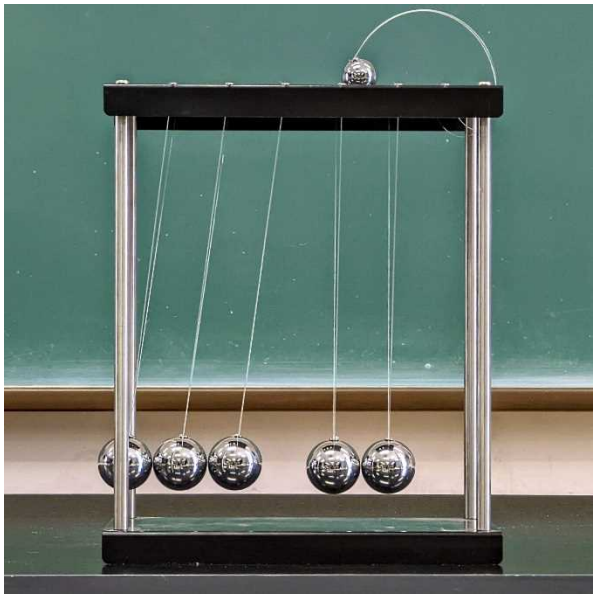
物理　英語定義集

Japanese-English Physics Vocabulary with English Definitions



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岡山県立倉敷天城高等学校

Okayama Prefectural Kurashiki Amaki Senior High School

※ＰａＲｅＳＫ（パレスク）について

本校が定義し，提唱している中等教育における科学英語の取組です。「**Pa**ragraph **Re**ading for **S**cience with **K**ey Words」の略語で，「タイトル，図や写真などのキャプションに記載されている専門用語などをキーワードとし，パラグラフごとの大意をつかみながら読み解いていく読解法」と定義しています。実践事例や効果などの詳細は，国立研究開発法人科学技術振興機構が運営している J-Stage に掲載されている次の学術論文をご覧ください：仲達・白神「中等教育における科学英語の実践的研究 －倉敷天城中学校・高等学校での実践を通して－」(2018)。

巻頭言

岡山県立倉敷天城高等学校
校　長　　藤　井　省　吾

このたび，既刊の「物理基礎 英語定義集」の続編となります「物理 英語定義集（ Japanese-English Physics Vocabulary with English Definitions)」を刊行するに当たり，一言ご挨拶申し上げます。

本校は，平成１７年度に文部科学省からＳＳＨ（スーパーサイエンスハイスクール）の指定を受けて以来，理数教育に関するカリキュラム開発の一環として国際性の育成にも力を注いでまいりました。平成２４年度には「英語が使える科学技術系人材の育成のための戦略構想」を策定し，これまで継続的に実践を行っており，成果を上げています。この構想の趣旨は，「間違えてもよいからどんどん英語を使っていこう」と呼び掛け，英語を使う抵抗感を小さくする試みで，本校が命名した科学英語読解メソッドＰａＲｅＳＫ（パレスク：Paragraph Reading for Science with Key Words）の理念の下，併設中学校及び高等学校の理科や課題研究の授業などでの実践を積み重ねています。その研究成果物として，平成２６年７月には，本校の元講師で現在京都にお住まいの Ramon Fargas 先生の多大なご尽力により，「物理基礎 英語定義集」を刊行いたしました。このブックレットは，国内のＳＳＨ校やＳＧＨ（スーパーグローバルハイスクール）校はもとより，国内の大学の留学生や外国人教員，一般の高等学校における帰国生徒のための教材として，また，外国の大学で，日本の大学に留学する準備のための講座などでもご活用いただいていると聞いております。また，ＡＯ入試や推薦入試の準備のために活用し，見事合格を勝ち取ったとうれしい報告をしてくれた高校生もいると聞いております。このように，国内外で様々な目的で活用され，好評をいただいている「物理基礎 英語定義集」の続編を，７年間にわたる関係者の地道な努力により，ＰａＲｅＳＫ１０周年に当たります今年度，ようやく世に出すことができ，感慨ひとしおであります。

本書を手にした高校生の皆さんが，日々の物理の学習や課題研究などで活用され，将来科学技術の世界で国際的に活躍されることを願ってやみません。

最後になりましたが，日ごろから本校のＳＳＨ研究開発事業をご支援・ご指導いただいております，文部科学省初等中等教育局，同省科学技術・学術政策局，国立研究開発法人科学技術振興機構，岡山県教育委員会，本校ＳＳＨ運営指導委員の皆様に深く感謝申し上げます。また，本校ＳＳＨ運営指導委員で指定第Ⅰ期から本校科学英語の充実に多大なご尽力をいただいております岡山大学の喜多雅一 名誉教授をはじめ，これまで本校の外国人教員（非常勤講師）としてお勤めいただきました同大学大学院への留学生・教員研修留学生の皆様に，紙面をお借りして厚く御礼申し上げます。

【作成者より】

◯ルシアン グレニー（Lucian Glenny：岡山県立倉敷天城高等学校　ＡＬＴ）

There's a quote often attributed to Einstein that goes something like "Everything should be made as simple as possible, but no simpler". It's a great quote, but like so many quotations that have the man's name underneath, he never actually said it. Einstein's original quote was, ironically, much longer and more complicated. But the point was the same: as long as we account for all the necessary information, simple explanations are the best. I think this is excellent advice not only for a physicist, but for a language learner too. If we make things simple, communication in a second language becomes easier, faster, and more fun.

To the reader:

Writing and reviewing this book was an exercise in clear, simple communication. We worked hard to explain the principles and vocabulary of physics using language that you can understand (with a bit of effort and study), while keeping all of the scientific content intact. I hope this book will make it easier for you to access materials written in English, and give you valuable experience in using English in a scientific context. Good luck and have fun!

To my colleagues:

Contributing to this project was a real privilege; thanks for involving me and for giving me the chance to do some science again. Working on this book was a pleasure. I hope that it will inspire more students to make the most of the language skills they've developed, and continue to study both physics and English with confidence and creativity in the future.

◯仲達修一（Shuichi Nakadachi：岡山県立倉敷天城高等学校　教諭）

「仲達：Let's have a definition meeting around 10am.」「Lucian：Sounds good!」という会話で毎朝始まり，ようやく本書の完成にこぎ着けました。平成２７年９月に Ramon 先生が岡山を去った後，先生が執筆された原稿をＡＬＴの Lucian（英国の大学で物理学を専攻）が引き継ぎ，年２回 Ramon 先生をお招きして，ゆっくりとしたペースで編集会議を持っていました。ところが，令和２年にはコロナ禍による休校という思いがけないことが起こり，教材作成の時間を多く確保することができました。この間ほぼ毎日２時間程度のミーティングを持ち，ようやく本書の完成にこぎ着けることができました。

「Sounds good!」を直訳すると，「いい響きだね。」となるでしょうか。英語は音声言語と言われているように，今回は「音」「響き」にこだわって作成しました。候補となる同じ意味を持つ複数の単語がある場合，文章全体を３人のメンバーで音読してみて，「よい響き」がする方を採択しました。そして音読を重ね，全体の「響き」がよりよくなり，美しいフレーズとなるよう語順や接続詞などを調整していきました。少し英国風に仕上がっているかと思います。内容的には，私たち高校の物理の教員が授業で説明する程度のもので，高校生が辞書なしで意味を理解できるよう，日本語のルビを付しています。

私の世代が大学生のころ，教官からよく「明治期の『お雇い外国人』は二流や三流などではなく，一流の学者を呼んできていて，一軒の家が建つほどの高給で雇っていた。我々はその土台の上に乗っかっているのだ。」という話をよく聞かされたものです。今日の日本の科学技術の礎を築いてくださった当時の英国人をはじめとする外国の学者や日本人学生のたゆまぬ努力に思いを馳せながらミーティングを重ねてきました。このミーティングは江戸末期の「蕃書調所」の逆バージョンとも言えるかもしれません。

多くの日本の高校生が物理・英語の学習や課題研究の英語での発表などで活用してくれることを願っています。そして将来，科学技術の世界で世界を牽引してくれることを期待しています。

なお，令和４年度には Lucian が本書の文章を読み上げた音声データの作成に着手しています。完成し次第アップする予定です。ご期待ください。

それでは英国の響きと香り，そして味覚（本文中に *pudding* が登場します）をお楽しみください。

◯白神 陽一朗（Yoichiro Shirakami：岡山県立倉敷天城高等学校　実習助手）

本校発刊の，英語で書かれた物理関連書籍も３冊目になりました。自身の，アメリカで過ごした学生時代を思い返すと，このような本があればもう少し楽に勉強できたかな，と益体もない回想をしてしまいます。「もしこの本を手に取る皆さんの中で，国外へ留学するつもりがある，または日本へ留学に来ている方がいれば，本書は強力な補助教材となる・・・といいな」と思って作成しました。是非役立ててもらえれば嬉しいです。

本書を作成するに当たって，過去２冊と同じく日本人学生が辞書なしでも理解できるよう，おおよそ高校２年生以上で習う単語にはルビを付しています。英語を読んで，英語のまま理解できるのが理想ですが，最初はそう上手くはいかないと思います。そのため，訳を必要とする際にはより自然な形に翻訳しやすいように語を選んだつもりです。複数の単語で一つの意味（日本語の一つの単語）となるものには，それらの単語全体にまたがる形でルビが振られています。文字も小さく少々読みづらい部分があるかもしれませんが，読者の皆さんの助けになれば幸いです。

目次

Japanese-English Physics Vocabulary

with English Definitions（物理 英語定義集）

Force Acting on Rigid Bodies

1. 剛体(ごうたい) = *Rigid body* = a model of an object with a constant (一定の) shape and size (e.g., a turntable). The distance between two points on a *rigid body* is constant.

2. トルク(とるく) = *Torque* (τ) = the ability of a force to rotate (回転) an object. A *torque* causes rotational (回転の) acceleration.
[SI unit: **N** · **m**]

$$\tau = F \cdot d \cdot \sin\theta$$

3. (回転の)中心((かいてんの)ちゅうしん) = *Pivot point* = a central point where an object balances (つりあっている) or turns (回転している).

4. 偶力(ぐうりょく) = *Couple* = *Couple of forces* = two parallel (平行な) forces that are equal in magnitude (大きさ). They act on a rigid (剛体) body in opposite directions.

5. 偶力のモーメント(ぐうりょくのもーめんと) = *Moment of a couple* (*M*) = the force of a *couple* multiplied (掛け算される) by the distance between the two opposite forces.
[SI unit: **N** · **m**]

$$M = F \cdot d$$

6. 質量中心(質量中心)/重心(じゅうしん) = *Center of mass* = the average center point of the mass (質量) of an object. When calculating (計算する) translational (並進運動) motion, we can consider all the mass (質量) to be centered at this point.

7. 重心(じゅうしん) = *Center of gravity* = the average center point of an object's weight. In a uniform (一様な) gravitational (重力場) field, the *center of gravity* is the same as the *center of mass*.

Conservation of Momentum

8. 運動量(うんどうりょう) = *Momentum* (*p*) = the mass (質量) of an object multiplied (掛け算される) by its velocity (速度).
[SI unit: **kg** · **m** / **s**]

$$p = m \cdot v$$

9. 力積(りきせき) = *Impulse* = the total force acting (作用している) on an object multiplied (掛け算される) by the length of time the force acts.
[SI unit: **N** · **s**]

$$\text{Impulse } = F \cdot t$$

10. 平均の力(へいきんのちから) = *Average force* = the force acting (作用している) on an object as it changes velocity (速度) in a collision (衝突) over a specified (特定の) time interval (間隔). The *average force* is equal to the change in the object's momentum (運動量) divided (割り算される) by the time taken by the collision (衝突).
[SI unit: **N**]

$$F_{\text{average}} = \frac{\Delta(m \cdot v)}{t}$$

11. 撃力(げきりょく) = *Impulsive force* = the force that two objects exert (及ぼす) on each other when they collide (衝突する). An *impulsive force* acts for a short time (e.g., a bat hitting a baseball).
[SI unit: **N**]

12. 系(けい) = *System (of bodies)* = two or more bodies that interact (互いに作用しあう（相互作用する）) with each other.

13. 内力(ないりょく) = *Internal force* = the force exerted (及ぼされる) on any part of a system (系) by another object in the same system (e.g., a collision (衝突) between two billiard (ビリヤード) balls).
[SI unit: **N**]

14. 外力(がいりょく) = *External force* = the force exerted (及ぼされる) on any part of a system (系) by an object outside the system (e.g., a billiards player hitting a ball).
[SI unit: **N**]

15. 運動量保存の法則(うんどうりょうほぞんのほうそく) = *Law of conservation of momentum*:

> If there is no external (外) force (力), the total momentum (運動量) in the system (系) before an interaction is equal to the total momentum in the system after the interaction (相互作用).

16. 反発係数(はんぱつけいすう) = *Coefficient of restitution* = the ratio (比) of the velocity (速度) of an object before and after a collision (衝突). The *coefficient of restitution* is equal to 1 for an *elastic collision* (弾性衝突) and 0 for an *inelastic collision* (非弾性衝突).
[Unitless]

17. 弾性衝突(だんせいしょうとつ) = *Elastic collision* = a collision that conserves the total kinetic energy of the bodies. No kinetic energy changes into other forms, such as heat (e.g., a collision between two billiard balls).

18. 非弾性衝突(ひだんせいしょうとつ) = *Inelastic collision* = a collision that does not conserve the total kinetic energy of the bodies. Kinetic energy changes into other forms, such as heat or sound (e.g., a collision between cars).

19. 完全非弾性衝突(かんぜんひだんせいしょうとつ) = *Completely inelastic collision* = a collision that does not conserve the total kinetic energy of the bodies, and causes the colliding bodies to stick together. All the kinetic energy is changed into other forms, such as heat (e.g., a bullet shot into a thick block of wood). The *coefficient of restitution*(16) is zero.

Circular, Simple Harmonic, and Gravitational Motion

20. 等速円運動(とうそくえんうんどう) = *Uniform circular motion* = the motion of an object moving in a circular path at a constant speed.

21. 角速度(かくそくど) = *Angular velocity* (ω) = the rate of an object's rotation (around an axis).
[SI unit: **rad** / **s**]

22. 周期(しゅうき) = *Period* (T) = the time taken for an object in circular motion to make one cycle (full rotation).
[SI unit: **s**]

$$T = \frac{2\pi}{\omega}$$

23: 回転数(かいてんすう) = *Rotational frequency* (f) = the number of cycles (full rotations) per second.
[SI unit: **Hz** = **1** / **s**]

24. 向心力(こうしんりょく) = *Centripetal force* = the force that keeps a body rotating. This force always points toward the center of the circle (e.g., the gravitational force that causes the moon to orbit the earth).
[SI unit: **N**]

25. 慣性(かんせい) = *Inertia* = the tendency of an object to remain at rest or in uniform motion unless an external force acts on it.

26. 慣性系(かんせいけい) = *Inertial frame of reference* = a frame of reference where an object moves only in a straight line with constant speed. The object has no *external force* acting on it. Newton's 1st, 2nd and 3rd laws of motion apply.

27. 慣性力(かんせいりょく) = *Inertial force* = a fictitious force that seems to act on an object because of *inertia* or acceleration of the frame of reference (e.g., the coriolis force).

28. 遠心力(えんしんりょく) = *Centrifugal force* = a fictitious force that acts on a body in circular motion. A *Centrifugal force* points always away from the center of the circle.

29. 各周波数(かくしゅうはすう) = *Angular frequency* (ω) = the rate of change of angle (in radians) when an object rotates.
[SI unit: **rad** / **s**]

$$\omega = \frac{\theta}{t}$$

30. 単振動(たんしんどう) = *Simple harmonic motion* = the motion of a moving object due to a *restoring force*(31). A projection of *uniform circular motion*(20) along the diameter of the circle can be treated (considered) as *simple harmonic motion*. Another example is a moving object on a spring.

$$x = A\sin(\omega \cdot t + \varphi)$$

31. 復元力(ふくげんりょく) = *Restoring force* = the force that pushes an object in *simple harmonic motion*(30) back toward the middle point ('equilibrium position'). The *restoring force* is in the opposite direction to the object's displacement from the equilibrium position.
[SI unit: **N**]

32. ばね振り子(ばねふりこ) = *Spring pendulum* = a system that contains a mass attached to a spring. A *spring pendulum* can act as a spring or a *simple pendulum*.

33. 単振り子(たんふりこ) = *Simple pendulum* = a model with a small mass attached to a string or wire. The string has no mass and does not stretch. A *simple pendulum* oscillates back and forth through a small angle.

$$T = 2\pi\sqrt{\frac{L}{g}}$$

34. 振り子の等時性(ふりこのとうじせい) = *Isochronism* of a pendulum = a property of a *simple pendulum*. This means the pendulum has a constant(一定の) frequency(周期) that does not change, even if the mass(質量) or the amplitude(振幅) of the oscillation(振動) changes.

35. ケプラーの惑星運動の法則(けぷらーのわくせいうんどうのほうそく) = *Kepler's laws of planetary motion*:

I. Every planet moves in an elliptical(楕円の) orbit(軌道) around the sun, and the sun is at one of the focal(焦) points(点) of the elliptical orbit.

II. A line from the sun to any planet sweeps(通過する) over equal areas in equal time periods(期間).

III. The ratio(比) of the squares(2乗) of the *periods*(周期) of any two planets is equal to the ratio of the cubes(3乗) of their average distances from the sun.

$$\frac{T^2}{r^3} = \text{constant}$$

$$T^2 = a \cdot r^3$$

36. 惑星(わくせい) = *Planet* = a body(物体) in space (celestial body(天体)) that orbits(周回する) a sun. It must be sphere-shaped due to gravity. *Planets* have no debris(がれき) in their orbit(軌道), because they have collected debris and cleared the orbital area.

37. 天動説(てんどうせつ) = *Geocentric theory* = an ancient idea developed by the Greek-Egyptian astronomer Ptolemy. The idea described the sun, moon and planets as revolving(周回する) around the earth.

38. 地動説(ちどうせつ) = *Heliocentric theory* = a theory by the 16th-century Polish astronomer Nicolaus Copernicus. The *heliocentric theory* described the sun as the center of the universe(宇宙), with the planets revolving around it. Although *heliocentric theory* is more correct than *geocentric theory*, scientists now understand that all motion is relative(相対的) to other objects. Because of this, the universe does not have an absolute center(絶対的な中心).

39. 万有引力定数(ばんゆういんりょくていすう) = *Universal gravitational constant* (*G*) = a constant(定数) that relates gravitational force to mass(質量) and distance. The *gravitational constant* is part of Newton's law of universal gravitation.

$$F = \frac{G \cdot m_1 \cdot m_2}{r^2}$$

$$G = 6.673 \times 10^{-11}\ \mathbf{N} \cdot \frac{\mathbf{m^2}}{\mathbf{kg^2}}$$

40. 万有引力によるポテンシャルエネルギー(ばんゆういんりょくによるぽてんしゃるえねるぎー) = *Universal gravitational potential energy* = the potential energy stored in the gravitational field between two bodies. This is equal to the (negative) work done to move an object against the gravitational field.
[SI unit: **J**]

Properties of Gases and Motion of Molecules

41. 大気圧(たいきあつ) = *Atmospheric pressure* = a force exerted by air (or another gas) on the surface of every object. At sea level, *atmospheric pressure* is about 1 **atm**.
[SI unit: **Pa** = **N** / **m**^{2}]

$$1\ \mathbf{atm} = 1.013 \times 10^5 \frac{\mathbf{N}}{\mathbf{m^2}}$$

42. ボイルの法則(ぼいるのほうそく) = *Boyle's law*:

For a fixed amount of gas at a constant temperature, volume increases as pressure decreases. Pressure is inversely proportional to volume.

$$p_1 \cdot V_1 = p_2 \cdot V_2$$

43. シャルルの法則(しゃるるのほうそく) = *Charles' law*:

For a fixed amount of gas at a constant pressure, volume increases as temperature increases. Temperature is directly proportional to volume.

$$\frac{V_2}{V_1} = \frac{T_2}{T_1}$$

44. ボイル-シャルルの法則(ぼいる-しゃるるのほうそく) = *Boyle-Charles' law*:

The ratio between the temperature of a system (*T*) and the product of pressure (*p*) and volume (*V*) is constant.

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$

45. 物質量(ぶっしつりょう) = *Amount* of substance = the number of particles (atoms, molecules, or ions) in a substance measured in moles.
[SI unit: **mol**]

46. アボガドロ定数(あぼがどろていすう) = *Avogadro constant* (N_A) = *Avogadro number* = the number of particles in a mole of a substance.
[Unitless]

$$N_A = 6.022 \times 10^{23}$$

47. 標準温度と標準気圧(ひょうじゅんおんどとひょうじゅんきあつ) = *Standard temperature and pressure* (*STP*) = the temperature and pressure of matter in its pure state.

$$T = 273\ \mathbf{K}$$

$$p = 1\ \mathbf{atm} = 1.013 \times 10^5\ \frac{\mathbf{N}}{\mathbf{m^2}}$$

48. 理想気体(りそうきたい) = *Ideal gas* = an imaginary type of gas. An *ideal gas* has particles that do not interact with each other, and have a negligible volume. The ideal gas law describes an *ideal gas*, except at a high pressure or low temperature.

49. ボルツマン定数(ぼるつまんていすう) = *Boltzmann's constant* (k_B) = the constant of proportionality in the ideal gas law. It relates the energy of one molecule of an ideal gas to the temperature.

$$k_B = 1.38 \times 10^{-23}\ \frac{\mathbf{J}}{\mathbf{K}}$$

50. 気体定数(きたいていすう) = G*as constant* (*R*) = the constant of proportionality in the ideal gas law. It relates the energy of one mole of an ideal gas to the temperature.

$$R = N_A \cdot k_B = 8.314\ \frac{\mathbf{J}}{\mathbf{mol \cdot K}}$$

51. 理想気体の状態方程式(りそうきたいのじょうたいほうていしき) = *Ideal gas law* = a law that describes the relationship between pressure, volume, temperature, and the number of moles of an ideal gas.

$$p \cdot V = n \cdot R \cdot T = N \cdot k_B \cdot T$$

$$E = \frac{3}{2} k_B \cdot T$$

52. 二乗平均速度(にじょうへいきんそくど) = *Root mean square velocity* = *rms velocity* = the typical velocity of one particle in an ideal gas.

[SI unit: **m** / **s**]

$$v_{rms} = \sqrt{\frac{3R \cdot T}{M}}$$

53. 内部エネルギー(ないぶえねるぎー) = *Internal energy* (*U*) = the total kinetic (運動の) and potential (ポテンシャル) energy of the particles (粒子) in a substance (物質), object (物体), or system (系). *Internal energy* comes from the random motion of particles and the distances between them.
[SI unit: **J]**

$$U = \frac{3}{2} n \cdot R \cdot T$$

54. 単原子分子(たんげんしぶんし) = *Monoatomic molecule* = *monatomic molecule* = a molecule (分子) that is made up of only one atom (原子). The noble gases (希ガス / 貴ガス) (helium, neon, argon, krypton, xenon, and radon) are all *monoatomic molecules*.

55. 系(けい) = *System* = the components that are being studied at a given time. It may exchange matter (物質) or energy with the surroundings.

56. 外界(がいかい) = *Surroundings* = the space outside a system (系). The *surroundings* may interact (作用する) with the system (系) by exchanging energy or matter (物質).

57. 孤立系(こりつけい) = *Isolated system* = a system (系) that does not exchange matter (物質) or energy with its surroundings (e.g., hot coffee in a vacuum (真空の) flask).

58. 閉鎖系(へいさけい)/閉じた系(とじたけい) = *Closed system* = a system (系) that exchanges energy (but not matter (物質)) with its surroundings (e.g., boiling water in a pot with a lid).

59. 開放系(かいほうけい)/開いた系(ひらいたけい) = *Open system* = a system (系) that exchanges energy and matter (物質) with its surroundings (e.g., boiling water in a pot without a lid).

60. 熱力学第一法則(ねつりきがくだいいちほうそく) = *First law of thermodynamics*:

> The change in internal energy (内部エネルギー) (Δ*U*) equals the sum of the heat energy (*Q*) entering the system (系) and the work done (*W*) on the system. If the system releases heat or does work on something else, the change in internal energy equals the sum (和) of the heat released and the work done. The total energy is conserved (保存される).

$$\Delta U = Q + W$$

61. 等積過程(とうせきかてい) = *Isochoric process* = a thermodynamic process that happens at a constant volume. No work is done on or by the system.

62. 等圧過程(とうあつかてい) = *Isobaric process* = a thermodynamic process that happens at a constant pressure. Work is done when the volume of the gas changes.

63. 等温過程(とうおんかてい) = *Isothermal process* = a thermodynamic process that happens at a constant temperature. Work is done when the volume or the pressure changes. If the temperature is constant, the internal energy does not change.

64. 断熱過程(だんねつかてい) = *Adiabatic process* = a thermodynamic process that happens when no heat enters or leaves the system. The work done relates only to changes in internal energy due to a change in temperature.

65. モル熱容量(もるねつようりょう) = *Molar heat capacity* (c_n) = the amount of heat that increases the temperature of 1 **mol** of a substance by 1 **K**.
[SI unit: **J** / **K**]

$$c_n = \frac{Q}{\Delta T}$$

66. 定積モル熱容量(ていせきもるねつようりょう) = *Molar heat capacity at constant volume* (C_V) = the amount of heat that increases the temperature of 1 **mol** of a substance by 1 **K** at constant volume. This is an *isochoric process*, so no work is done.
[SI unit: **J** / **K**]

67. 定圧モル熱容量(ていあつもるねつようりょう) = *Molar heat capacity at constant pressure* (C_p) = the amount of heat that increases the temperature of 1 **mol** of a substance by 1 **K** at constant pressure. This is an *isobaric process*.
[SI unit: **J** / **K**]

68. 比熱容量(ひねつようりょう) = *Specific heat capacity* (*C*) = the amount of heat (**J**) that increases the temperature of 1 **kg** of a substance by 1 **K** = 1 **°C**.
[SI unit: **J** / (**g** · **K**)]

69. マイヤーの関係式(まいやーのかんけいしき) = *Mayer's relation* = an equation that shows the relationship between the heat capacity at constant pressure and at constant volume. It was named after the German scientist Julius von Mayer.

$$C_p - C_V = R$$

70. 比熱比(ひねつひ) = *Specific heat ratio* (*γ*) = the ratio of the specific heat capacities at constant pressure and constant volume.
[Unitless]

$$\gamma = \frac{C_p}{C_V}$$

71. ポアソンの方程式(ぽあそんのほうていしき) = *Poisson's formula* = *the adiabatic equation* = an equation that shows the relationship between pressure (*p*), volume (*V*) and gamma (*γ*). Gamma is the ratio of the specific heat capacities. *Poisson's formula* was named after the French physicist Siméon Denis Poisson.

$$p \cdot V^{\gamma} = \text{constant}$$

72. 熱サイクル(ねつさいくる) = *Heat engine cycle* = a process where a heat engine takes in heat (Q_H) from a hot reservoir, does an amount of work (*W*), and then gives out heat (Q_C) to a cold reservoir.

73. 熱効率(ねつこうりつ) = *Thermal efficiency* (*e*) = the ratio of the work that a heat engine does (*W*) to the heat (Q_H) that it takes in from the hot reservoir.
[Unitless]

$$e = \frac{W}{Q_H}$$

74. 熱力学第二法則(ねつりきがくだいにほうそく) = *Second law of thermodynamics*:

> Heat moves or transfers from a hot object to a cold object, and natural processes tend to move from order to disorder. A closed process or device cannot convert an amount of heat completely into work.

75. エントロピー(えんとろぴー) = *Entropy* (*S*) = the amount of disorder of the energy in a system. If the energy in the system is more spread out, it has a higher *entropy*. *Entropy* always increases in a real system (e.g., a heat engine). *Entropy* was introduced by the German scientist Rudolf J Clausius.
[SI unit: **J** / **K**]

$$\Delta S = \frac{Q}{T}$$

Transmission and Interaction of Waves

76. 波面(はめん) = *Wavefronts* = lines that represent the peaks and troughs of a wave in 2-D space. The *wavefront* is perpendicular (直角) to the direction of the wave's motion.

77. 平面波(へいめんは) = *Plane wave* = a 3-D wave with wavefronts that are plane surfaces. The surfaces are flat, nearly straight, and perpendicular (直角) to the direction of the wave's motion.

78. 球面波(きゅうめんは) = *Spherical waves* = circular waves (e.g., sound waves) that spread out in a circular shape.

79. 光線(こうせん) = *Ray* = a straight line that shows the direction of the wave's motion. The *ray* is perpendicular (直角) to the wavefront.

80. 波の干渉(なみのかんしょう) = *Interference* of waves = an interaction (作用) that happens when two or more waves move at the same time and in the same place.

81. 波の強め合う干渉(なみのつよめあうかんしょう) = *Constructive interference* of waves = an interaction (作用) where the crest (山) of one wave is in the same position as the crest of another wave. When *constructive interference* happens, the waves join together. The result is a new wave with a larger amplitude (振幅) that is the sum (和) of the original amplitudes. The two waves must be exactly in phase (同位相).

82. 波の弱めあう干渉(なみのよわめあうかんしょう) = *Destructive interference* of waves = the opposite of constructive interference. *Destructive interference* happens when the crest (山) of one wave is in the same position as the trough (谷) of another wave. The waves join together, and the result is a new wave with a smaller amplitude (振幅). If the amplitudes are equal, the waves cancel each other out. The two waves must be exactly out of phase (逆位相).

83. ホイヘンスの原理(ほいへんすのげんり) = *Huygens' principle*:

> Every point on a wavefront can cause secondary waves (二次波) or wavelets (ウェーブレット(小波)) (elementary waves (素元波)). The wavelets move forward at the same speed as the wave. The line tangent to a wavelet shows the position of the new wavefront.

84. 入射角(にゅうしゃかく) = *Angle of incidence* (θ_i) = the angle between a wave and the line perpendicular(直角) to the surface that it hits.
[SI unit: °]

85. 反射角(はんしゃかく) = *Angle of reflection* (θ_r) = the angle between a reflected(反射) wave(波) and the line perpendicular(直角) to the surface.
[SI unit: °]

86. 反射の法則(はんしゃのほうそく) = *Law of reflection*:

> When light reflects from a surface, the *angle of incidence* is the same as the *angle of reflection*.
>
> $$\theta_i = \theta_r$$

87. 屈折波(くっせつは) = *Refracted wave* = a wave that is produced when light moves at an angle from one medium(媒質) to another. The speed, direction, and wavelength(波長) can change, but the frequency(周波数) always stays the same.

88. 屈折角(くっせつかく) = *Angle of refraction* = the angle between a *refracted wave* and the line perpendicular(直角) to the surface.
[SI unit: °]

89. 屈折率(くっせつりつ) = *Index of refraction* (n) = *absolute index of refraction* = the ratio(比) of the speed of light in a vacuum(真空) to the speed of light in a medium(媒質).
[Unitless]

$$n = \frac{c}{v}$$

90. 相対屈折率(そうたいくっせつりつ) = *Relative index of refraction* = the ratio(比) of the *index of refraction* of the refracting(屈折する) medium to the *index of refraction* of the incident(入射する) medium(媒質).
[Unitless]

$$n = \frac{n_2}{n_1}$$

91. 屈折の法則(くっせつのほうそく)/スネルの法則(すねるのほうそく) = *Law of refraction* (*Snell's law*):

> The speed of light waves in two media(媒質) is related to the angle between the wave and the boundary.

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

92. 回折(かいせつ) = *Diffraction* = a change in the direction of a wave that happens when it meets an opening, edge, or obstacle.

93. ドップラー効果(どっぷらーこうか) = The *Doppler effect* = an observed change in a wave's frequency because of relative motion between the source and the observer.

Light Waves

94. 光(ひかり) = *Light* = an electromagnetic wave, for example visible light, infrared, and ultraviolet.

We can treat light as a wave or as a beam of particles (photons). A light wave is a changing electric and magnetic field. Light can travel without a medium, and it moves more slowly in a medium. The speed of light without a medium is about 3 x 10^8 **m** / **s**.

95. 臨界角(りんかいかく) = *Critical angle* = an angle of incidence that has an angle of refraction of 90°.

[Si unit: °]

$$\sin\theta_{\text{crit}} = \frac{n_r}{n_i}$$

96. 全反射(ぜんはんしゃ) = *Total internal reflection* = complete reflection of a wave in a medium.

This happens when the angle between the wave and the line perpendicular to the boundary is greater than the *critical angle*. *Total internal reflection* only happens when light goes from a medium with a higher index of refraction into a medium with a lower index of refraction (e.g., from water into air).

97. 光の分散(ひかりのぶんさん) = *Dispersion* of *light* = a process where light separates into individual wavelengths. It occurs because the index of refraction depends on the wavelength of the light.

98. スペクトル(すぺくとる) = *Spectrum* = a pattern (distribution) of specific light wavelengths. A material's *absorption spectrum* shows which wavelengths it absorbs, and a light source's *emission spectrum* shows which wavelengths it emits.

99. 白色光(はくしょくこう) = *White light* = light that seems to have no color, for example sunlight.

White light is actually a combination of waves with different wavelengths of visible light.

100. 単色光(たんしょくこう) = *Monochromatic light* = light with only one wavelength.

Monochromatic light is difficult to make, although it can be made using filters or lasers, with varying purity.

101. 連続スペクトル(連続スペクトル) = *Continuous spectrum* = a spectrum with no gaps over a wide range of wavelengths, for example rainbows and incandescent light bulbs.

102. 線スペクトル(せんすぺくとる) = *Line spectrum* = the opposite of a continuous spectrum. A *line spectrum* has very specific wavelengths. Different atoms and molecules have their own characteristic *line spectrum*.

103. 光の散乱(ひかりのさんらん) = *Scattering* of *light* = an effect that happens to sunlight on Earth. Light enters the atmosphere and hits gases and particles. The gas absorbs the light and re-emits it in different directions. Short wavelengths are scattered more, so blue and green light scatter more than red and yellow light. When we look at the sky, we only see the scattered light. This is why the sky is blue (human eyes are less sensitive to violet light, so the sky does not appear violet). Sunsets are yellow and red because *scattering* removes blue light when it travels through more atmosphere. Clouds are white and grey because the water drops are large enough to scatter all wavelengths of light.

104. 偏光(へんこう) = *Polarization* = a process that makes light waves oscillate in only one direction. Only transverse waves can be polarized. Longitudinal waves, for example sound, cannot be polarized.

105. 集光レンズ(しゅうこうれんず)/凸レンズ(とつれんず) = *Converging lens* = *convex lens* = a lens that curves outwards on the surface, so that the middle is thicker (e.g., a magnifying glass). When parallel light waves hit a *converging lens*, they all move toward the *focal point*. These lenses can be used to correct far-sightedness.

106. 発散レンズ(はっさんれんず) /凹レンズ(おうれんず) = *Diverging lens* = *concave lens* = a lens that curves inward on the surface, so that the middle is thinner. When parallel light waves hit a *diverging lens*, they move away from the *focal point* in different directions. These lenses can be used to correct near-sightedness.

107. 光学中心(こうがくちゅうしん) = *Optical center* = a point at the center of a lens. When light goes through the *optical center*, it keeps moving in a straight line.

108. 光軸(こうじく) = *Optical axis* = a straight line that passes through the *optical center* and the center of curvature(湾曲) of a lens.

109. 焦点(しょうてん) = *Focal point* = a point on the *optical axis* where light converges(収束する) or appears to come from.

110. 焦点距離(しょうてんきょり) = *Focal length* (*f*) = the distance from the focal point to the optical center.
[SI unit: **m**]

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

111. 実像(じつぞう) = *Real image* = an image that is formed when light waves converge(収束する). A *real image* can be projected onto a screen. The image is usually inverted(倒立), and it can be larger or smaller than the object.

112. 虚像(きょぞう) = *Virtual image* = an image that is formed when light waves appear to diverge(発散する) from a single point (e.g., a *diverging lens*). A *virtual image* cannot be projected(投影する) onto a screen. The image is usually erect(直立), and it can be larger or smaller than the object. The image made by a *plane mirror* is virtual, erect, and reversed.

113. 倍率(ばいりつ) = *Magnification* (*M*) = the ratio(比) of the size of the image to the size of the object.
[Unitless]

$$M = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

114. 平面鏡(へいめんきょう) = *Plane mirror* = a mirror that has a flat and smooth surface.

115. 球面鏡(きゅうめんきょう) = *Spherical mirror* = a mirror that has a curved surface. The surface curves either toward the viewer (a convex mirror(凸面鏡)) or away from the viewer (a concave mirror(凹面鏡)).

116. ヤングの干渉実験(やんぐのかんしょうじっけん) = *Young's interference experiment* = *Young's Double-Slit Experiment* = a significant experiment that was done by the British scientist Thomas Young in 1801. Young passed sunlight through two very narrow slits, which were very close to each other (a similar distance to the light's wavelength(波長)) toward a screen. He expected to see two bright lines on the screen. Instead, he observed interference(干渉) patterns(縞). Bright fringes(縞) appeared where *constructive interference* occurred, and dark fringes appeared where *destructive interference* occurred.

117. 回折格子(かいせつこうし) = *Diffraction grating* = a device that has many parallel, equally spaced slits. This device *disperses* light into separate colors due to *diffraction* and *interference*. *Diffraction gratings* can be made using light or by scratching a surface using a diamond-tipped tool.

118. 格子定数(こうしていすう) = *Grating constant* (*d*) = *grating spacing* = the distance between each slit in a *diffraction grating*.
[SI unit: **m**]

$$n \cdot \lambda = d \cdot \sin\theta$$

119. ニュートンリング(にゅーとんりんぐ) = *Newton rings* = concentric rings of light that appear when a convex glass surface is placed on a flat glass surface and is lit from above. *Newton rings* appear because the waves that are reflected by the top and bottom surfaces interfere with each other.

Electricity and Magnetism

Electric Fields and Electric Potential

120. 正電荷(せいでんか) = *Positive electric charge* = a region or an object (e.g., an atom) that has more protons (usually shown with a (+) sign) than electrons (usually shown with a (–) sign). In atoms, the proton has a positive charge. It attracts negative charges and repels other positive charges.
[SI unit: **C**]

121. 負電荷(ふでんか) = *Negative electric charge* = the opposite of a positive electric charge. A *negative electric charge* is a region or an object (e.g., an atom) that has more electrons than protons. In atoms, the electron has a negative charge. It attracts positive charges and repels other negative charges.
[SI unit: **C**]

122. 電気量保存則(でんきりょうほぞんそく) = *Principle of conservation of charge*:

> When a charge transfer happens, the total electric charge in the system does not change. In a charging process, charge is never created or destroyed in the system.

123. 静電気に関するクーロンの法則(せいでんきにかんするくーろんのほうそく) = *Coulomb's law* of electrostatic force:

> The electric force between two charged points is directly proportional to the product（掛け算の）積 of the amount of charge 電荷 and inversely 反比例 proportional to the square 2乗 of the distance between the points. This is similar to Newton's law of universal gravitation.

$$F = \frac{k_e \cdot q_1 \cdot q_2}{r^2}$$

124. 電場(でんば) = *Electric field* = a region 領域 around a charged particle 荷電粒子 or object. In an *electric field*, an electric force acts on any charged particle or object placed in the field 場. The strength of the field is written as *E*.
[SI unit: **V** / **m**]

$$F = q \cdot E$$

125. 電場ベクトル(でんばべくとる) = *Electric field vector* ($\vec{E}$) = a vector (a value with a magnitude 大きさ and a direction 方向) that describes an electric field. The direction of the vector is the direction where a charge 電荷 is pushed or pulled if it is placed in the field. This direction is always toward or away from the source charge 電場の元となっている点電荷.

126. 電場の重ね合わせの原理(でんばのかさねあわせのげんり) = *Principle of superposition* of *electric fields*:

> When there are more than two charges 電荷, the total force on a charge is the vector sum 和 of the forces on it due to the other charges.

127. 電気力線(でんきりきせん) = *Electric field lines* = *lines of force* = imaginary 想像上の lines (straight or curved) that show the vector nature 性質 of an electric field. These lines always point from positive charges to negative charges or, if there is only one charge 電荷, from the charge to infinity 無限遠 (if the charge is positive) or from infinity to the charge (if the charge is negative). The *field line* always points in the same direction as the electric field (and therefore the electric force). *Field lines* are always perpendicular 直角 to the surface of charged 帯電した objects. They never cross each other. The denser the lines, the stronger the field.

128. 一様な電場(いちようなでんば)/均一電場(きんいつでんば) = *Uniform electric field* = an electric field (e.g., between two parallel 平行 plates of a capacitor コンデンサー) with the same strength at all points. The magnitude and direction of the field $\vec{E}$ are the same at all points.

129. 電位(でんい) = *Electric potential* (*V*) = the electric potential energy per Coulomb of charge(電荷). [SI unit: **V** = **J** / **C**]

$$V = \frac{U}{q}$$

130. 等電位面(とうでんいめん) = *Equipotential surface* = a surface where every point has the same potential, so the potential difference between any two points on the surface is zero (e.g., the surface of a conductor(導体) when the charges are at rest). No work is needed to move a charge on the surface. An *equipotential surface* is always perpendicular(直角) to the electric field at any point.

131. 等電位線(とうでんいせん) = *Equipotential lines* = lines or curves that show the amount of *electric potential* in a given region(領域). They are always perpendicular(直角) to the electric field. They are usually represented by dashed lines (---) instead of solid lines (which are used for Electric field lines).

132. 自由電子(じゆうでんし) = *Free electrons* = *conduction electrons* = Electrons in a conducting(導電性) material (e.g., a metal) that are bound(結びつけられた) weakly(弱く) to the nuclei(原子核) and can move freely inside the material. *Free electrons* move quickly toward a positive charge and move quickly away from a negative charge. A semiconductor(半導体) has fewer free electrons and an insulator(不導体) has almost none.

133. 静電誘導(せいでんゆうどう) = *Electrostatic induction* = a method of charging a neutral object by using a charged object and a ground (earth). A charged object is moved near a neutral conductor(導体) without touching it. *Free electrons* in the neutral object move closer to or further from the charged object inside the neutral object (depending on whether the charge is positive or negative). This is called an induced(誘導された) charge at the two ends of the neutral object. When the object is grounded (earthed)(アースされた) using a wire or pipe leading to the ground, many electrons(電子) move into the ground if a negatively charged object is moved close to it. The wire is cut and the negatively charged object is moved away. This leaves a positive charge on the original neutral object.

134. 箔検電器(はくけんでんき) = *Leaf electroscope* = a device used for detecting electric charge and for determining polarity(極性).

135. アース(あーす) = *Ground* = *earth* = a very large source of electrons(電子) (usually the ground) which can give or take electrons from a charged object when they are connected. The *ground* can be used to neutralize a charged object. Electrical plugs in the UK and some other countries have a third pin which acts as a *ground*.

136. 電気遮蔽(でんきしゃへい) = *Electric shielding* = *electrostatic shielding* = an effect that happens inside a hollow(中空の) conductor(導体) (a Faraday cage). The inside of the conductor is not affected by the electric field on the outside, so the *electric field strength* is always zero even if there are charges outside. *Electric shielding* only happens when the conductor is kept at a constant(一定の) potential. Because of *electric shielding*, the inside of a car is usually safe during a lightning storm.

137. 静電平衡(せいでんへいこう) = *Electrostatic equilibrium* = the state of a conductor(導体) when all of the free charge has moved as far as possible to reduce the total amount of repulsive(反発の) force. When a conductor is in *electrostatic equilibrium*, the charges do not move.

138. 電極(でんきょく) = *Electrode* = a conductor(導体) that can give or take electrons(電子) (e.g., in a battery or a semiconductor(半導体)). A positively charged *electrode* (which takes electrons out of the device) is called an anode(アノード) and a negatively charged *electrode* (which gives electrons to the device) is called a cathode(カソード).

139. コンデンサー(こんでんさー) = *Capacitor* = *condenser* = a device that stores electric charge and energy (e.g., in computers or a camera flash). A *capacitor* is usually two conducting plates that are placed parallel to each other without touching each other. *Capacitors* are used in many electronic devices, for example condenser microphones(コンデンサーマイク).

140. コンデンサーの充電(こんでんさーのじゅうでん) = *Charging* a *capacitor* = a process that stores charge and energy in a capacitor. First, a battery creates a current(電流) (sending electrons(電子) from the negative terminal), which is used to move electrons to the right-side plate of the capacitor. This makes a strong negative charge on the plate. The charge repels(反発する) the same number of electrons from the left-side plate; these electrons move toward the battery's positive terminal(端子). Soon, a large number of electrons are on the right-side plate. This negative charge repels electrons in the circuit(回路), so the current(電流) stops. The voltage of the capacitor is equal to the voltage of the battery, and the capacitor is fully charged.

141. コンデンサーの放電(こんでんさーのほうでん) = *Discharging* a *capacitor* = a process that removes charge(電荷) from a charged capacitor. The battery is disconnected, and the capacitor(コンデンサー) creates a current(電流) in the circuit(回路). The voltage between the plates slowly reduces to zero.

142. 静電容量(せいでんようりょう) = *Capacitance* (*C*) = a *capacitor's* ability to store charge(電荷). This value depends on the size, shape, position and material of the plates, and the *dielectric*.

[SI unit: **F** = **C** / **V**]

$$C = \frac{Q}{V}$$

$$C_0 = \frac{\varepsilon_0 \cdot A}{d}$$

$$\varepsilon_0 = 8.85 \times 10^{-12}\ \frac{\mathbf{C}}{\mathbf{V \cdot m}}$$

143. 絶縁体(ぜつえんたい) = *Dielectric* = a sheet of insulating (電気を通さない) material (e.g., air or a solid material such as plastic, ceramic or glass) that is placed between plates in a capacitor. This stops the plates from touching each other and allows the capacitor (コンデンサー) to have a small separation (*d*) between the plates. This increases the capacitance (静電容量), due to the electric field strength between the plates reducing in proportion with the dielectric constant (定数) (*K*). A higher capacitance allows charge to be held at a lower voltage.

144. 誘電分極(ゆうでんぶんきょく) = *Dielectric polarization* = a change in the position and orientation of charges (電荷) that happens with an electric field in a dielectric (絶縁体) material. The positive charges align with the electric field and the negative charges align against it. This causes a shift in charge distribution.

145. 誘電率(ゆうでんりつ) = *Permittivity* (*ε*) = a value that measures how much a material resists an electric field. *Permittivity* occurs because dipole moments (双極子モーメント) are created by a material's molecules (分子). The molecules move to oppose the field.
[SI unit: **C** / (**V** · **m**)]

146. 比誘電率(ひゆうでんりつ) = *Dielectric constant* (*K*) = *relative permittivity* = the ratio (比) of the *permittivity* of a material to the *permittivity of free space*. The *dielectric constant* is 1 for free space, 3.7 for paper, and 2–4 for vinyl.
[Unitless]

147. 耐電圧(たいでんあつ) = *Withstanding voltage* = the maximum voltage that a capacitor can have (withstand). In a DC circuit (直流回路) this is called the working voltage (使用電圧), and in an AC circuit (交流回路) this is called the RMS (root mean square) working voltage.
[SI unit: **V**]

148. 合成静電容量(ごうせいせいでんようりょう) = *Combined capacity* = the total *capacitance* of a circuit (回路). In a parallel circuit, this is the sum of the capacitance of each capacitor. In a series circuit, this is the reciprocal (逆数) of the sum of the reciprocals of each capacitance.
[SI unit: **F** = **C** / **V**]

$$C_{parallel} = C_1 + C_2 + \cdots + C_n$$

$$C_{series} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}\right)^{-1}$$

149. 静電エネルギー(せいでんえねるぎー) = *Electrostatic energy* (*U*) = the energy stored in a capacitor.
[SI unit: **J**]

$$U = \frac{Q \cdot V}{2} = \frac{C \cdot V^2}{2} = \frac{Q^2}{2C}$$

Electric Current

150. 電圧降下(でんあつこうか) = *Voltage drop* = *potential drop* = the amount of voltage that is lost due to resistance (e.g., in the conductor(導体) or in a device like a light bulb). The *voltage drop* in a wire depends on the current(電流) and the resistance(抵抗).
[SI unit: **V**]

151. 低効率温度係数(ていこうりつおんどけいすう) = *Temperature coefficient of resistivity* = the rate of change of resistivity(低効率) when the temperature in the conductor(導体) changes. A semiconductor(半導体) can have a negative *temperature coefficient* because the higher the temperature, the more electrons(電子) are free.

$$\rho = \rho_0\big(1 + a(T - T_0)\big)$$

$$R = R_0\big(1 + a(T - T_0)\big)$$

152. ジュールの法則(じゅーるのほうそく) = *Joule's law*:

> When a conductor(導体) turns energy into heat, the heat is proportional(比例) to the resistance, the square(2乗) of the current, and time.

$$Q = R \cdot I^2 \cdot t$$

153. 電流計(でんりゅうけい) = *Ammeter* = a device that measures electric current(電流). An *ammeter* must be connected in series(直列) and should have a very low resistance.

154. 内部抵抗(ないぶていこう) = *Internal resistance* = resistance inside the source of a current (e.g., a battery or a generator(発電機)).
[SI unit: **Ω**]

155. シャント抵抗器(しゃんとていこうき)/電流検出抵抗器(でんりゅうけんしゅつていこうき) = *Shunt* = *shunt resistor* = a parallel (並列) resistor which is used to measure high currents (電流) safely. It is connected to an ammeter in parallel. It has a very low resistance, so the *voltage drop* is small and it takes almost no energy.

156. 電圧計(でんあつけい) = *Voltmeter* = a device that measures voltage. A *voltmeter* must be connected in parallel (並列) and should have a very high resistance.

157. 検流計(けんりゅうけい) = *Galvanometer* = a device that measures small electric currents. It can be used with a *shunt* in parallel (並列) to measure the current or in series (直列) to measure voltage.

158. 倍率器(ばいりつき) = *Multiplier* = a device that allows a voltmeter to measure greater voltages. A large resistor is connected in series (直列) to extend the range of measurement.

159. 起電力(きでんりょく) = *Emf* (of a source) = electromotive force = ε = the voltage between the terminals (端子) of the source (電源) when there is no current. This is the maximum voltage that the source can apply. It is not actually a force, but a potential difference.
[SI unit: **V**]

160. 端子電圧(たんしでんあつ) = *Terminal voltage* = the voltage of the source (電源) of current (電流) (e.g., a battery) across its terminals (端子). If there is no current, the *terminal voltage* is the same as the electromotive force (emf). If there is a current, the voltage is given by the below equation (等式).

$$V = \varepsilon - I \cdot r_0$$

161. キルヒホッフの法則(きるひほっふのほうそく) = Kirchhoff's laws:

I. At any junction (分岐) point, the sum of the currents (電流) that enter the junction equals the sum of the currents that leave the junction. This is also called the junction rule.

II. The sum (和) of the changes in voltage in a closed loop of a circuit (回路) equals zero. This is also called the loop rule.

$$\varepsilon = \sum_i R_i \cdot I_i$$

162. ホイートストンブリッジ(ほいーとすとんぶりっじ) = Wheatstone bridge = a circuit (回路) connected in bridge form that measures an unknown resistance (不明な抵抗値) (e.g., due to a temperature change). Usually there are two resistors (抵抗器) (R_1 and R_2) with known resistances, one resistor (R_3) with a variable

resistance, and one resistor (R_x) with an unknown resistance. The variable resistor (rheostat) is adjusted so that the voltmeter (generally a galvanometer) shows 0 **V** (so that the bridge is balanced). Because three of the resistances are known, the unknown value can be calculated.

$$R_x = \frac{R_2 \cdot R_3}{R_1}$$

163. 電位差計(でんいさけい) = *Potentiometer* = a variable resistor that can be controlled by moving a contact. Because of this, it can be used to increase or decrease the voltage output. *Potentiometers* are used in devices like audio or video equipment to control volume. It can be used to measure electric potential (voltage).

164. 非線形抵抗(ひせんけいていこう) = *Nonlinear resistance* = a resistance that changes when the voltage or current in the circuit changes. It is called *nonlinear* because the graph of current against voltage is not a straight line. There are many causes, for example a change in temperature due to the current.
[SI unit: **Ω**]

165. 正孔(せいこう)/ホール(ほーる) = (Positive) *hole* = a *charge carrier* in a semiconductor that has a positive charge. A *hole* has the same amount of charge as an electron but the opposite sign (polarity), and moves from plus to minus.

166. 半導体内の電荷担体(はんどうたいないのでんかたんたい)/電荷キャリアー(でんかきゃりあー) = *Charge carrier* in a semiconductor = an electron or a *hole* that moves charge in an electric current. In a metal, the *charge carriers* are electrons; in a gas, they are electrons and positive ions; in an electrolyte, they are positive and negative ions.

167. 真性半導体(しんせいはんどうたい) = *Intrinsic semiconductor* = a chemically pure material (e.g., silicon or germanium) that has an equal number of electrons and holes and is a poor conductor. At room temperature, thermal energy can excite electrons so that they move to the conduction band. This gives the *intrinsic semiconductor* some conductivity. As the temperature increases, more electrons can enter the conduction band, so the conductivity increases.

168. 不純物半導体(ふじゅんぶつはんどうたい) = *Extrinsic semiconductor* = a semiconductor that has a small amount of impurities, caused by a process called doping. Doping improves the conductivity of the semiconductor by adding a material with more electrons (for an *n-type* semiconductor) or holes (for a *p-type* semiconductor).

169. n 型半導体(えぬがたはんどうたい) = *n-type* semiconductor = a semiconductor material where most of the charge carriers are electrons.

170. p 型半導体(ぴーがたはんどうたい) = *p-type* semiconductor = a semiconductor material where most of the charge carriers are holes.

171. 整流(せいりゅう) = *Rectification* = a process that converts alternating current (AC) into direct current (DC) using a device like a *diode*, which allows current in only one direction.

172. ダイオード(だいおーど) = *Diode* = a device that conducts electric current in only one direction. *Diodes* are made of semiconductor materials (e.g., silicon or germanium) and they have two electrodes. The positive electrode is called the anode and the negative electrode is called the cathode.

173. p-n 接合(ぴーえぬせつごう) = *p-n junction* = *p-n* = a boundary between a *p-type* and *n-type* material. Current can only flow in one direction at a *p-n junction*, so it forms a diode. Current flows from p to n, but electrons flow from n to p.

174. 順方向バイアス(じゅんほうこうばいあす) = *Forward bias* (*forward biased*) = a state of a *p-n junction* where the *p-type* region is connected to the positive terminal of a voltage source (e.g., a battery) and the *n-type* region is connected to the negative terminal of a voltage source. Some electrons in the conduction band of the *n-type* region diffuse across the junction, and have a higher energy than the holes. The electrons and the holes combine, which allows a forward current through the junction. The current increases with the increase in voltage.

175. 逆方向バイアス(ぎゃくほうこうばいあす) = *Reverse bias* (*reverse biased*) = a state of a *p-n junction* where the *p-type* region is connected to the negative terminal of a voltage source and the *n-type* region is connected to the positive terminal of a voltage source. electrons and holes are pulled away from the junction, causing a temporary current. The *depletion layer* becomes wider, which causes a potential difference. When this voltage equals the voltage of the voltage source, the current stops (except for the small thermal current).

176. 空乏層(くうぼうそう) = *Depletion layer* = *Depletion region* = a layer or region where holes and electrons combine to reduce the number of conducting holes (in the *p-type* region) and electrons (in the *n-type* region). Due to this, the majority charge carriers are removed, so conduction cannot

happen. The *depletion layer* has a barrier potential (e.g., 0.7 **V** in silicon or 0.3 **V** in germanium), which is the minimum voltage needed to cause a current.

177. トランジスタ(とらんじすた) = *Transistor* = a small electronic component with three terminals (usually made of silicon) that controls or amplifies current. It acts as a switch or gate for electronic signals. The three terminals are called the base, the collector, and the emitter. Modern microprocessors contain tens of millions of transistors.

178. バイポーラトランジスタ(ばいぽーらとらんじすた) = Bipolar junction transistor (BJT) = a type of transistor that can be npn-type or pnp-type. An npn-type BJT has a very thin p-doped region between two n-doped layers, and a pnp-type BJT has a very thin n-doped region between two p-doped layers. BJTs were important in the early development of computer technology.

179. 増幅(ぞうふく) = *Amplification* = a process that increases (multiplies) a current using a transistor. First, a current is applied to the emitter of an npn-type transistor. Electrons move to the *p-type* base, filling the holes. This creates a negative charge, which repels more electrons from the emitter, so the transistor stops conducting. Then, a small positive current is applied to the base, which produces more holes. This allows electrons to pass through into the collector. The strength of the current that flows into the collector depends on the number of holes created. The current in the collector can be hundreds of times greater than the current in the base, so the transistor is a powerful amplifier. The small base current becomes a high collector current. A signal (any change in current) in the base current also appears as a larger change in the collector current. The proportional increase in the current is called the amplification factor or the "gain" (β).

$$I_C = \beta \cdot I_B$$

180. 集積回路(しゅうせきかいろ) = *Integrated circuit* (*IC*) = *microchip* = a small electronic circuit (chip) made of semiconductor material (wafer). An *IC* can be used as an amplifier, oscillator, timer, counter, computer memory, or a microprocessor. *Integrated circuits* are used in computers, audio and video equipment, and other devices. There are different types of *IC*, depending on how many transistors and other components they have. ICs containing thousands of components are called medium-scale integrations (MSIs) and ICs containing hundreds of thousands or millions of components are called large-scale integrations (LSIs). Modern computers, smartphones and game consoles contain many billions of transistors in their chips.

Electric Current and Magnetic Field

181. 磁荷(じか)/磁気量(じきりょう) = *Magnetic charge* = a property of a magnetic monopole(単極子) that is similar to electric charge but causes a magnetic force. Magnetic monopoles are not found in nature and have never been observed, so the magnetic charge is a hypothetical(仮説の) property. There are some experiments to search for magnetic monopoles today, including the ATLAS detector in the Large Hadron Collider at CERN in Geneva (the same detector that found the Higgs particle).

182. 磁力に関するクーロンの法則(じりょくにかんするくーろんのほうそく) = *Coulomb's law of magnetic force* = a version of *Coulomb's law of electric force*. It shows the force that acts on two *magnetic charges*.

183. 磁場ベクトル(じばべくとる) = *Magnetic field vector* ($\vec{B}$) = a vector(ベクトル) that shows the strength and direction of the magnetic(磁) field(場) (*B*). The vector points in the same direction as a compass needle. A longer vector represents a stronger magnetic field. The vector always points in the same direction as the *magnetic field lines*.
[SI unit: **T**]

184. 磁力線(じりょくせん) = *Magnetic field lines* = imaginary(想像上の) lines that show the direction of the magnetic(磁) field(場) at different points. They are always closed curves that never cross over each other. The lines point from a magnet's north pole to its south pole outside the magnet, and from the south pole to the north pole inside the magnet. Near the poles, where the field is stronger, the *field lines* are closer to each other.

185. フレミングの左手の法則(ふれみんぐのひだりてのほうそく) = *Fleming's left-hand rule* = a way to show the direction of the force on a conductor(導体) that has a current, when the current(電流) is at a right angle(直角) to a magnetic(磁) field(場). The thumb, index finger and middle finger are placed at right angles. The index finger points in the direction of the magnetic field, and the middle finger points in the direction of the current (from positive to negative). The thumb shows the direction of the magnetic force. The order from thumb to middle finger is “F-B-I”.

186. 透磁率(とうじりつ) = *Magnetic permeability* (μ) = the ability of a material to contain a magnetic(磁) field(場). This also shows how much induced(誘導) magnetism(磁気) will occur when there is an external magnetic field.
[SI unit: **Wb** / (**A** · **m**)]

187. 比透磁率(ひとうじりつ)/相対透磁率(そうたいとういじりつ) = *Relative permeability* (μ_r) = the ratio(比) of the *magnetic permeability* (μ) in the material and the *permeability* of free space(真空) (μ_0). It

shows how much the magnetic field strength increases or decreases when induced magnetization occurs in the material (when placed in an external magnetic field). The value is 1.000037 in air, 1.00000043 in wood, 1.000022 in aluminum, and 0.999994 in copper, and 260,000 in iron (a magnetic material)
[Unitless]

$$\mu_0 = 4\pi \times 10^{-7} \frac{\mathbf{T \cdot m}}{\mathbf{A}}$$

$$\mu_r = \frac{\mu}{\mu_0}$$

188. 磁化(じか) = *Magnetization* = the process that turns a magnetic material into a magnet (temporary or permanent). It can be induced by an external magnetic field. Some materials (ferromagnets) remain magnetized permanently. Others (paramagnets) lose their magnetization when the external field is removed. There are also diamagnetic materials, which create a magnetic field in the opposite direction to the external field.

189. 強磁性体(きょうじせいたい) = *Ferromagnetic* material = a material (e.g., iron or nickel) that becomes strongly magnetized in the direction of an external magnetic field. The material can stay magnetized even after the external field is removed.

190. 常磁性体(じょうじせいたい) = *Paramagnetic* material (substance) = a material (e.g., aluminum or air) that becomes weakly magnetized in the direction of an external magnetic field. It does not stay magnetized when the external field is removed.

191. 反磁性体(はんじせいたい) = *Diamagnetic* material (substance) = A material (e.g., gold, copper or water) that becomes weakly magnetized in the opposite direction of an external magnetic field.

192. 磁束(じそく) = *Magnetic flux* (*Φ*) = a value that shows the total magnetic field that passes through a given area. This depends on the strength and the size of the field.
[SI unit: **Wb**]

$$\Phi = B \cdot A$$

193. 磁場の強度(じばのきょうど)/磁界強度(じかいきょうど) = *Magnetic field strength* (*B*) = 磁束密度(じそくみつど) = *magnetic flux density* = a value that shows the magnetic flux per unit area (per 1 $\mathbf{m}^2$) at a right angle (perpendicular) to the magnetic field lines. *Magnetic flux density* can be measured using a magnetometer.
[SI unit: **T** = **Wb** / $\mathbf{m}^2$]

194. ローレンツ力(ろーれんつりょく) = *Lorentz force* (*F*) = the force exerted on a moving charge by a magnetic field. It is at a right angle to the magnetic field and the direction that the charge moves in. We can use the right-hand rule to show the direction of the *Lorentz force*. The force (*F*) depends on the electric charge (*q*), the velocity of the charge (*v*), the magnetic field strength (*B*), and the angle between *v* and *B* (*θ*). In the right-hand rule, the thumb is the direction of the charge, the index finger is the magnetic field direction, and the middle finger is the direction of the force. If the charge is negative (e.g., an electron) the force direction is opposite. The speed of the electron doesn't change, only the direction, because the *Lorentz force* does no work on the charge. The force is always perpendicular to the motion of the charge.
[SI unit: **N**]

$$F = q \cdot v \cdot B \sin\theta$$

195. ホール効果(ほーるこうか) = *Hall effect* = an effect that occurs when a charge moves in a magnetic field. A magnetic force acts on the charge, at a right angle to its movement. It pushes the charge to the side of the conductor. The *Hall effect* moves charges to one side of the conductor, so there is a voltage (called the Hall voltage) between the two sides. The *Hall effect* demonstrates the *Lorentz force*. The voltage can be measured to calculate the magnetic field strength.

196. ファラデーの電磁誘導の法則(ふぁらでーのでんじゆうどうのほうそく) = *Faraday's law of induction*:

> When a changing magnetic field acts on a circuit, an induced emf is created. The induced emf (*ε*) is proportional to the rate of change of magnetic flux (*Φ*) through the circuit. It depends on the number of turns (*N*) in the coil that causes the magnetic field.
>
> $$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

197. レンツの法則(れんつのほうそく) = *Lenz's law*:

> When a changing magnetic field field causes a current, the current creates a new magnetic field, which opposes the original change in flux. Note that there are two separate magnetic fields. First, the changing magnetic field that causes the current, and second, the new magnetic field that is created by the current. The second field opposes the change in the first field. *Lenz's law* gives only the direction of the new field, not the magnitude, so the field is not completely opposed.

198. 渦電流(うずでんりゅう) = *Eddy currents* = *Foucault currents* = small, curved currents that occur inside a conductor when there is a changing magnetic field. They flow in closed loops which are at 90° to the magnetic field. *Eddy currents* can be created with a transformer or by relative motion between the conductor and a magnet. The strength of the current is proportional to the rate of change of flux. It is inversely proportional to the resistivity. Because of *Lenz's law*, *eddy currents* create a new magnetic field that opposes the first field.

199. 誘導加熱(ゆうどうかねつ) = *Induction heating* = a process that heats a conductor (e.g., copper) using electromagnetic induction, without touching the conductor. A changing magnetic field is created by applying a high-frequency alternating current to a coil. The conductor is placed inside the field without touching the coil. The changing magnetic field creates *eddy currents* in the conductor, making it hot. If the material contains iron crystals, they are magnetized and demagnetized many times at a very high frequency (not the frequency of the AC current). This causes the magnetic domains to move back and forth, which also causes heat. Therefore, magnetic conductors are heated much faster than non-magnetic conductors.

200. 自己誘導(じこゆうどう) = *Self-induction* = a process that causes an induced voltage in a coil when the wire's current changes. The changing current creates a magnetic field which induces a voltage in the same circuit.

201. 自己インダクタンス(じこいんだくたんす) = *Self-inductance* (*L*) = the ratio of the *self-induced* emf and the rate of change of current in the coil.

$$L = N\frac{\Phi}{I}$$

$$\varepsilon = -L\frac{\Delta I}{\Delta t}$$

202. 相互誘導(そうごゆうどう) = *Mutual induction* = an effect that occurs when two coils are close to each other. The first (primary) coil creates a changing magnetic field, which induces a changing voltage and current in the second (secondary) coil.

203. 相互インダクタンス(そうごいんだくたんす) = *Mutual inductance* (*M*) = the proportional change in current in the secondary circuit when *mutual induction* happens. The *mutual induction* depends on the size, shape, number of turns, and the relative positions of the two coils, and whether iron or other *ferromagnetic material* is present.

$$M = N\frac{\Phi}{I}$$

$$\varepsilon_2 = -M\frac{\Delta I_1}{\Delta t}$$

204. 誘導リアクタンス(ゆうどうりあくたんす) = *Inductive reactance* (X_L) = opposition to a change in current, due to back emf, caused by an inductor. An inductor is an electrical component that drops or supplies voltage to oppose changes in the current.
[SI unit: **Ω**]

$$X_L = \omega \cdot L$$

205. 容量リアクタンス(ようりょうりあくたんす) = *Capacitive reactance* (X_C) = opposition to alternating current due to a capacitor.
[SI unit: **Ω**]

$$X_C = \frac{1}{\omega \cdot C}$$

206. インピーダンス(いんぴーだんす) = *Impedance* (Z) = a circuit's opposition to alternating current. Impedance is caused by resistance and reactance in the circuit.

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

Quantum Physics

207. ミリカンの実験(みりかんのじっけん) = *Millikan experiment* = a significant experiment that was conducted by the American physicist Robert Millikan in 1909. In this experiment, the charge of an electron was measured for the first time. Millikan used an electric field to put ionized oil drops in equilibrium against gravity, and calculated the charge by comparing the *Coulomb force* with the gravitational force.

208. ブドウパンモデル(ぶどうぱんもでる) = *Plum pudding model* = an early model of the atom's structure, created in 1904. All of the positive charge in a *plum pudding* atom is distributed (spread out) evenly in the volume of the atom, but the negative charge is contained in floating electrons. The model was useful because it explained the overall neutral charge of the atom, but the later *Geiger-Marsden experiments* showed that it was incorrect. The model was named after a dessert that was popular in England at the time (also called Christmas pudding). The electrons in the *plum*

pudding atom are similar to the small raisins that are spread out in an actual pudding and the positive charge is similar to the dough.

209. ガイガー・マースデンの実験(がいがー・まーすでんのじっけん) = *Geiger-Marsden experiments* = ラザフォードの散乱実験(らざふぉーどのさんらんじっけん) = *Rutherford experiments* = a significant series of experiments that were conducted by Hans Geiger, Ernest Marsden and their professor Ernest Rutherford from 1908 to 1913 in Manchester, England. The experiments were conducted by firing positively-charged alpha particles (アルファ粒子) at a small sheet of gold, and measuring how the particles (粒子) deflected. It was necessary to spend hours counting the particles one-by-one. Geiger and Marsden were Rutherford's juniors (Marsden was only 20 and was still a university student), so Rutherford made them do this difficult job. Due to the *plum pudding model*, they expected the particles to pass through the foil, because the particle never hits a dense region (領域) of charge (電荷). Most of the particles passed through, but they found that some particles were strongly deflected (そらされた). Moreover, some particles were reflected (反射された). This was because a small number of the particles passed close to a small volume of positive charge. Rutherford concluded that the atom (原子) must have a very small and very dense region of positive charge. He called it the nucleus (核).

210. ラザフォードの原子模型(らざふぉーどのげんしもけい) = *Rutherford model* = an early model of the atom (原子)'s structure that was created in 1911. The Rutherford model has a small, positive nucleus, with the electrons (電子) far from the nucleus.

211. ボーアの原子模型(ぼーあのげんしもけい) = *Bohr model* = an early model of the atom (原子)'s structure, created in 1913. In the Bohr model, there is a small, positive nucleus, and electrons (電子) orbiting (周回している) in *energy levels* (エネルギー準位) at different distances. The energy levels were thought to be similar to the kinetic energy of planets in orbit (軌道) at different distances. This model was significant because it explained why hydrogen (水素) has an *emission spectrum* (発光スペクトル). It was named after the Danish physicist Niels Bohr.

212. エネルギー準位(えねるぎーじゅんい) = *Energy level* = a discrete (不連続の) amount of energy that an electron (電子) can have inside an atom (原子). According to the Bohr model, higher *energy levels* are farther from the nucleus. Energy levels exist because of the principal *quantum number* (量子数). They are discrete because this number always has an integer (整数) value.

213. 基底状態(きていじょうたい) = *Ground state* = the lowest energy level that an electron (電子) can have inside an atom (原子). An electron in the *ground state* can enter an *excited state* if it absorbs (吸収する) a

photon with the same energy as the difference between the two energy levels. The change in energy *E* depends on the *Planck constant* and the frequency of the photon *υ* (the Greek letter nu).

$$\Delta E = h\upsilon$$

214. 励起状態(れいきじょうたい) = *Excited state* = a higher energy level than the ground state. An electron in an *excited state* can go back to the ground state by emitting a photon with the same energy as the difference between the two energy levels.

215. 発光スペクトル(はっこうすぺくとる) = *Emission spectrum* = a pattern that shows the different wavelengths of light that can be emitted from an atom. An unknown atom can be identified by looking at its *emission spectrum*, since different atoms have different wavelengths of emitted light (due to the *energy levels* of the electrons.)

$$c = \upsilon\lambda$$

216. 吸収スペクトル(きゅうしゅうすぺくとる) = *Absorption spectrum* = a similar pattern to the *emission spectrum*. An *absorption spectrum* shows the wavelengths of light that are absorbed by an atom. An absorption spectrum can be seen when white sunlight passes through a cloud of gas (for example helium or hydrogen) in space. The atoms in the gas remove certain frequencies of light because these photons have the same energy as the difference in energy levels in the atom.

217. 光子(こうし) = *Photon* = a particle of light. It has energy but does not have a rest mass. Photons always travel at the speed of light.

$$E = h\upsilon$$

218. 波動-粒子の二重性(はどう-りゅうしのにじゅうせい) = *Wave-particle duality* = *wave-particle dualism* = a principle that applies to matter under quantum conditions. It states that waves can act like particles, and particles can act like waves. Light has two natures: a wave nature and a particle nature. The particle nature of light in *wave-particle duality* is the photon. In the same way, matter (e.g., electrons) can act as a wave in some situations (e.g., an electron microscope).

219. ド・ブロイ波(ど・ぶろいは) = *De Broglie Wave* = a wave of matter particles (e.g., an electron beam). Particles can act as a de Broglie wave due to *wave-particle duality*. It was named after the French physicist Louis de Broglie.

$$\lambda = \frac{h}{m \cdot v}$$

220. 光電効果(こうでんこうか) = *Photoelectric effect* = an effect that happens when light hits a conductor (導体) and makes it emit (発する) an electron (電子). This effect can only happen in some materials (usually metals), and the photons (光子) must have a minimum amount of energy. Although he is more famous for discovering relativity, Albert Einstein won his Nobel Prize in 1921 for his research into the photoelectric effect.

221. プランク定数(ぷらんくていすう) = *Planck constant* (*h*) = a constant (定数) named after the German physicist Max Planck. It relates the energy of a photon (光子) to the frequency (周波数) of the EM (electromagnetic) wave.

$$h = 6.63 \times 10^{-34}\ \mathbf{J \cdot s}$$

$$E = h \cdot v = \frac{h \cdot c}{\lambda}$$

222. 電子ボルト(でんしぼると) = *Electronvolt* = **eV** = the amount of energy that an electron (電子) gains if a voltage of 1 **V** accelerates it. It is often used as a unit in particle physics. **MeV** (10^6 **eV**) and **GeV** (10^9 **eV**) are also used.

223. 質量欠損(しつりょうけっそん) = *Mass defect* = a part of the mass (質量) of protons (陽子) and neutrons (中性子) that is changed into *binding energy* to make a nucleus (原子核). Different isotopes (同位体) have different *mass defects*. When the nucleus is formed, some mass (質量) is lost, so the particles (粒子) become lighter. This is an example of mass-energy equivalence.

224. 結合エネルギー(けつごうえねるぎー) = *Binding energy* = the amount of energy needed to separate the protons (陽子) and neutrons (中性子) in a nucleus (原子核). This is the same as the amount of energy created by the mass defect (質量欠損). The *binding energy* Δ*E* is related to the mass defect Δ*m* and the speed of light according to Einstein's famous equation (等式).

$$E = m \cdot c^2$$

$$\Delta E = \Delta m \cdot c^2$$

225. 標準模型(ひょうじゅんもけい) = *Standard model* = a model that attempts to describe all of known physics. It was confirmed in the 1970s. It includes three fundamental forces (the electromagnetic (電磁力) force, the strong nuclear force (強い力/強い相互作用/強い核力) and the weak nuclear force (弱い力/弱い相互作用/弱い核力)) and three categories of elementary particles (素粒子) (*quarks* (クォーク), *leptons* (レプトン) and elementary *bosons* (ボソン)). The standard model is useful because it unifies (brings together) many areas of physics. However, it does not include gravity, and it does not explain some phenomena in modern physics. Theories that are not part of the *standard model* are called "physics beyond the standard model" (BSM).

226. クォーク(くぉーく) = *Quark* = a type of fundamental particle. Nuclear particles (protons and neutrons) and other *hadrons* are made of *quarks*. There are six kinds of quark: up, down, strange, charm, top, and bottom.

227. レプトン(れぷとん) = *Lepton* = a category of particle in the standard model. All *leptons* are elementary particles. Leptons are not affected by the strong nuclear force, so they do not form part of the nucleus of an atom. There are 12 kinds of lepton. They are the electron, the muon, the tauon, 3 kinds of *neutrino*, and all their 6 *antiparticles*.

228. ニュートリノ(にゅーとりの) = *Neutrino* = a type of fundamental particle. Neutrinos have very low mass and no charge, therefore they don't interact with other particles and are difficult to detect. However, they are not rare particles. Many neutrinos are always passing through Earth at the speed of light.

229. 反粒子(はんりゅうし) = *Antiparticle* = a type of fundamental particle that has the same mass as a particle, but opposite charge. When particles meet *antiparticles*, they destroy each other and release energy. In cosmology, *antiparticles* can be called "antimatter". Every kind of *fermion* has an antiparticle. Antiparticles include the *positron* (anti-electron) and antiquarks.

230. 陽電子(ようでんし) = *Positron* = the electron's *antiparticle*. It has the same mass as an electron and the opposite charge (i.e., the same charge as a proton). *Positrons* are created in radioactive beta decay.

231. ボソン(ぼそん) = *Boson* = a category of particle in the standard model. Some *bosons* are elementary particles but others are composite (made from more than one elementary particle). *Bosons* can be force carriers, which means they allow forces to occur between other particles. The elementary *bosons* are the photon (the electromagnetic force carrier), the W and Z bosons (the weak nuclear force carrier), and gluons (the strong nuclear force carrier). There is also the Higgs boson, which was proposed by the Scottish physicist Peter Higgs in 1964. After nearly 50 years, the Higgs boson was finally detected in 2012 by the Large Hadron Collider.

232. ハドロン(はどろん) = *Hadron* = a category of composite particle in the standard model that includes *baryons* (such as protons and neutrons) and *mesons* (such as pions). They are made of quarks that are held together by the strong nuclear force. According to the standard model, baryons are a kind of fermion and mesons are a kind of boson.

233. フェルミオン(ふぇるみおん) = *Fermion* = a category of particle in the standard model that includes *baryons* and *leptons* (i.e., the particles(粒子) that form atoms(原子)).

234. バリオン(ばりおん) = *Baryon* = a category of composite(複合) particle(粒子). They are made of an odd(奇数) number of *quarks*. *Baryons* in nature are made of 3 quarks, but there is some evidence that *baryons* with 5 or more quarks (called pentaquarks) could exist. The `proton(陽子), neutron(中性子), antiproton(反陽子) and antineutron(反中性子) are all examples of *baryons*.

235. 中間子(ちゅうかんし) = *Meson* = a category of composite(複合) particle(粒子). They are made of two particles(粒子): one quark and one antiquark. They are created in high-energy particle collisions(衝突) (such as in a particle accelerator(粒子加速器)) and they can be used to understand the behavior of quarks in these experiments. They can be created for a short time during strong force interactions between baryons. They are highly unstable(不安定) and they decay(崩壊する) quickly. *Mesons* were first proposed in 1935 by the Japanese physicist Hideki Yukawa.

236. パウリの排他律(ぱうりのはいたりつ) = *Pauli exclusion principle* = a principle in quantum mechanics(量子力学) that affects fermions(フェルミオン) but does not affect *bosons*. It states that two identical(同一の) *fermions* in a system(系) cannot both have the same quantum mechanical(量子力学的) properties(性質) (i.e., the same values of the four quantum numbers: the principal(主) quantum(量子) number(数), the azimuthal(方位) quantum(量子) number(数), the magnetic(磁気) quantum(量子) number(数), and the spin(スピン) quantum(量子) number(数)). This principle is one of the reasons why electrons(電子) in an atom(原子) have discrete energy levels.

237. 量子数(りょうしすう) = *Quantum number* = properties of a fermion(フェルミオン) in a quantum(量子) system(系), for example an electron(電子) in an atom(原子). There are four quantum numbers in total. They are the principal number (*n*), the angular number (*l*), the magnetic number (m_l), and the spin number (m_s). Quantum numbers have integer(整数) or half-integer values. The possible states of an electron are shown by the combinations of the allowed values of these numbers.

$$n = 1, 2, 3 \ldots$$

$$l = 0 \text{ to } n - 1$$

$$m_l = -l \text{ to } l$$

$$m_s = \pm {}^1/_2$$

238. 殻(かく) = *Shell* = a volume around an atom(原子) that a specific number of electrons(電子) can orbit(周回する) in. The first shell can contain 2 electrons, the second shell can contain 8 electrons, the third shell can contain 18 electrons, and so on. The number of electrons depends on how many combinations of l, m_l and m_s are possible for a given value of n. Each shell is made of *orbitals*(原子軌道/電子軌道).

239. 原子軌道(げんしきどう)/電子軌道(でんしきどう) = *Orbital* = a region(領域) around an atom(原子) (part of the *shell*) that a single electron(電子) can exist in. The shape of an *orbital* depends on the values of the quantum number l. Each orbital can contain 2 electrons. *Orbitals* are very important in chemistry because they determine the properties of an atom(原子).

Prepared and Compiled by:

【作成者】
岡山県立倉敷天城高等学校
元　講　師　　ラモン ファーガス：Ramon Fargas
ＡＬＴ　　ルシアン グレニー：Lucian Glenny
元指導教諭　　仲達修一：Shuichi Nakadachi
実習助手　　白神陽一朗：Yoichiro Shirakami

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岡山県立倉敷天城高等学校

Okayama Prefectural Kurashiki Amaki Senior High School

〒710-0132　　岡山県倉敷市藤戸町天城２６９番地

Zip code：　710-0132

269 Amaki Fujito-cho, Kurashiki-shi, Okayama-ken, Japan

TEL　086-428-1251　　FAX　086-428-1253

URL　http://www.amaki.okayama-c.ed.jp/

e-mail　amaki@pref.okayama.jp　（学校代表）

amaki-ssh@pref.okayama.jp　（ＳＳＨ）