards, including the National Science Teaching Association Preparation Standards for physics. Content and practices measured reflect the Disciplinary Core Ideas (DCIs) and Science and Engineering Practices (SEPs) established by the National Research Council in A Framework for K-12 Science Education and included in the Next Generation Science Standards.

In November 2021, a multistate standard-setting study was designed and conducted by the Educational Testing Service (ETS) to support the decision-making process of education agencies establishing a passing score (cut score) for the Praxis® Physics (5266) test. Panelists from 11 states participated on the panel. Additionally, the panel included an educator representing Western Governors University (WGU), a nationally-accredited online university. The education agencies and WGU recommended panelists with (a) experience as either teachers of visually impaired students or college faculty who prepare those physics teachers and (b) familiarity with the knowledge and skills required of beginning physics teachers.

A detailed summary of the study, Multistate Standard-Setting Technical Report - Praxis® Physics (5266) is attached. The technical report contains three sections. The first section describes the content and format of the test. The second section describes the standard-setting processes and methods. The third section presents the results of the standard-setting study.

A copy of the Praxis® Physics Study Companion is attached. This document describes the purpose and structure of the test. In brief, the test measures knowledge and competencies that are important for safe and effective beginning practice as a physics teacher. The two-hour and thirty minute assessment contains 125 selected-response items covering five content areas: *Nature and Impact of Science and Engineering (approximately 15 items), Principles and Models of Matter and Energy (approximately 19 items), Mechanics (approximately 44 items), Electricity and Magnetism (approximately 26 items), and Waves (approximately 21 items)*. Of these 125 items, over 40% also integrate a Science and Engineering Practice and about 25% assess content applied to a Task of Teaching Science. The reporting scale for the Praxis Physics test ranges from 100 to 200 scale-score points.

Multistate Standard-Setting Study

The Multistate standard-setting study for the Praxis® Physics (5266) test is detailed in the attached report.

The following table presents the estimated conditional standard error of measurement (CSEM) around the recommended passing score. A standard error represents the uncertainty associated with a test score. The scale scores associated with one and two CSEM above and below the recommended passing score are provided. The conditional standard error of measurement provided is an estimate.

Conditional Standard Error of Measurement Summaries
PRAXIS® PHYSICS (5266)

	Raw Score	Scale Score Equivalent
Recommended passing score (CSEM)	***56 (4.99)***	***145***
- 2 CSEM	47	133
- 1 CSEM	52	140
+1 CSEM	61	152
+2 CSEM	66	159

ETS provides a recommended passing score from the multistate standard-setting study to help education agencies determine an appropriate operational passing score. For the Praxis Physics test, the recommended passing score is 56 out of a possible 100 raw-score points. The scale score associated with a raw score of 56 is **145** on a 100–200 scale.

The current Praxis® Physics: Content Knowledge (5265) Test has a Board prescribed passing score of 147 on a 100-200 scale. The Praxis® Physics (5266) test is a **new** assessment and the previous passing score was not a consideration of ETS or ABTEL when establishing this test's passing score. Because this is a **new** assessment, ABTEL is also recommending that a data review be conducted after one year to determine if the passing score is providing for the greatest opportunity of teachers entering the profession while maintaining rigor.

On September 19, 2022 information regarding the multistate standard-setting process was presented to the Advisory Board members by Malik K. McKinley, Sr., Director of Client Relations, Professional Educator Programs, Office for Teacher Licensure and Certification, Student and Teacher Assessment Division, Educational Testing Service. The Advisory Board members reviewed the standard-setting report and recommended that the Board approve the passing score of 145 (the standard setting panel's recommendation).

The *Code of Virginia* provides the authority for the Board of Education to promulgate *Licensure Regulations for School Personnel*.

Section **22.1-298.1** of the *Code of Virginia* states, in part, the following:

> § **22.1-298.1** **Regulations governing licensure.**
> *C. The Board of Education's regulations shall include requirements that a person seeking initial licensure:*
> *1. Demonstrate proficiency in the relevant content area, communication, literacy, and other core skills for educators by achieving a qualifying score on professional assessments or meeting alternative evaluation standards as prescribed by the Board;*
> *2. Complete study in attention deficit disorder;*
> *3. Complete study in gifted education, including the use of multiple criteria to identify gifted students; and*
> *4. Complete study in methods of improving communication between schools and families and ways of increasing family involvement in student learning at home and at school.*

Code of Virginia, Section 22.1-16. Bylaws and regulations generally.
Code of Virginia, Section 22.1-299. License required of teachers.
Code of Virginia, Section 22.1-305.2. Advisory Board on Teacher Education and Licensure.

The *Licensure Regulations for School Personnel* state, in part, the following:

> 8VAC20-22-40. Conditions for Licensure.
> … *B. All candidates who hold at least a baccalaureate degree from a regionally accredited college or university and who seek an initial Virginia teaching license shall obtain passing scores on professional teacher's assessments prescribed by the Virginia Board of Education. With the exception of the career switcher program that requires assessments as prerequisites, individuals shall complete the professional teacher's assessment requirements within the three-year validity of the initial provisional license….*
>
> 8VAC20-22-70. Additional Endorsements.
> *A. An individual who holds a teaching license may add an additional teaching endorsement to the license by passing a rigorous academic subject test for endorsements in which a test is prescribed by the Virginia Board of Education. This testing option does not apply to individuals (i) who are seeking an early/primary education preK-3 or elementary education preK-6 endorsement, special education endorsements, or a reading specialist endorsement or (ii) who hold a Technical*

Professional License, Vocational Evaluator License, Pupil Personnel Services License, School Manager License, or Division Superintendent License.

Timetable for Further Review/Action:
It is anticipated that this item will come back to the Board for final review on November 17, 2022.

Impact on Fiscal and Human Resources:
The individuals taking the Praxis® Physics (5266) Test will incur the costs for the test.

Multistate Standard-Setting Technical Report for the

Praxis® Physics (5266)

Student and Teacher Assessments: Validity and Test Use

ETS

Princeton, New Jersey

November 2021

Executive Summary

To support the decision-making process of education agencies establishing a passing score (cut score) for the *Praxis*® Physics (5266) test, research staff from Educational Testing Service (ETS) designed and conducted a multistate standard-setting study (Tannenbaum, 2011, 2012).

Participating States

Panelists representing 11 states were recommended by their respective education agencies. Additionally, the panel included an educator representing Western Governors University (WGU), a nationally-accredited online university. The education agencies and WGU recommended panelists with (a) experience as either teachers of visually impaired students or college faculty who prepare those physics teachers and (b) familiarity with the knowledge and skills required of beginning physics teachers.

Recommended Passing Score

ETS provides a recommended passing score from the multistate standard-setting study to help education agencies determine an appropriate operational passing score. For the *Praxis* Physics test, the recommended passing score[1] is 56 out of a possible 100 raw-score points. The scale score associated with a raw score of 56 is 145 on a 100–200 scale.

[1] Results from the two panels participating in the study were averaged to produce the recommended passing score. One outlier from Panel 2 was removed from the panel's recommendations before the results from both panels were averaged.

Introduction

To support the decision-making process for education agencies establishing a passing score (cut score) for the *Praxis*® Physics (5266) test, research staff from ETS designed and conducted a multistate standard-setting study (Tannenbaum, 2011, 2012) in October 2021. Education agencies[2] recommended panelists with (a) experience as either physics teachers and (b) familiarity with the knowledge and skills required of beginning physics teachers. Eleven states and Western Governors University (WGU), (Table 1) were represented by 19 panelists. (See Appendix A for the names and affiliations of the panelists.)

Table 1
Participating States and Western Governors University and the Number of Panelists

Delaware (2 panelists)	Rhode Island (2 panelists)
Idaho (1 panelist)	Tennessee (2 panelists)
Indiana (2 panelists)	Utah (2 panelists)
Kansas (1 panelist)	Virginia (2 panelists)
Maryland (1 panelist)	West Virginia (2 panelists)
Mississippi (1 panelist)	Western Governors University (1 panelist)

The following technical report contains three sections. The first section describes the content and format of the test. The second section describes the standard-setting processes and methods. The third section presents the results of the standard-setting study.

ETS provides a recommended passing score from the multistate standard-setting study to education agencies. In each state, the department of education, the board of education, or a designated educator licensure board is responsible for establishing the operational passing score in accordance with applicable regulations. This study provides a recommended passing score, which represents the combined judgments of a group of experienced educators. Each state may want to consider the recommended passing score but also other sources of information when setting the final *Praxis* Physics passing score (see Geisinger & McCormick, 2010). A state may accept the recommended passing score, adjust the score upward to reflect more stringent expectations, or adjust the score downward to reflect

[2] States and jurisdictions that currently use *Praxis* tests were invited to participate in the multistate standard-setting study.

more lenient expectations. There is no *correct* decision; the appropriateness of any adjustment may only be evaluated in terms of its meeting the state's needs.

Two sources of information to consider when setting the passing score are the standard error of measurement (SEM) and the standard error of judgment (SEJ). The former addresses the reliability of the *Praxis* Physics test score and the latter, the reliability of panelists' passing-score recommendation. The SEM allows states to recognize that any test score on any standardized test—including a *Praxis* Physics test score—is not perfectly reliable. A test score only *approximates* what a candidate truly knows or truly can do on the test. The SEM, therefore, addresses the question: How close of an approximation is the test score to the *true* score? The SEJ allows states to gauge the likelihood that the recommended passing score from the current panel would be similar to the passing scores recommended by other panels of experts similar in composition and experience. The smaller the SEJ, the more likely that another panel would recommend a passing score consistent with the recommended passing score. The larger the SEJ, the less likely the recommended passing score would be reproduced by another panel.

In addition to measurement error metrics (e.g., SEM, SEJ), each state should consider the likelihood of classification errors. That is, when adjusting a passing score, policymakers should consider whether it is more important to minimize a false-positive decision or to minimize a false-negative decision. A false-positive decision occurs when a candidate's test score suggests that they should receive a license/certificate, but their actual level of knowledge/skills indicates otherwise (i.e., the candidate does not possess the required knowledge/skills). A false-negative decision occurs when a candidate's test score suggests that they should not receive a license/certificate, but they actually do possess the required knowledge/skills. States need to consider which decision error is more important to minimize.

Overview of the *Praxis*® Physics Test

The *Praxis*® Physics *Study Companion* document (ETS, in press) describes the purpose and structure of the test. In brief, the test measures whether entry-level physics teachers have the knowledge/skills believed necessary for competent professional practice.

The two-hour and 30 minute assessment contains 125 selected-response items[3] covering five content areas: *Nature and Impact of Science and Engineering* (approximately 15 items), *Principles and*

[3] Twenty-five of the 125 selected-response items are pretest items and do not contribute to a candidate's score.

Models of Matter and Energy (approximately 19 items), *Mechanics* (approximately 44 items), *Electricity and Magnetism* (approximately 26 items), and *Waves* (approximately 21 items).[4] Of these 125 items, over 40% also integrate a Science and Enginnering Practice and abou 25% assess content applied to a Task of Teaching Science (ETS, in press). The reporting scale for the *Praxis* Physics test ranges from 100 to 200 scale-score points.

Processes and Methods

The design of the standard-setting study included two, independent expert panels. Before the study, panelists received an email explaining the purpose of the standard-setting study and requesting that they review the content specifications for the test. This review helped familiarize the panelists with the general structure and content of the test.

Both panels were combined for the beginning of the standard-setting study. The first day began with a welcome and introduction by the meeting facilitators. The lead facilitator described the test, provided an overview of standard setting, and presented the agenda for the study. Appendix B shows the standard-setting study agenda.

Reviewing the Test

The standard-setting panelists from both panels were combined as they first took the test and then discussed the content measured as a large group. This discussion helped bring the panelists to a shared understanding of what the test does and does not cover, which serves to reduce potential judgment errors later in the standard-setting process.

The test discussion covered the major content areas being addressed by the test. Panelists were asked to remark on any content areas that would be particularly challenging for entry-level physics teachers or areas that address content particularly important for entry-level physics teachers.

Defining the Just-Qualified Candidate

Following the review of the test, panelists described the just-qualified candidate. The *just-qualified candidate description* plays a central role in standard setting (Perie, 2008); the goal of the standard-setting process is to identify the test score that aligns with this description.

[4] The number of items for each content area may vary slightly from form to form of the test.

The panelists created a description of the just-qualified candidate, focusing on the knowledge/skills that differentiate a *just-qualified* from a *not quite-qualified* candidate. To create this description, the panelists from both panels were assigned to three smaller groups in order to create a draft description. Then they reconvened and, through whole-group discussion of the three drafts, reached consensus on to determine the final version. This final description of the just-qualified candidate was used by both panels for the remainder of the study.

The description of the just-qualified candidate summarized the panels' discussion in a list format. The description was not intended to describe all the knowledge and skills of the just-qualified candidate but only highlight those that differentiate a *just-qualified candidate* from a *not-quite-qualified* candidate. A clean, PDF-version of the final description was distributed to panelists to use for the remaining phases of the study (see Appendix C for the just-qualified candidate description).

Given that the two-panel multistate standard-setting study was designed to provide two recommendations for the same performance standard, it was important that panels use a consistent just-qualified candidate description to frame their judgments. Therefore, the panelists from both panels worked together until the just-qualified candidate description was finalized.

Panelists' Judgments

The standard-setting process for the *Praxis* Physics test was a probability-based Modified Angoff method (Brandon, 2004; Hambleton & Pitoniak, 2006). Using this method, each panelist judged each item on the likelihood (probability or chance) that the just-qualified candidate would answer the item correctly. Panelists made their judgments using the following rating scale: 0, .05, .10, .20, .30, .40, .50, .60, .70, .80, .90, .95, 1. The lower the value, the less likely it is that the just-qualified candidate would answer the item correctly because the item is difficult for the just-qualified candidate. The higher the value, the more likely it is that the just-qualified candidate would answer the item correctly.

Panelists were asked to approach the judgment process in two stages. First, they reviewed both the description of the just-qualified candidate and the item and determined the probability that the just-qualified candidate would answer the question correctly. The facilitator encouraged the panelists to consider the following rules of thumb to guide their decision:

- Items in the 0 to .30 range were those the just-qualified candidate would have a *low chance* of answering correctly.

- Items in the .40 to .60 range were those the just-qualified candidate would have a *moderate chance* of answering correctly.
- Items in the .70 to 1 range were those that the just-qualified candidate would have a *high chance* of answering correctly.

Next, panelists decided how to refine their judgment within the range. For example, if a panelist thought that there was a *high chance* that the just-qualified candidate would answer the question correctly, the initial decision would be in the .70 to 1 range. The second decision for the panelist was to judge if the likelihood of answering it correctly is .70, .80, .90, .95 or 1.

After the training, panelists made practice judgments. They then discussed those judgments and their rationales. All panelists completed a post-training evaluation to confirm that they had received adequate training in the Modified Angoff method and felt prepared to continue; the standard-setting process continued only if all panelists confirmed their readiness. If panelists had any questions, those questions were addressed and retraining was provided, if necessary, before proceeding to the first round of judgments.

Following this first round of judgments (*Round 1*), panel-level summaries and item-level feedback were provided to each panel. For each panel, the panelists' judgments were displayed for each item and summarized across the panelists. Item-level data were highlighted to show when panelists converged in their judgments or diverged in their judgments (i.e., when at least two-thirds of the panelists' judgments were in the same difficulty range).

Each panel discussed their item-level judgments. These discussions helped panelists maintain a shared understanding of the knowledge/skills of the just-qualified candidate and helped to clarify aspects of items that might not have been clear to all panelists during the Round 1 judgments. The purpose of the discussion was not for panelists to conform to another's judgment, but for them to understand the different relevant perspectives among the panelists.

During Round 2, each panel discussed their Round 1 judgments and were encouraged by the facilitator to (a) share the rationales for their judgments and (b) consider their judgments in light of the rationales provided by the other panelists. Panelists recorded their Round 2 judgments only for items when they wished to change their Round 1 judgment. For each panel, the final judgments for the study, therefore, consist of the panelists' Round 1 judgments and any adjusted judgments made during Round 2.

Other than the description of the just qualified candidate, results from Panel 1 were not shared with Panel 2 and vice versa. The feedback (data), item-level judgments, and resulting discussions for each panel were independent from the other panel.

Results

Expert Panels

Table 2 presents a summary of the panelists' demographic information. The panels included 19 educators representing 11 states and WGU. (See Appendix A for a listing of panelists.) Fifteen panelists were teachers, three were college faculty, and one was an instructional coach. Two of the three faculty members' job responsibilities included the training of physics teachers. The number of experts by panel and their demographic information are presented in Appendix D (Table D1).

Table 2
Panel Member Demographics (Across Panels)

Background Survey Question	Number	Percent
What is your current position?	**N**	**%**
Teacher	15	79
College faculty	3	10
Instructional Coach	1	5
How do you describe yourself (i.e., race/ethnicity)?	**N**	**%**
American Indian or Alaskan Native	1	5
Asian or Asian American	1	5
Black or African American	2	11
White	14	74
Prefer not to respond	1	5
What is your gender?	**N**	**%**
Female	8	42
Male	11	58
Are you currently certified to teach physics in your state?	**N**	**%**
Yes	16	84
No	3	16
Are you currently teaching physics in your state?	N	%
Yes	17	89
No	2	11

(table continues on the next page)

Table 2 ***(continued from the previous page)***
Panel Member Demographics (Across Panels)

Background Survey Question	Number	Percent
Are you currently supervising or mentoring other physics teachers?	**N**	**%**
Yes	9	47
No	10	53
At what P–12 grade level are you currently teaching physics?	**N**	**%**
High school (9–12 or 10–12)	15	79
Other	1	5
Not currently teaching at the P–12 level	3	16
In all, how many years of experience do you have teaching physics?	**N**	**%**
3 years or less	1	5
4–7 years	6	32
8–11 years	3	16
12–15 years	2	11
16 years or more	7	37
Which best describes the location of your P–12 school?	**N**	**%**
Urban	3	16
Suburban	9	47
Rural	4	21
Not currently working at the P–12 level	3	16
If you are college faculty, are you currently involved in the training/ preparation of physics teacher candidates?	**N**	**%**
Yes	2	11
No	1	5
Not college faculty	16	84

Standard-Setting Judgments

Table 3 summarizes the standard-setting judgments of each panel. The mean represents the panel's passing score recommendation after Round 2 Table 3 includes the summary data with the lowest outlier from Panel 2 removed (High, 2000; see Appendix E). The panelist who provided the lowest score, was believed to be making judgments that would lower the mean, instead of making judgments based on the standard-setting training.

Table 3 also includes the standard deviation and the standard error of judgment (SEJ). The SEJ is one way of estimating the reliability or consistency of a panel's standard-setting judgments. It indicates how likely it would be for several other panels of educators similar in makeup, experience, and standard-setting training to the current panel to recommend the same passing score on the same form of the test. (Appendix E provides the technical notes, which further describe the SEJ.)

Table 3
Summary of Round 2 Standard-setting Judgments by Panel

Statistic	Panel 1	Panel 2	Panel 2 (1 outlier removed)
Mean	52.84	57.54	58.38
Minimum	47.50	50.80	54.35
Maximum	58.75	63.50	63.50
SD	3.76	3.89	3.17
SEJ	1.19	1.30	1.12

Panelist-level judgments, for Rounds 1 and 2, for each panel are presented in Appendix D (Tables D2 – D5). Round 1 judgments are made without discussion among the panelists. The most variability in judgments, therefore, is typically present in the first round. Round 2 judgments, however, are informed by panel discussion; thus, it is common to see a decrease both in the standard deviation and SEJ.

The Round 2 mean score is the panel's final recommended passing score. The values were rounded to the next highest whole number to determine the functional recommended passing scores. The panel's passing score recommendation for the *Praxis* Physics test are listed in Table 4, with the outlier removed from Panel 2. The recommendations are out of the 100 raw score points available for the *Praxis* Physics test.

In addition to the recommended passing score for each panel, the mean passing score across both panels is provided to help education agencies determine an appropriate passing score. Table 4 displays those results, also rounded to the next highest whole number to determine the functional recommended passing score.

Table 4
Summary of Round 2 Standard-setting Judgments by Panel

	Raw Score	Praxis Score (100 – 200 Scale)
Panel 1	53	141
Panel 2	59	150
Combined	56	145

The conditional standard error of measurement (CSEM) around the recommended passing score of 56 is 4.99 raw points[5]. A standard error represents the uncertainty associated with a test score (See the Technical Notes in Appendix E for further information about the CSEM.) Table 5 shows the raw scores and the scale scores associated with one and two CSEM below and above the recommended passing score.

Table 5
Scores 1 and 2 CSEM Around the Recommended Passing Score (RPS)

Scores	Raw Score Points out of 100	Praxis Scale Score Equivalent
RPS - 2 CSEM	47	133
RPS - 1 CSEM	52	140
RPS	**56**	**145**
RPS +1 CSEM	61	152
RPS +2 CSEM	66	159

Notes. CSEM = conditional standard error(s) of measurement. The CSEM of the recommended passing score is 4.99 raw points. The unrounded CSEM value is added to, or subtracted from, the rounded passing-score recommendation. The resulting values are rounded up to the next-highest whole number and then converted to scale scores.

Final Evaluations

The panelists completed an evaluation at the conclusion of the standard-setting study. The evaluation asked the panelists to provide feedback about the quality of the standard-setting implementation and the factors that influenced their decisions. The responses to the evaluation provided evidence of the validity of the standard-setting process, and, as a result, evidence of the reasonableness of the recommended passing score.

Panelists were shown their panel's recommended passing score after Round 2 and asked, in the evaluation, (a) how comfortable they are with the recommended passing score and (b) if they think the score was *too high*, *too low*, or *about right*. A summary of the final evaluation results, per panel, is presented in Appendix D (Tables D6 – D13).

All panelists *strongly agreed* or *agreed* that they understood the purpose of the study and that the facilitator's instructions and explanations were clear. All panelists *strongly agreed* that they were prepared to make their standard-setting judgments. All panelists *strongly agreed* or *agreed* that the standard-setting process was easy to follow.

[5] When all data are included, the average recommended score from both panels is 56 and the CSEM is 4.99 raw score points. These values are the same with the outlier removed.

All panelists reported that the description of the just-qualified candidate was at least *somewhat influential* in guiding their standard-setting judgments. All of the panelists reported that between-round discussions were at least *somewhat influential* in guiding their judgments. Sixteen of the 19 panelists indicated that their own professional experience was *very influential* in guiding their judgments.

Each panel was presented with their passing score that was calculated during the study, 53 for panel and 58 for panel 2 (out of 100 raw score points). The recommendation to remove the outlier occurred after the meeting. Based on each panel's data, all of the panelists indicated they were at least *somewhat comfortable* with the passing score they recommended. Sixteen of the 19 panelists indicated the recommended passing score was *about right*; one panelist indicated the passing score was *too low* and two indicated it was *too high.*

Summary

To support the decision-making process for education agencies establishing a passing score (cut score) for the *Praxis* Physics test, research staff from ETS designed and conducted a multistate standard-setting study.

ETS provides a recommended passing score from the multistate standard-setting study to help education agencies determine an appropriate operational passing score. For the *Praxis* Physics test, the recommended passing score[6] is 56 out of a possible 100 raw-score points. This recommendation includes the removal of one outlier because the panelist was not believed to be making judgments based on the standard-setting training. The scale score associated with a raw score of 56 is 145 on a 100–200 scale.

[6] Results from the two panels participating in the study were averaged to produce the recommended passing score.

References

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Appendix A: Panelists' Names & Affiliations

Participating Panelists With Affiliation and State

Panelist Name	Panelists' Affiliation and State Abbreviation
Ranella Anderson	Jim Hill High School (MS)
Megan Barnes	Powhatan High School (VA)
Brenna Gillman	Western Governors University (WGU)
Christian Horner	Westfield High School (IN)
Robert Lancaster	Concord High School (DE)
Francis Lenox	East Greenwich High School (RI)
Stacy Mann	Manchester Valley High School (MD)
Milo Maughan	Brighton High School (UT)
Wesley Morgan	Nebo School District (UT)
Alison Murray	Central Falls High School (RI)
Steven Nease	Morristown Hamblen High School West (TN)
AdeBanjo Oriade	University of Delaware (DE)
Zach Riffle	University High School (WV)
Joy Scales	Blacksburg High School (VA)
Shayne Seubert	Owyhee High School (ID)
Brent Strong	Hauser High School/Ivy Tech (IN)
Masakatsu Watanabe	Fort Hays State University (KS)
Tamara Westfall	Poca High School (WV)
Marcie Williams	Ooltewah High School (TN)

Appendix B: Agenda

Praxis® Physics (5266)

Standard-Setting Study

Day 1 Agenda

Welcome and Introduction

Overview of Standard Setting and the *Praxis* Physics Test

Review the *Praxis* Physics Test

AM Break

Discuss the *Praxis* Physics Test

Lunch

Define the Knowledge/Skills of a Just-Qualified Candidate (small-group drafts)

PM Break

Define the Knowledge/Skills of a Just-Qualified Candidate (small-group drafts) *(continued)*

Collect Materials; End of Day 1

Praxis® Physics (5266)

Standard-Setting Study

Day 2 Agenda

Overview of Day 2

Define the Knowledge/Skills of a Just-Qualified Candidate (whole-group consensus)

AM Break - Split into two panels

Standard Setting Training in the Modified Angoff Method

Practice Round – Independent Judgments

Lunch

Practice Round –Discussion

Round 1 Standard Setting Judgments

PM Break

Round 1 Standard Setting Judgments *(continued)*

Collect Materials; End of Day 2

Praxis® Physics (5266)

Standard-Setting Study

Day3 Agenda

Overview of Day 3

Honoraria Presentation

Round 1 Feedback – Panel Summary

Round 1 Feedback and Round 2 Judgments

AM Break

Round 1 Feedback and Round 2 Judgments *(continued)*

Lunch

Feedback on Round 2 Recommended Passing Score

Complete Final Evaluation

Collect Materials; End of Study

Appendix C: Just-Qualified Candidate Description

Description of the Just-Qualified Candidate[7]

A just-qualified candidate…

Nature and Impact of Science and Engineering

1. Knows how to connect basic principles to real-world applications.
2. Understands experimental design, how the manipulation of variables can test hypotheses, and what can be inferred from the data.
3. Understands units, unit conversions, and significant figures.

Principles and Models of Matter and Energy

4. Is familiar with the forms and definitions of temperature, heat, and energy as they relate to thermodynamics
5. Is familiar with conceptual characteristics, processes, and effects of atomic and nuclear interactions.

Mechanics

6. Understands the algebraic and graphic nature of linear kinematics.
7. Understands the algebraic and vector nature of 2D motion (including projectile motion and inclined planes).
8. Understands the basics of circular motion.
9. Is familiar with the basic properties of simple harmonic motion, including the motion of springs and pendulums.
10. Is familiar with the basics of rotational motion, including angular momentum, rotational inertia, and torque.
11. Understands applications of Newton's Laws of Motion and gravitation in the analysis of systems and interactions
12. Know and be able to differentiate between impulse and momentum and apply conservation laws in the analysis of 1D systems.
13. Understands how to analyze the mathematical and conceptual interrelation among work, energy, and power.

Electricity and Magnetism

14. Knows how to experimentally and theoretically analyze the basics of DC circuits.
15. Is familiar with electric and magnetic forces, fields, and how they are related.
16. Understands the basics of charges and electrostatics.

[7] Description of the just-qualified candidate focuses on the knowledge/skills that differentiate a *just* from a *not quite* qualified candidate.

Description of the Just-Qualified Candidate (*continued*)

A just-qualified candidate…

Waves

17. Understands types of waves and their properties, such as wavelength, amplitude, frequency, and speed.
18. Knows the properties of the electromagnetic spectrum and the relationship between frequency, speed, energy, and wavelength.
19. Is familiar with wave phenomena such as refraction, interference, diffraction, dispersion, scattering and the Doppler Effect.
20. Is familiar with the concepts of simple lenses and mirrors.

Tasks of Teaching Science / Science and Engineering Practices

21. Knows inquiry-based instructional methods, scaffolding, and sequencing.
22. Knows how to manipulate formulas to highlight a quantity of interest or proportional relationship.
23. Understands scientific language, discourse, vocabulary, and definitions to explain phenomena, models, and basic representations.

Appendix D: Panel-Specific Results

Table D1

Panel Member Demographics per Panel

Background Survey Question	Panel 1 Number	Panel 1 Percent	Panel 2 Number	Panel 2 Percent
What is your current position?	N	%	N	%
Teacher	8	80	7	78
College faculty	1	10	2	22
Instructional Coach	1	10	0	0
How do you describe yourself (i.e., race/ethnicity)?	N	%	N	%
American Indian or Alaskan Native	0	0	1	11
Asian or Asian American	1	10	0	0
Black or African American	1	10	1	11
White	8	80	6	67
Prefer not to respond	0	0	1	11
What is your gender?	N	%	N	%
Female	5	50	3	33
Male	5	50	6	67
Are you currently certified to teach physics in your state?	N	%	N	%
Yes	9	90	7	78
No	1	10	2	22
Are you currently teaching physics in your state?	N	%	N	%
Yes	9	90	8	89
No	1	10	1	11
Are you currently supervising or mentoring other physics teachers?	N	%	N	%
Yes	5	50	4	44
No	5	50	5	56

Table D1 (*continued from previous page*)
Panel Member Demographics per Panel

Background Survey Question	Panel 1 Number	Panel 1 Percent	Panel 2 Number	Panel 2 Percent
At what P–12 grade level are you currently teaching physics?	**N**	**%**	**N**	**%**
High school (9–12 or 10–12)	8	80	7	78
Not currently teaching at the P–12 level	2	20	2	22
Including this year, how many years of experience do you have teaching physics?	**N**	**%**	**N**	**%**
3 years or less	0	0	1	11
4–7 years	5	50	1	11
8–11 years	2	20	1	11
12–15 years	0	0	2	22
16 years or more	3	30	4	44
Which best describes the location of your P–12 school?	**N**	**%**	**N**	**%**
Urban	2	20	1	11
Suburban	5	50	4	44
Rural	2	20	2	22
Not currently working at the P–12 level	1	10	2	22
If you are college faculty, are you currently involved in the training/ preparation of physics teacher candidates?	**N**	**%**	**N**	**%**
Yes	0	0	2	22
No	1	10	0	0
Not college faculty	9	90	7	78

Table D2

Panel 1 Passing Score Summary by Round of Judgments

Panelist	Round 1	Round 2
1	60.70	55.35
2	45.40	47.50
3	48.30	49.90
4	61.75	58.75
5	57.50	55.10
6	51.60	50.80
7	55.35	53.15
8	60.00	57.00
9	53.15	52.70
10	50.60	48.10

Table D3

Panel 2 Passing Score Summary by Round of Judgments

Panelist	Round 1	Round 2
1	56.55	56.95
2	53.20	50.80
3	54.05	54.35
4	58.10	58.30
5	62.70	62.40
6	60.10	59.00
7	55.60	55.90
8	56.85	56.65
9	64.60	63.50

Table D4

Summary of Standard-setting Judgments by Panel and by Round (Panel 2 Outlier Removed)

Statistic	Panel 1, Round 1	Panel 1, Round 2	Panel 2, Round 1	Panel 2, Round 2
Mean	54.44	52.84	57.97	58.38
Minimum	45.40	47.50	53.20	54.35
Maximum	61.75	58.75	64.60	63.50
SD	5.55	3.76	3.84	3.17
SEJ	1.76	1.19	1.28	1.12

Note. The judgments from Panelist 2 are a low outlier. It is recommended that the Round 2 judgmnts be removed from the Panel 2 data. The Round 2 summary data from Panel 2 shown in Table D5 includes the outlier.

Table D5

Summary of Panel 2 Standard-setting Judgments (Outlier Included)

Statistic	Panel 2, Round 2
Mean	57.54
Minimum	50.80
Maximum	63.50
SD	3.89
SEJ	1.30

Table D6: Panel 1 Final Evaluation: Process Questions

Likert Statement	Strongly agree *N*	Strongly agree %	Agree *N*	Agree %	Disagree *N*	Disagree %	Strongly disagree *N*	Strongly disagree %
I understood the purpose of this study.	10	100	0	0	0	0	0	0
The instructions and explanations provided by the facilitators were clear.	10	100	0	0	0	0	0	0
The training in the standard-setting method was adequate to give me the information I needed to complete my assignment.	10	100	0	0	0	0	0	0
The explanation of how the recommended passing score is computed was clear.	10	100	0	0	0	0	0	0
The opportunity for feedback and discussion between rounds was helpful.	9	90	1	10	0	0	0	0
The process of making the standard-setting judgments was easy to follow.	9	90	1	10	0	0	0	0

Table D7: Panel 1 Final Evaluation: Influences in Standard-Setting Judgments

How influential was each of the following factors in guiding your standard-setting judgments?	Very influential *N*	Very influential %	Somewhat influential *N*	Somewhat influential %	Not influential *N*	Not influential %
The description of the just-qualified candidate	10	100	0	0	0	0
The between-round discussions	7	70	3	30	0	0
The knowledge/skills required to answer each test item	8	80	2	20	0	0
The passing scores of other panel members	2	20	8	80	0	0
My own professional experience	8	80	2	20	0	0

Table D8: Panel 1 Final Evaluation: Comfort with the Panel's Recommendation

Question	Very comfort-able *N*	Very comfort-able %	Somewhat comfort-able *N*	Somewhat comfort-able %	Somewhat uncom-fortable *N*	Somewhat uncom-fortable %	Very uncom-fortable *N*	Very uncom-fortable %
Overall, how comfortable are you with the panel's recommended passing score?	8	80	2	20	0	0	0	0

Table D9: Panel 1 Final Evaluation: Opinion of the Final Recommendation

Statement	Too low *N*	Too low %	About right *N*	About right %	Too high *N*	Too high %
Overall, the recommended passing score is:	1	10	8	80	1	10

Table D10: Panel 2 Final Evaluation: Process Questions

Likert Statement	Strongly agree *N*	Strongly agree %	Agree *N*	Agree %	Disagree *N*	Disagree %	Strongly disagree *N*	Strongly disagree %
I understood the purpose of this study.	8	89	1	11	0	0	0	0
The instructions and explanations provided by the facilitators were clear.	8	89	1	11	0	0	0	0
The training in the standard-setting method was adequate to give me the information I needed to complete my assignment.	9	100	0	0	0	0	0	0
The explanation of how the recommended passing score is computed was clear.	6	67	3	33	0	0	0	0
The opportunity for feedback and discussion between rounds was helpful.	7	78	2	22	0	0	0	0
The process of making the standard-setting judgments was easy to follow.	7	78	2	22	0	0	0	0

Table D11: Panel 2 Final Evaluation: Influences in Standard-Setting Judgments

How influential was each of the following factors in guiding your standard-setting judgments?	Very influential *N*	Very influential %	Somewhat influential *N*	Somewhat influential %	Not influential *N*	Not influential %
The description of the just-qualified candidate	8	89	1	11	0	0
The between-round discussions	3	33	6	67	0	0
The knowledge/skills required to answer each test item	8	89	1	11	0	0
The passing scores of other panel members	2	22	6	67	1	11
My own professional experience	8	89	1	11	0	0

Table D12: Panel 2 Final Evaluation: Comfort with the Panel's Recommendation

Question	Very comfort-able *N*	Very comfort-able %	Somewhat comfort-able *N*	Somewhat comfort-able %	Somewhat uncom-fortable *N*	Somewhat uncom-fortable %	Very uncom-fortable *N*	Very uncom-fortable %
Overall, how comfortable are you with the panel's recommended passing score?	6	67	3	33	0	0	0	0

Table D13: Panel 2 Final Evaluation: Opinion of the Final Recommendation

Statement	Too low *N*	Too low %	About right *N*	About right %	Too high *N*	Too high %
Overall, the recommended passing score is:	0	0	8	89	1	11

Appendix E: Technical Notes

Standard Error of Judgment (SEJ)

The standard error of judgment (SEJ) is one way of estimating the reliability or consistency of a panel's standard-setting judgments. It indicates how likely it would be for several other panels of educators similar in makeup, experience, and standard-setting training to the current panel to recommend the same threshold score on the same form of the assessment. The SEJ assumes that panelists are randomly selected and that standard-setting judgments are independent. It is seldom the case that panelists are randomly sampled, and only the first round of judgments may be considered independent. The SEJ, therefore, likely underestimates the uncertainty of threshold scores (Tannenbaum & Katz, 2013).

The SEJ is calculated by dividing the standard deviation of the panelists' judgments (*SD*) by the square root of the number of panelists (*n*). The result serves as an estimate of the standard error of the mean (Brennan, 2002).

$$SEJ = \mathrm{SD} \big/ \sqrt{n}$$

Outlier Analysis

An analysis of the data is conducted per panel. Judgments that are above or below 1.5 times the interquartile range for that panel are identified as outliers (High, 2000). ETS makes recommendations on the removal of *specific* outliers based on the observations of the panel facilitator. The panel facilitator reports whether or not the specified panelist was faithfully participating in the standard-setting process. The decision to accept the panel recommendation with or without the outlier data is solely at the discretion of the state or jurisdiction.

Conditional Standard Error of Measurement (CSEM)

The conditional standard error of measurement (*CSEM*) for a test is computed from the study value (*SV*) of the recommended passing score and the number of selected-response items (*n*) on the test (see Lord, 1984):

$$CSEM = \sqrt{(SV)(n - SV)/(n - 1)}$$

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Physics (5266)

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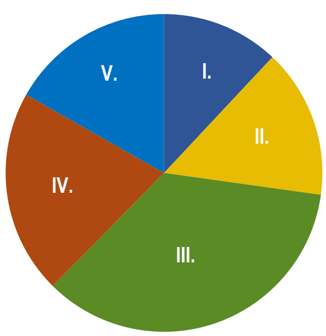
Physics (5266)

Test at a Glance

The *Praxis*® Physics test is designed to measure knowledge and competencies important for safe and effective beginning practice as a teacher of physics. Test takers have typically completed a bachelor's degree program with appropriate coursework in physics and education.

Test Name	Physics
Test Code	5266
Time	2 hours 30 minutes
Number of Questions	125 selected-response questions
Format	The test consists of a variety of selected-response questions, where you select one or more answer choices and other types of questions. You can review the possible question types in Understanding Question Types.
Test Delivery	Computer Delivered



Content Categories	Approximate Number of Questions	Approximate Percentage of Examination
I. Nature and Impact of Science and Engineering	15	12%
II. Principles and Models of Matter and Energy	19	15%
III. Mechanics	44	35%
IV. Electricity and Magnetism	26	21%
V. Waves	21	17%

Half or more of the questions integrate a Science and Engineering Practice, and approximately one-quarter to one-third of the questions assess content applied to a Task of Teaching of Science.

About The Test

The Physics test content topics span the physics curriculum, including content related to (I) Nature and Impact of Science and Engineering, (II) Principles and Models of Matter and Energy, (III) Mechanics, (IV) Electricity and Magnetism, and (V) Waves.

The assessment is designed and developed through work with practicing physics teachers, teacher educators, and higher education physics specialists to reflect the science knowledge teachers need to teach the physics curriculum and to reflect state and national standards, including the National Science Teaching Association Preparation Standards for physics. Content and practices measured reflect the Disciplinary Core Ideas (DCIs) and Science and Engineering Practices (SEPs) established by the National Research Council in A Framework for K-12 Science Education and included in the Next Generation Science Standards.

The 125 selected-response questions measure concepts, terms, phenomena, methods, applications, data analysis, and problem solving in science. A full list of the topics covered is provided in Content Topics.

Test takers do not need to use a calculator in taking this test. The periodic table of the elements is available as a Help screen, along with a table of information that presents various physical constants and a few conversion factors among SI units. Whenever necessary, additional values of physical constants are included with the text of a question.

Test takers can expect half or more of the questions on the test to integrate physics content knowledge with one or more of the SEPs, listed under Science and Engineering Practices.

Test takers will also find that approximately one-quarter to one-third of the percent of questions call for application of physics content and processes within a teaching scenario or an instructional task. Such questions—designed to measure applications of physics knowledge to the kinds of decisions and evaluations a teacher must make during work with students, curriculum, and instruction—situate physics content questions in tasks critical for teaching. Below, in Tasks of Teaching Science, is a list of tasks that are a routine part of physics instruction. These tasks, identified based on research on science instruction, have been confirmed by a national committee of teachers and teacher educators as important for effective teaching of secondary science.

This test may contain some questions that will not count toward your score.

Content Topics

This list details the topics that may be included on the test. All test questions cover one or more of these topics.

Discussion Questions

In this section, discussion questions are open-ended questions or statements intended to help test your knowledge of fundamental concepts and your ability to apply those concepts to classroom or real-world situations. We do **not** provide answers for the discussion questions but thinking about the answers will help improve your understanding of fundamental concepts and may help you answer a broad range of questions on the test. Most of the questions require you to combine several pieces of knowledge to formulate an integrated understanding and response. They are written to help you gain increased understanding and facility with the test's subject matter. You may want to discuss these questions with a teacher or mentor.

I. Nature and Impact of Science and Engineering

A. Nature of Science

1. Nature of scientific knowledge
   a. Involves a variety of investigation methods
   b. Based on experimental evidence that is reproducible
   c. Major concepts develop and change over time in light of new evidence
   d. Constructing and testing hypotheses
   e. Explain natural phenomena by using existing models and theories
   f. Developing, using, evaluating, and revising models
   g. Involves process skills, including observing, categorizing, comparing, generalizing, inferring, concluding, and communicating
2. Experimental design, data collection, and analysis
   a. Standard units of measurement, dimensional analysis, and unit conversion
   b. Scientific notation
   c. Vector and scalar quantities including vector addition (graphical and mathematical)
   d. Experimental design, including developing and using models, identifying variables, planning data collection, and supporting the testing of the hypothesis
   e. Processing data using mathematical and computational thinking, organizing data, and reporting data
   f. Error analysis, including accuracy and precision, means, and percent error
   g. Identifying sources and effects of error
   h. Interpreting and drawing conclusions from data
3. Laboratory procedures
   a. Appropriate preparation, use, storage, and disposal of materials

b. Appropriate use of laboratory and measurement equipment, including selection, calibration, and maintenance
c. Safety procedures and precautions for the laboratory

B. Science, Engineering, Technology, Society, and the Environment

1. Interdependence of science, engineering, and technology
   a. Engineering advances lead to important discoveries in science (e.g., telescopes, lasers, super collider)
   b. Science and technology drive each other forward (e.g., in communications with wireless devices, in medicine with imaging, in transportation with superconductors and magnetic levitation)
   c. Ethics, values, and social and cultural circumstances impact how scientific advances are utilized
2. Application of the engineering design process to the physics classroom
   a. Defining problems, including identifying the criteria and the constraints
   b. Designing solutions, including proposing and evaluating in terms of criteria, constraints, and limitations
   c. Optimizing the design, including systematic modification and refinement
3. Real-world environmental and societal problems impacted by technology or subject to solution through engineering design
   a. Environmental (e.g., climate change, ozone layer depletion, noise pollution)
   b. Sustainability (e.g., production, reduction, reusing, and recycling of consumer goods)
   c. Energy (e.g., renewable and nonrenewable energy resources)

Discussion Questions: Nature and Impact of Science and Engineering

- Be able to present a scientific argument with supporting data.
- Be able to explain the difference between a hypothesis and a theory.
- Be able to determine and control the parameters of measuring devices.
- Be familiar with expressing numbers in scientific notation.
- Be proficient with the use of significant figures.
- Be able to determine the number of significant digits from various measurement instruments.
- Be able to develop mathematical and graphical representations of experimental data.
- Be able to explain what is meant by the greenhouse effect.
- Be able to identify the environmental reasons underlying the development of new refrigerants.
- Be able to describe the procedures to be followed when discarding consumer products.

- Be able to identify the factors that must be taken into consideration when discarding nuclear waste.
- Be familiar with the applications of lasers in daily life.

II. Principles and Models of Matter and Energy

A. Conceptual Understanding of Atomic and Nuclear Structure and Processes

1. Atomic and subatomic structures
   a. Atomic components (protons, neutrons, and electrons)
   b. Bohr model
2. Relationship between atomic spectra and electron energy levels
   a. Electron energy transitions in atoms
   b. Absorption and emission spectra
3. Characteristics and effects of nuclear processes
   a. Radioactivity and radioactive decay processes, including half-life
   b. Alpha particles, beta particles, and gamma radiation
   c. Fission and fusion (conservation of mass energy, charge, and nucleons)
4. Basic quantum physics
   a. Wave-particle duality of matter and electromagnetic energy
   b. Photoelectric effect

B. Relationships Between Energy and Matter

1. Temperature, forms of energy, heating, and heat capacity
   a. Temperature as a measure of average kinetic energy
   b. Distinguish between temperature, heating, and thermal energy
   c. Heat capacity, specific heat, and latent heat
   d. Thermal mechanisms of energy transfer (conduction, convection, radiation)
   e. Meaning and use of different temperature scales (Kelvin, Celsius, Fahrenheit)
2. Conceptual relationships of thermodynamics to physical processes
   a. Conservation of energy for thermal processes (first law)
   b. Entropy does not decrease in a closed system (second law)
   c. Absolute zero (third law)
   d. Thermal equilibrium (zeroth law)

Discussion Questions: Principles and Models of Matter and Energy

- Be familiar with the assumptions of the Bohr model of the atom.
- Be familiar with the Bohr expression for the frequency of the light emitted or absorbed when an electron makes a transition between two energy levels.
- Be able to distinguish between nuclear fission and nuclear fusion.
- Be able to explain why energy is released during the fusion of two deuterium nuclei.

- Be able to determine the amount of radioactive substance left after a specified number of half-lives have elapsed.
- Be able to identify the daughter nucleus that results from the alpha decay of a nucleus of an atom.
- Be able to describe the relationship between the frequency of light incident on a metal and the energy of the ejected photoelectrons.
- Be able to describe the difference between heat and temperature.
- Be able to explain how the concepts of mass and energy are integrated.
- Be able to determine the amount of thermal energy needed for a given amount of ice at zero degrees Celsius to change to a gaseous state at 100 degrees Celsius.
- Be able to explain why metal feels cooler to the touch than wood at the same temperature.
- Be able to make calculations involving the ideal gas law.
- Be able to calculate the work done during the isothermal expansion of an ideal gas.
- Be able to describe the relationship between internal energy and the first law of thermodynamics.
- Be able to describe the relationship between entropy and the second law of thermodynamics.

III. Mechanics

A. Basic Concepts and Applications of Forces and Motion

1. Description of motion
   a. Properties of scalar quantities (e.g., distance, mass, speed, time, energy)
   b. Properties of vector quantities (e.g., displacement, velocity, acceleration, force, momentum)
   c. Linear motion
   d. Two-dimensional motion (e.g., projectile motion)
   e. Graphical analysis of motion
   f. Circular motion
   g. Simple harmonic motion
2. Frames of reference and their applications
   a. Frames of reference (coordinate systems, inertial reference frames)
   b. Relative velocity
3. Newton's laws of motion
   a. First law (mass, inertia, inertial reference frame)
   b. Second law (net force, mass, acceleration)
   c. Third law
4. Gravitation
   a. Newton's law of universal gravitation
   b. Satellites and orbital motion
   c. Acceleration due to gravity and gravitational field
5. Weight, mass, and density
   a. Relationship between weight and mass

   b. Relationship between density and mass
6. Kepler's laws of orbital motion
   a. First law (elliptical orbits)
   b. Second law (equal areas in equal times)
   c. Third law (relationship between orbital period and mean orbital radius)
7. Basic fluid mechanics
   a. Fluid statics (buoyancy, density, pressure)
   b. Fluid dynamics (Bernoulli's principle and the continuity equation)

B. Advanced Concepts and Applications in Mechanics

1. Friction
   a. Normal force and frictional force
   b. Coefficients of static and kinetic friction Mechanisms of evolution
2. Uniform circular motion
   a. Net force directed toward the center
   b. Centripetal acceleration
3. Harmonic motion
   a. Restoring force (Hooke's law)
   b. Period, frequency, amplitude
   c. Pendulums and spring oscillation
4. Energy
   a. Mechanical energy (kinetic and potential)
   b. Conservation of energy, including energy transfers and transformations
   c. Work and power
5. Linear momentum and impulse
   a. Center of mass
   b. Linear momentum and its conservation
   c. Change in momentum (impulse)
6. Rotational motion
   a. Angular displacement, velocity, and acceleration
   b. Angular momentum and conservation of angular momentum
   c. Rotational inertia (moment of inertia)
   d. Torque
   e. Static equilibrium
7. Collisions
   a. Elastic and inelastic collisions
   b. Conservation of momentum
   c. Conservation of mechanical energy
   d. Collisions in one and two dimensions

Discussion Questions: Mechanics

- Be able to determine distance, displacement, average speed, average velocity, and average acceleration for an object in motion.
- Be able to determine the magnitude and direction of the resultant of two vectors.
- Be able to calculate the magnitude and direction of the vector from the cross product of two vectors A and B.
- Be able to describe in graphical form the position, velocity, and acceleration of an object that is thrown vertically upward and returns to its starting point.

- Be able to determine displacement, distance, velocity, and acceleration from graphs of position versus time, velocity versus time, and acceleration versus time.
- Be able to calculate the horizontal and vertical components of velocity for a projectile.
- Be able to identify, compare, and sum the forces acting on a block that is accelerating or moving at constant velocity on a rough horizontal surface, including the reaction forces.
- Be able to explain why gymnasts performing on a balance beam raise their arms to regain their balance.
- Be familiar with the coefficients of static, kinetic, and rolling friction.
- Be able to determine the coefficient of kinetic friction for a box sliding down an inclined plane at constant speed.
- Be able to calculate the centripetal force acting on an object moving at constant speed in a circular path.
- Be able to calculate the period and frequency of a simple pendulum or a spring in simple harmonic motion.
- Be able to plot the potential energy, kinetic energy, and total mechanical energy of a linear harmonic oscillator as a function of position.
- Be able to describe the changes that occur to the moment of inertia, angular momentum, and rotational kinetic energy of a student who extends their arms outward from an initial downward position while rotating about a vertical axis on a frictionless platform.
- Be able to apply the principles of conservation of momentum and energy to predict the results of collisions between objects in one or two dimensions.
- Be able to use the law of conservation of energy to predict the energy transformations of a bungee-cord jumper.
- Be able to calculate the gravitational force between two masses separated by a certain distance.
- Be able to determine the acceleration and period of a satellite in circular orbit about Earth.
- Be able to describe the relationship between a planet's period about the Sun and its mean distance from the Sun.
- Be able to calculate the buoyant force acting on an object.

IV. Electricity and Magnetism

A. Electricity

1. Electrostatics
   a. Electric charge and induced charge
   b. Conservation of charge, including charge transfer
   c. Coulomb's law and point charges
   d. Electric forces and electric fields
   e. Electric potential, energy, and potential difference
2. Conductors and insulators
   a. Electrical properties
   b. Material examples
3. Properties and relationships involving electric current and capacitance

   a. Current, resistance, potential difference, and resistivity
   b. Ohm's law
   c. Energy and power
   d. Direct current and alternating current
   e. Capacitance and capacitors
4. Analysis of simple and combination circuits
   a. Series, parallel, and combination circuits
   b. Ohm's law
   c. Equivalent resistance and capacitance
   d. Kirchhoff's laws
   e. Power
5. Generation of electrical potential
   a. Sources (Batteries, photocells, generators)
   b. Electromotive force (EMF)

B. Magnetism

1. Magnetic fields, forces, and materials
   a. Magnetic field and magnetic flux
   b. Magnetic force
   c. Magnets (bar magnets and poles, permanent magnets, electromagnets)
   d. Transformers, motors, and generators
   e. Direction of fields and forces (right-hand rules)
   f. Magnetic field generated by steady current (Biot-Savart law)
   g. Force between current-carrying wires
   h. Force on moving charges in magnetic fields (Lorentz force)
2. Basic conceptual relationships between electric fields and magnetic fields
   a. Magnetic field caused by changing electric field (Ampere's law)
   b. Direction of induced current caused by changing magnetic field (Lenz's law)
   c. Induced EMF (Faraday's law of induction)
   d. EMF (due to motion of conductor)

Discussion Questions: Electricity and Magnetism

- Be able to calculate the electrostatic force between two point charges separated by a certain distance.
- Be able to determine the electric field and electric potential at a point midway between two point charges.
- Be able to determine the electric potential energy of a simple configuration of point charges.
- Be able to calculate the power dissipated by a resistor in a circuit.
- Be able to describe how the resistivity of a wire depends on its length and cross-sectional area.
- Be able to calculate the equivalent capacitance of two capacitors connected in series or two capacitors connected in parallel.
- Be able to calculate the capacitance of a parallel-plate capacitor.
- Be familiar with the effect of a dielectric on the capacitance of a parallel-plate capacitor.
- Be able to calculate the equivalent resistance of two resistors

connected in series or two resistors connected in parallel.
- Be able to calculate the current in a circuit consisting of series and parallel combinations of resistors.
- Be able to describe how to measure the resistance of a resistor in a circuit using a voltmeter and an ammeter.
- Be able to determine the magnitude and direction of the electric field needed to allow an electron to travel eastward undeflected in Earth's magnetic field.
- Be able to determine the magnitude and direction of the resultant magnetic field at a point midway between two long, parallel wires carrying currents in opposite directions and separated by a certain distance.
- Be able to determine the magnitudes and directions of the magnetic forces on two long, parallel current-carrying wires.
- Be able to determine the direction of the current induced in a metal rod that is aligned east-west and is dropped in Earth's magnetic field.

V. Waves

A. Conceptual Understanding of Wave Characteristics and Phenomena

1. Types of waves and their characteristics
   a. Transverse and longitudinal
   b. Mechanical and electromagnetic
   c. Relationships between amplitude, wavelength, frequency, period, speed of propagation, and energy
   d. Superposition and phase
   e. Intensity
   f. Spherical and plane waves
   g. Standing waves
2. Wave phenomena
   a. Reflection, refraction (including Snell's law), and total internal reflection
   b. Diffraction, interference and Young's double-slit interference experiment
   c. Polarization
   d. Scattering, absorption, dispersion, and transmission
   e. Resonance and natural frequencies, harmonics
   f. Doppler effect (moving source or observer)

B. Electromagnetic Waves, Sound, and Geometric Optics

1. Electromagnetic waves and the electromagnetic spectrum
   a. Electromagnetic waves (electric and magnetic fields, speed of light, energy)
   b. Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, x-rays, gamma rays)
   c. The visible spectrum (red, orange, yellow, green, blue, violet)
   d. Applications of the Doppler effect involving electromagnetic waves

2. Sound
   a. Compression waves
   b. Speed of sound (sonic boom and sound barrier)
   c. Pitch (frequency) and loudness (intensity)
   d. Beats
   e. Resonance (open and closed pipes; strings)
   f. Applications of Doppler effect involving sound
3. Geometric optics
   a. Ray tracing
   b. Focal point, image distance, image size and magnification, real versus virtual image, image orientation
   c. Lenses (converging and diverging)
   d. Mirrors (plane, convex, concave)
   e. Simple instruments (magnifying glass, telescope, microscope, prisms)

Discussion questions: Waves

- Be able to explain why the sky appears blue.
- Be able to explain why colors are observed when sunlight falls on a soap bubble or an oil slick.
- Be able to calculate the fundamental frequency and harmonics of an organ pipe that is closed at one end.
- Be familiar with the procedures for ray tracing.
- Be able to locate and describe the image formed when an object is placed 50 centimeters in front of a thin converging lens of focal length 20 centimeters.

Science and Engineering Practices

The SEPs represent eight practices that scientists and engineers—and students and teachers—use to investigate the world and to design and build systems. Many test questions will integrate one or more of these practices.

1. Asking questions (for science) and defining problems (for engineering)
   - Ask questions that arise from careful observation of phenomena, models, or unexpected results, to clarify and/or seek additional information.
   - Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships.
   - Ask questions to determine relationships, including quantitative relationships, between independent and dependent variables.
   - Ask questions to clarify and refine a model, an explanation, or an engineering problem.
   - Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory.
   - Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design.
   - Define a design problem that can be solved through the development of an object, tool, process or system

and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.

2. Developing and using models
   - Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria.
   - Design a test of a model to ascertain its reliability.
   - Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
   - Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.
   - Develop a complex model that allows for manipulation and testing of a proposed process or system.
   - Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

3. Planning and carrying out investigations
   - Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled.
   - Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
   - Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts.
   - Select appropriate tools to collect, record, analyze, and evaluate data.
   - Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated.
   - Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.

4. Analyzing and interpreting data
   - Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

- Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.
- Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.
- Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations.
- Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.
- Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.

5. Using mathematics and computational thinking
   - Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.
   - Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.
   - Apply techniques of algebra and functions to represent and solve scientific and engineering problems.
   - Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world.
   - Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m^3, acre-feet, etc.).

6. Constructing explanations (for science) and designing solutions (for engineering)
   - Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.
   - Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
   - Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
   - Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.
   - Design, evaluate, and/or refine a solution to a complex real-world

problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

7. Engaging in argument from evidence
   - Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.
   - Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.
   - Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining what additional information is required to resolve contradictions.
   - Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.
   - Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge, and student-generated evidence.
   - Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and/or logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations).

8. Obtaining, evaluating, and communicating information
   - Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
   - Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.
   - Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.
   - Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible.
   - Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).

Tasks of Teaching Science

This list includes instructional tasks that teachers engage in that are essential for effective Physics teaching. Many test questions will measure content through application to one or more of these tasks.

Scientific Instructional Goals, Big Ideas, and Topics

1. Selecting or sequencing appropriate instructional goals or big ideas for a topic
2. Identifying the big idea or instructional goal of an instructional activity
3. Choosing which science ideas or instructional activities are most closely related to a particular instructional goal
4. Linking science ideas to one another and to particular activities, models, and representations within and across units

Scientific Investigations and Demonstrations

5. Selecting investigations or demonstrations, including virtual, that facilitate understanding of disciplinary core ideas, scientific practices, or crosscutting concepts
6. Evaluating investigation questions for quality (e.g., testable, empirical)
7. Determining the variables, techniques, or tools that are appropriate for use by students to address a specific investigation question
8. Critiquing scientific procedures, data, observations, or results for their quality, accuracy, or appropriateness
9. Supporting students in generating questions for investigation or identifying patterns in data and observations

Scientific Resources (texts, curriculum materials, journals, and other print and media-based resources)

10. Evaluating instructional materials and other resources for their ability to address scientific concepts; engage students with relevant phenomena; develop and use scientific ideas; promote students' thinking about phenomena, experiences, and knowledge; take account of students' ideas and background; and assess student progress
11. Choosing resources that support the selection of accurate, valid, and appropriate goals for science learning

Student Ideas (including common misconceptions, alternate conceptions, and partial conceptions)

12. Analyzing student ideas for common misconceptions regarding intended scientific learning
13. Selecting diagnostic items and eliciting student thinking about scientific ideas and practices to identify common student misconceptions and the basis for those misconceptions
14. Developing or selecting instructional moves, approaches, or representations that provide evidence about common student misconceptions and help students move toward a better understanding of the idea, concept, or practice

Scientific Language, Discourse, Vocabulary, and Definitions

15. Selecting scientific language that is precise, accurate, grade-appropriate, and illustrates key scientific concepts
16. Anticipating scientific language and vocabulary that may be difficult for students
17. Modeling the use of appropriate verbal and written scientific language in critiquing arguments or explanations, in describing observations, or in using evidence to support a claim, etc.
18. Supporting and critiquing students' participation in and use of verbal and written scientific discourse and argumentation

Scientific Explanations (includes claim, evidence, and reasoning)

19. Critiquing student-generated explanations or descriptions for their generalizability, accuracy, precision, or consistency with scientific evidence
20. Selecting explanations of natural phenomena that are accurate and accessible to students

Scientific Models and Representations (analogies, metaphors, simulations, illustrations, diagrams, data tables, performances, videos, animations, graphs, and examples)

21. Evaluating or selecting scientific models and representations that predict or explain scientific phenomena or address instructional goals
22. Engaging students in using, modifying, creating, and critiquing scientific models and representations that are matched to an instructional goal
23. Evaluating student models or representations for evidence of scientific understanding
24. Generating or selecting diagnostic questions to evaluate student understanding of specific models or representations
25. Evaluating student ideas about what makes for good scientific models and representations

Physics (5266) Sample Test Questions

The sample questions that follow represent a number of the types of questions and topics that appear on the test. They are not, however, representative of the entire scope of the test in either content or difficulty. Answers with explanations follow the questions.

Directions: Each of the questions or incomplete statements below is followed by suggested answers or completions. Select the one that is best in each case.

1. A teacher is preparing a classroom demonstration. Of the following, which **TWO** should the teacher use as examples of material with high electrical conductivity?

   (A) Copper
   (B) Distilled water
   (C) Hard rubber
   (D) Stainless steel

2. Based on Snell's law, which **THREE** of the following are true about a ray of visible light that travels obliquely from air into glass?

   (A) The wavelength of the light increases.
   (B) The speed of the light decreases.
   (C) The frequency of the light remains the same.
   (D) The light ray bends toward the normal.

3. Which of the following is true about the production of electricity by means of nuclear power?

   (A) It causes carbon dioxide to be emitted in large amounts into the atmosphere.
   (B) Radioactive waste is produced as a by-product and must be disposed of safely.
   (C) It is much less efficient than other methods of producing electricity.
   (D) It involves nuclear fusion as the primary energy source for producing electricity.

4. A teacher explains that in the photoelectric effect, light incident on the surface of a metal results in the emission of electrons from the surface. Which of the following student statements after the lesson indicates the best understanding about the photoelectric effect?

   (A) The incident light must be above a threshold frequency for electrons to be emitted.
   (B) The work function of the metal surface must be equal to zero for electrons to be emitted.
   (C) The number of electrons emitted is independent of the intensity of the incident light.
   (D) The energy of the emitted electrons increases with an increase in the wavelength of the incident light.

5. A large rock is dropped from rest from the edge of a cliff that is 200 m above the surface of the ocean. How long does it take for the rock to hit the water? (Note: Ignore air resistance and assume $g = 10 \text{ m/s}^2$).

   (A) $2\sqrt{5}$ s
   (B) 5 s
   (C) $2\sqrt{10}$ s
   (D) 20 s

6. Object 1 has kinetic energy K_1. Object 2 has 4 times the mass and 1/4 the speed of object 1. What is the kinetic energy K_2 of object 2?

   (A) $K_2 = \frac{1}{16}K_1$
   (B) $K_2 = \frac{1}{4}K_1$
   (C) $K_2 = K_1$
   (D) $K_2 = 4K_1$

7. The electrostatic force between two point charges, q_1 and q_2, is F_1. If the distance R between the two charges is decreased to $1/3\,R$, what is the force F_2 between the charges?

   (A) $F_2 = 9F_1$
   (B) $F_2 = 3F_1$
   (C) $F_2 = F_1$
   (D) $F_2 = \frac{1}{9}F_1$

8. What is the speed of a wave if the wave crests are 4 meters apart and the period of the wave is 2 seconds?

   (A) 0.5 m/s
   (B) 2 m/s
   (C) 4 m/s
   (D) 8 m/s

9. Which of the following scientists first proposed the concept of matter waves?

   (A) Bohr
   (B) Einstein
   (C) Planck
   (D) de Broglie

10. The Bohr model was successful at explaining which of the following?

    (A) Electromagnetic induction
    (B) Wave-particle duality
    (C) Expansion of the universe
    (D) Emission and absorption spectra of hydrogen

11. A person, starting at point A, walks 300 m directly north. The person then turns and walks 400 m directly east, stopping at point B. What is the displacement of the person between points A and B?

(A) 100 m
(B) 350 m
(C) 500 m
(D) 700 m

12. A block of mass m is sliding at constant speed v down a ramp inclined at an angle θ with respect to level ground. The magnitude of the frictional force acting on the block is equal to which of the following? (Note: g is the acceleration due to gravity.)

(A) 0
(B) mv
(C) mg
(D) $mg\sin\theta$

13. According to kinetic molecular theory, the average translational kinetic energy of the particles of an ideal gas is proportional to which of the following properties of the gas?

(A) Pressure
(B) Absolute temperature
(C) Volume
(D) Entropy

14. A projectile is launched upward at a $45°$ angle relative to level ground. In the absence of air resistance, which of the following statements is true about the projectile at all points along its path of motion?

(A) The net force acting on the projectile is equal to zero.
(B) The only force acting on the projectile is the force of gravity.
(C) The speed of the projectile is constant.
(D) The acceleration of the projectile is equal to zero.

15. A simple pendulum that has a period T on Earth's surface is transported to the surface of a planet where the force of gravity is twice as great as the force of gravity on Earth. What is the period of the pendulum on the planet? (Note: Assume air resistance is negligible on both planets.)

(A) $2T$
(B) T
(C) $\frac{T}{\sqrt{2}}$
(D) $\frac{T}{2}$

16. After a lesson about electromagnetic induction, students are asked to name a device that transforms mechanical energy into electrical energy. Which of the following student responses indicates a good understanding about electromagnetic induction?

(A) A transformer
(B) A generator
(C) A motor
(D) A solar cell

17. Of the following regions of the electromagnetic spectrum, which has waves with the highest frequencies?

(A) X-ray
(B) Radio
(C) Visible
(D) Ultraviolet

X	*Y*
2.0	0.50
3.0	0.33
4.0	0.25
5.0	0.20

18. In a lab experiment, students were asked to determine the relationship between two variables *X* and *Y*. Based on the experimental data in the preceding table, which of the following student conclusions about the relationship between the two variables is correct?

(A) *X* and *Y* have a direct linear relationship.
(B) *X* and *Y* have an inverse linear relationship.
(C) *X* and *Y* have a direct nonlinear relationship.
(D) *X* and *Y* have an inverse nonlinear relationship.

19. The transfer of thermal energy through a vacuum by means of electromagnetic wave propagation is known as

(A) radiation
(B) convection
(C) absorption
(D) conduction

20. A satellite of mass *m* is in a circular orbit of radius *R* around Earth. What is the orbital speed of the satellite? (Note: M_E is the mass of Earth and *G* is the universal constant.)

(A) 0

(B) $\sqrt{\frac{GM_E}{R}}$

(C) $\sqrt{\frac{GmM_E}{R^2}}$

(D) $\sqrt{GM_ER}$

21. In a lesson about Kepler's laws, a teacher explains that Earth takes 1 year to make a complete revolution around the Sun and that Jupiter has an orbital radius slightly greater than 5 times the orbital radius of Earth. The students are asked to predict how long it takes Jupiter to make a complete revolution around the Sun. Which of the following student responses is best?

(A) $\sqrt{5}$ years
(B) 5 years
(C) $5\sqrt{5}$ years
(D) 25 years

22. How much power is dissipated by a 4.0-ohm resister connected in series to a 12-volt battery?

(A) 3.0 watts
(B) 12 watts
(C) 36 watts
(D) 72 watts

23. A 2-ohm resistor and a 4-ohm resistor are connected in parallel to an ideal 12-volt battery to form a closed circuit. What is the current supplied by the battery?

(A) 2 amps
(B) 6 amps
(C) 9 amps
(D) 16 amps

24. Which of the following phenomena is an example of the Doppler effect?

(A) Diffraction of electrons
(B) Emission and absorption spectra of hydrogen
(C) Blackbody radiation
(D) Redshift of light from distant galaxies

25. Of the following devices, which would be the best choice for a teacher to use in a lesson about the photoelectric effect?
    (A) Camera
    (B) Telescope
    (C) LED lightbulb
    (D) Automatic door opener

26. The first law of thermodynamics is a relationship involving which of the following quantities?
    (A) Internal energy, heat, and work
    (B) Force, mass, and acceleration
    (C) Voltage, current, and resistance
    (D) Pressure, volume, and temperature

27. After a lesson about buoyancy, students are asked to indicate a property of an object that determines whether the object will float or sink in water. Which of the following student responses identifies a property of the object that determines its buoyancy?
    (A) Density
    (B) Inertia
    (C) Volume
    (D) Weight

28. After a lesson about angular momentum, which of the following student claims about the angular momentum of a rotating object is true?
    (A) The angular momentum is always conserved.
    (B) The angular momentum decreases as the speed of rotation of the object increases.
    (C) The angular momentum depends on the mass of the rotating object.
    (D) The angular momentum is equal to the kinetic energy of a rotating object.

29. A block of mass m, moving to the right with speed v along a frictionless surface, collides with and sticks to a second block of mass $2m$ that is initially at rest. With what speed and in what direction do the blocks move after the collision?

(A) $\frac{1}{3}v$ to the right

(B) $\frac{1}{3}v$ to the left

(C) $\frac{1}{2}v$ to the right

(D) $\frac{1}{2}v$ to the left

30. An electron moving with velocity **v** enters a region in which the magnetic field **B** is perpendicular to the velocity of the electron. The magnetic force on the electron in the region is

(A) equal to zero
(B) parallel to **v**
(C) parallel to **B**
(D) perpendicular to both **v** and **B**

31. According to which of the following laws does a changing magnetic flux through a closed circuit induce an electromotive force in that circuit?

(A) Gauss's law
(B) Coulomb's law
(C) Faraday's law
(D) Lorentz force law

32. An organ pipe of length *L*, open at both ends, will vibrate at a fundamental frequency equal to which of the following? (Note: v_s is the speed of sound in air.)

(A) $\frac{v_s}{4L}$

(B) $\frac{v_s}{2L}$

(C) $\frac{v_s}{L}$

(D) $\frac{2v_s}{L}$

Physics (5266) Answers

1. **Options (A) and (D) are correct.** Copper and stainless steel (an alloy of iron) are both good conductors of electricity.

Content	IV A
Science and Engineering	3
Task of Teaching	1

2. **Options (B), (C) and (D) are correct.** The index of refraction of a medium is defined as the ratio of the speed of light in a vacuum to the speed of light in that medium. Glass has a higher index of refraction than air, which means that the speed of the visible light is less in the glass. The frequency is not affected by the medium and remains the same. According to Snell's law, the light ray will bend toward the normal. Since the speed of the light is equal to the wavelength multiplied by the frequency, the wavelength does not increase but decreases.

Content	V A
Science and Engineering	2

3. **Option (B) is correct.** Radioactive waste is a by-product of a nuclear power plant and must be disposed of safely. Nuclear power plants use nuclear fission as the primary energy source.

Content	I B

4. **Option (A) is correct.** There is a minimum frequency of the incident light, known as the threshold frequency, below which electrons will not be emitted.

Content	II A
Science and Engineering	6

5. **Option (C) is correct.** From kinematics, the distance traveled *y* is found from $y = y_0 + v_0 t + \frac{1}{2}gt^2$. Since $v_0 = 0$ and assuming that the distance traveled *y* is 200 m and that the initial starting point y_0 is 0, then $y = 200 \text{ m} = \frac{1}{2}gt^2$. Solving for *t* gives

$t = \sqrt{\frac{2 \times 200 \text{ m}}{10 \text{ m/s}^2}} - \sqrt{40} \text{ s} - 2\sqrt{10} \text{ s}$.

Content	III A
Science and Engineering	5

6. **Option (B) is correct.** $K_2 = \frac{1}{2}m_2 \upsilon_2^2 = \frac{1}{2}4m_1 \times \left(\frac{1}{4}\upsilon_1\right)^2 = \frac{1}{8}m_1 \times \upsilon_1^2 = \frac{1}{4}K_1$

Content	III B
Science and Engineering	1
Task of Teaching	1

7. **Option (A) is correct.** According to Coulomb's law, the electrostatic force between the two point charges separated by a distance *R* is $F_1 = \frac{1}{4\pi\varepsilon_0} \times \frac{q_1 q_2}{R^2}$. If the distance is decreased to $1/3\, R$, the force between the charges is $F_2 = \frac{1}{4\pi\varepsilon_0} \times \frac{q_1 q_2}{(R/3)^2} = 9F_1$.

Content	IV A
Science and Engineering	1

8. **Option (B) is correct.** The speed is found from $\upsilon = \lambda \times f$, where λ is the wavelength or distance between wave crests and *f* is the frequency of the wave. The frequency is found from the period from $f = \frac{1}{\text{period}} = \frac{1}{2 \text{ s}} = 0.5 \text{ s}^{-1}$. Thus the speed of the wave is

$\upsilon = \lambda \times f = 4 \text{ m} \times 0.5 \text{ s}^{-1} = 2 \text{ m/s}$

Content	V A
Science and Engineering	5

9. **Option (D) is correct.** Louis de Broglie first proposed that all matter has wave properties.

Content	I A

10. **Option (D) is correct.** The Bohr model of the atom, which introduced the concept of discrete atomic energy levels, was able to explain the emission and absorption spectra of hydrogen.

Content	II A
Science and Engineering	2

11. **Option (C) is correct.** The person's path from point A to point B consists of two sides of a 3-4-5 right triangle of lengths 300 m and 400 m. The displacement of the person is equal to the length of the hypotenuse of the triangle, which is 500 m, since $(300 \text{ m})^2 + (400 \text{ m})^2 = (500 \text{ m})^2$ for the triangle.

Content	III A
Science and Engineering	5

12. **Option (D) is correct.** The block is moving at constant speed down the ramp, which means that the net force on the block is equal to zero. Thus, the frictional force must be equal in magnitude to the component of the weight of the block that is directed along the ramp, or $mg\sin\theta$.

Content	III B
Science and Engineering	5

13. **Option (B) is correct.** For an ideal gas, the average translational kinetic energy of the gas particles is proportional to absolute temperature, since it is equal to $\frac{3}{2}kT$, where k is Boltzmann's constant and T is the absolute temperature.

Content	II B
Science and Engineering	6

14. **Option (B) is correct.** In the absence of air resistance, gravity is the only force acting on the projectile at all points along its path of motion.

Content	III A
Science and Engineering	7

15. **Option (C) is correct.** The correct answer is (C). The period T of a simple pendulum is given by $T = 2\pi\sqrt{\frac{L}{g}}$, in which L is the length of the pendulum and g is the acceleration due to gravity. On the planet, the period of the pendulum is T_{planet} and acceleration due to gravity is g_{planet}. Thus, on the planet the period of the pendulum is found from $T_{\text{planet}} = 2\pi\sqrt{\frac{L}{g_{\text{planet}}}} = 2\pi\sqrt{\frac{L}{2g}} = \frac{T}{\sqrt{2}}$.

Content	III B
Science and Engineering	1

16. **Option (B) is correct.** A generator converts mechanical energy into electrical energy by means of electromagnetic induction.

Content	IV B
Science and Engineering	4

17. **Option (A) is correct.** Of the listed regions of the electromagnetic spectrum, waves in the x-ray region have the highest frequencies.

Content	V B

18. **Option (D) is correct.** The relationship between X and Y is expressed in the equation $Y = k\frac{1}{x}$, where k is a constant. A plot of the data will yield a curve that indicates a nonlinear relationship.

Content	I A
Science and Engineering	4
Task of Teaching	2

19. **Option (A) is correct.** Radiation is the transfer of thermal energy through a vacuum by means of electromagnetic waves.

Content	II B

20. **Option (B) is correct.** For circular motion in a gravitational field, the centripetal force on the satellite is equal to the gravitational force on the satellite, which is found from $F = \frac{mv^2}{R} = \frac{GmM_E}{R^2}$. Solving for the orbital speed gives $v = \sqrt{\frac{GM_E}{R}}$.

Content	III A
Science and Engineering	5

21. **Option (C) is correct.** According to Kepler's third law, the square of the orbital period *T* of a planet is proportional to the cube of its semimajor axis *R*. The constant of proportionality is the same for all of the planets. Thus,

$$T_{\text{Jupiter}} = T_{\text{Earth}} \times \left(\frac{R_{\text{Jupiter}}}{R_{\text{Earth}}}\right)^{\frac{3}{2}} \cong 1\,\text{year} \times \left(\frac{5}{1}\right)^{\frac{3}{2}} = 5\sqrt{5}\ \text{years}.$$

Content	III A
Science and Engineering	5
Task of Teaching	6

22. **Option (C) is correct.** The power *P* dissipated is found from $P = iR^2$, where $i = \frac{V}{R}$. Thus,

$$P = \left(\frac{V}{R}\right)^2 R = \frac{V^2}{R} = \frac{12\text{ V} \times 12\text{ V}}{4.0\text{ ohms}} = 36\text{ watts}.$$

Content	IV A
Science and Engineering	1

23. **Option (C) is correct.** According to Ohm's law, the current supplied by the battery is given by $I = \frac{12\text{ V}}{R_{eq}}$, where R_{eq} is the equivalent resistance. The resistors are connected in parallel, and the battery is ideal with zero internal resistance. This means that

$$R_{eq} = \frac{2\text{ ohms} \times 4\text{ ohms}}{2\text{ ohms} + 4\text{ ohms}} = \frac{4}{3}\text{ ohms}.\ \text{Thus,}\ I = \frac{12\text{ V}}{4/3\text{ ohms}} = 9\text{ amps}.$$

Content	IV A
Science and Engineering	5

24. **Option (D) is correct.** The Doppler effect is used to explain the shift toward longer wavelengths of the spectral lines from distant, receding galaxies.

Content	V B
Science and Engineering	5

25. **Option (D) is correct.** When a person passes through a beam of infrared light, the beam of light is interrupted from reaching a sensor that is based on the photoelectric effect. This results in a process that opens the door.

Content	I B
Science and Engineering	1

26. **Option (A) is correct.** The first law of thermodynamics is a statement of the law of conservation of energy and relates the following quantities: internal energy, heat, and work.

Content	II B

27. **Option (A) is correct.** From Archimedes' principle, it is the density of an object that determines whether the object will float or sink in water. Objects with a density less than the density of water will float.

Content	III A
Science and Engineering	5

28. **Option (C) is correct.** The equation for the angular momentum L of the rotating object is $L = m\upsilon r$. Hence the angular momentum depends on the mass m. As the speed of rotation v increases, the angular momentum increases rather than decreases. The angular momentum is not equal to the kinetic energy. Angular momentum is not conserved unless the net external torque acting on the object is zero.

Content	III B
Science and Engineering	7
Task of Teaching	7

29. **Option (A) is correct.** Linear momentum is conserved because there are no external forces acting on the system. The magnitude of the momentum before the collision is mv and is directed to the right. Thus, the magnitude of the momentum after the collision must also be mv and be directed to the right. The combined mass of the two blocks is $3m$, which means their speed is equal to $\frac{1}{3}\upsilon$.

Content	III B
Science and Engineering	7

30. **Option (D) is correct.** According to the Lorentz force law, the magnetic force **F** on the electron is equal to the vector product $-e\mathbf{v} \times \mathbf{B}$, which means that **F** is perpendicular to both **v** and **B**.

Content	IV B

31. **Option (C) is correct.** Faraday's law of electromagnetic induction states that the induced electromotive force in a closed circuit is equal to the rate of change of the magnetic flux through it.

Content	IV B

32. **Option (B) is correct.** For an open organ pipe vibrating at the fundamental frequency f, both ends of the pipe must be antinodes. This means that the length L of the pipe must be equal to half the wavelength λ of the sound, or $L = \frac{\lambda}{2}$.

Thus, $f = \frac{\upsilon_s}{\lambda} = \frac{\upsilon_s}{2L}$.

Content	V B
Science and Engineering	5

Understanding Question Types

The *Praxis*® assessments include a variety of question types: constructed response (for which you write a response of your own); selected response, for which you select one or more answers from a list of choices or make another kind of selection (e.g., by selecting a sentence in a text or by selecting part of a graphic); and numeric entry, for which you enter a numeric value in an answer field. You may be familiar with these question formats from taking other standardized tests. If not, familiarize yourself with them so you don't spend time during the test figuring out how to answer them.

Understanding Selected-Response and Numeric-Entry Questions

For most questions, you respond by selecting an oval to select a single answer from a list of answer choices.

However, interactive question types may also ask you to respond by:

- Selecting more than one choice from a list of choices.
- Typing in a numeric-entry box. When the answer is a number, you may be asked to enter a numerical answer. Some questions may have more than one entry box to enter a response. Numeric-entry questions typically appear on mathematics-related tests.
- Selecting parts of a graphic. In some questions, you will select your answers by selecting a location (or locations) on a graphic such as a map or chart, as opposed to choosing your answer from a list.
- Selecting sentences. In questions with reading passages, you may be asked to choose your answers by selecting a sentence (or sentences) within the reading passage.
- Dragging and dropping answer choices into targets on the screen. You may be asked to select answers from a list of choices and to drag your answers to the appropriate location in a table, paragraph of text or graphic.
- Selecting answer choices from a drop-down menu. You may be asked to choose answers by selecting choices from a drop-down menu (e.g., to complete a sentence).

Remember that with every question you will get clear instructions.

Understanding Constructed-Response Questions

Some tests include constructed-response questions, which require you to demonstrate your knowledge in a subject area by writing your own response to topics. Essays and short-answer questions are types of constructed-response questions.

For example, an essay question might present you with a topic and ask you to discuss the extent to which you agree or disagree with the opinion stated. You must support your position with specific reasons and examples from your own experience, observations, or reading.

Review a few sample essay topics:

- *Brown v. Board of Education of Topeka*

  "We come then to the question presented: Does segregation of children in public schools solely on the basis of race, even though the physical facilities and other 'tangible' factors may be equal, deprive the children of the minority group of equal educational opportunities? We believe that it does."

  A. What legal doctrine or principle, established in *Plessy v. Ferguson* (1896), did the Supreme Court reverse when it issued the 1954 ruling quoted above?

  B. What was the rationale given by the justices for their 1954 ruling?

- *In his self-analysis, Mr. Payton says that the better-performing students say small-group work is boring and that they learn more working alone or only with students like themselves. Assume that Mr. Payton wants to continue using cooperative learning groups because he believes they have value for all students.*

  - Describe **TWO** strategies he could use to address the concerns of the students who have complained.
  - Explain how each strategy suggested could provide an opportunity to improve the functioning of cooperative learning groups. Base your response on principles of effective instructional strategies.

- *"Minimum-wage jobs are a ticket to nowhere. They are boring and repetitive and teach employees little or nothing of value. Minimum-wage employers take advantage of people because they need a job."*

  - Discuss the extent to which you agree or disagree with this opinion. Support your views with specific reasons and examples from your own experience, observations, or reading.

Keep these things in mind when you respond to a constructed-response question:

1. **Answer the question accurately.** Analyze what each part of the question is asking you to do. If the question asks you to describe or discuss, you should provide more than just a list.
2. **Answer the question completely.** If a question asks you to do three distinct things in your response, you should cover all three things for the best score. Otherwise, no matter how well you write, you will not be awarded full credit.
3. **Answer the question that is asked.** Do not change the question or challenge the basis of the question. You will receive no credit or a low score if you answer another question or if you state, for example, that there is no possible answer.
4. **Give a thorough and detailed response.** You must demonstrate that you have a thorough understanding of the subject matter. However, your response should be straightforward and not filled with unnecessary information.
5. **Take notes on scratch paper** so that you don't miss any details. Then you'll be sure to have all the information you need to answer the question.
6. **Reread your response.** Check that you have written what you thought you wrote. Be sure not to leave sentences unfinished or omit clarifying information.

General Assistance For The Test

Praxis® Interactive Practice Test

This full-length *Praxis*® practice test lets you practice answering one set of authentic test questions in an environment that simulates the computer-delivered test.

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- Correct answers with detailed explanations
- Practice test results for each content category

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Doing Your Best

Strategy and Success Tips

Effective *Praxis* test preparation doesn't just happen. You'll want to set clear goals and deadlines for yourself along the way. Learn from the experts. Get practical tips to help you navigate your Praxis test and make the best use of your time. Learn more at Strategy and Tips for Taking a *Praxis* Test.

Develop Your Study Plan

Planning your study time is important to help ensure that you review all content areas covered on the test. View a sample plan and learn how to create your own. Learn more at Develop a Study Plan.

Helpful Links

Ready to Register – How to register and the information you need to know to do so.

Disability Accommodations – Testing accommodations are available for test takers who meet ETS requirements.

PLNE Accommodations (ESL) – If English is not your primary language, you may be eligible for extended testing time.

What To Expect on Test Day – Knowing what to expect on test day can make you feel more at ease.

Getting Your Scores – Find out where and when you will receive your test scores.

Getting Your Scores – Find out where and when you will receive your test scores.

State Requirements – Learn which tests your state requires you to take.
Other Praxis Tests – Learn about other *Praxis* tests and how to prepare for them.

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