1. **The creation of this element can be prevented via the Cameron–Fowler mechanism during "hot-bottom burning," in which a lighter, cooled element is produced instead. One of this element's resonances has a nucleus shaped like an obtuse triangle and is named after Hoyle. One of this element's oxides shrouds the edges of molecular clouds and is constant between gas clouds, making it useful in finding galactic molecular hydrogen distributions. Stars creating this element by fusion travel up the** (*) asymptotic giant branch, and it is mainly distributed by stellar winds from red giants. Chondrites named after this element formed in oxygen-rich regions. The Fischer–Tropsch reaction IN SPACE produces hydrogen gas from its monoxide. Dead stars made primarily of this element are called white dwarfs. For 10 points, name this element produced via helium fusion in the triple-alpha process.
ANSWER: **carbon** [or **C**]

2. **A paper led by Kenneth Arrow that attempted to apply this concept to the measurement of wealth compared the US, China, India, Brazil, and Venezuela. Gro Harlem Brundtland chaired a United Nations commission whose report, *Our Common Future*, proposed an influential definition of this concept. According to Hartwick's rule, a weak form of this criterion results when rents from non-renewable resources are invested into manufactured capital as long as they are substitutable. The** (*) triple bottom-line accounting framework emphasizes the "three pillars" of this concept, including the economy, society, and environment. An xkcd comic plots the frequency of this word on a log-scale over time to extrapolate that all sentences will be this word over and over by 2109. For 10 points, name this word, often paired with "development," which refers to the ability to live in a way that allows future generations to live as well as the current one.
ANSWER: **sustainability** [accept word forms, or answers like "**sustainable** development" that include word forms]

3. **A closed one of these functions is distinguished from a lasso in that the lasso has their defining property at all but one point. The exponential map on a Riemannian manifold generates the flow named for these functions. The general definition of these functions is that the metric of the covariant derivative of the derivative of one them and the derivative of one of them vanishes. A set of equations describing these functions is: the second derivative of the coordinate plus sum over the** (*) Christoffel symbols times the first derivative of the coordinate squared the equals 0. For 2D spaces in R-3, these curves are the trajectories for which acceleration is perpendicular to the surface. On the sphere, these objects are great circles. For 10 points, name these trajectories which are the shortest path between two points on a space.
ANSWER: **geodesic**s

4. **This character asks another to guess a number between 1 and 3, not including 1 and 3, but lets that person win after that person guesses 4 and M. This character says "you can't just have your characters announce how they feel. That makes me feel angry!" The entrance to this character's home is in an amusement park that was shut down after a bunch of people got salmonella from the flume ride. This character sings Bender a song after Bender violates a contract to** (*) robotology, and wins a contest using a golden fiddle. This character has a "ridiculously circuitous" plan, which involves giving getting Bender to deafen Leela so that she can't hear Fry's concert and is tricked into marrying this character. That plan begins after Fry's frustration with his poor holophonor skill causes him to trade hands this character. For ten points, name this character whose hands, according to a classic Futurama episode, are "idle playthings."
ANSWER: Robot **Devil** [or **Beelzebot**; accept things like "**robot** version of **Satan**" or other equivalents]

5. **In string theory, the world-sheet must possess one of these operations named for Weyl ("vile"). If the classical action possesses one of these which the quantized theory does not, it is called anomalous. The Coleman–Mandula theorem constrains the types of these which the S-matrix may possess, and the Haag–Lopuszanski–Sohnius theorem found a loophole in that argument in the form of fermionic versions of them. A constructruction which removes one of these operations which for only works for scalar theories involves rewriting a field in the Lagrangian as its vev minus another field. Massless particles will be generated when the Lagrangian has one of these but the ground state does not according to (*)** Goldstone's theorem. Theories are abelian when their group of these transformations is abelian; that is the case for the U(1) group of electromagnetism. For ten points, W and Z bosons get mass through the Higgs mechanism in which what operations are "spontaneously broken"?
ANSWER: **symmetry** [accept **anomaly** before mention]

6. **Cone-in-cone structures are most commonly made from this compound. Like a similar sulphate compound, this compound's inverse solubility in water causes it to be a major source of fouling in heat exchangers. Sediments rich in this compound are absent below about 4500 meters in the ocean because lower concentration and temperature make more of it dissolve; that is its (*)** compensation depth. Pteropods are very sensitive to ocean acidification because their shells are made from a mineral of this compound. Those shells form an ooze made largely of this material, as do foraminiferan tests and coccoliths. Speleothems are formed in caves from to deposition of this compound. A less stable mineral form of this compound is vaterite. For 10 points, name this compound whose most common mineral forms are aragonite and calcite, the main components of limestone.
ANSWER: **calcium carbonate** or **CaCO₃** [prompt on "**limestone**," "**calcite**," "**aragonite**," or "**vaterite**"]

7. *Note to all: the answerline is broad.*
Beer's List concerns this process, whose kinetics are considered capacity-limited and saturable. Sandwich cultures, cocktail assays, and "reaction phenotyping" are methods to study this process. "Perpetrator-victim" competition during this process can cause "maximum exposure." BCS Classes I and II have this type of clearance. In the first component of the (*) two-component model, this process occurs along with excretion. Functionalization reactions during this process are done by mixed-function oxidases. Reduced [bilirubin conjugation to glucuronide] by UGTs in one phase of this process causes jaundice. Soft drugs and prodrugs are activated by this process. Drug "extraction" refers to susceptibility to the "first-pass" of this process. Cytochrome P450s in the liver "detoxify" drugs in this three-phase process, making them polar. For 10 points, name this process, the "M" in ADME.
ANSWER: xenobiotic **metabolism** [accept Phase I, II, or III **metabolism**; prompt on "**pharmacokinetics**" or "**ADME**(T)"; accept **liver detox**ification]

8. **The Von Frey test measures sensitivity to this sense, which is transduced by C-LTMRs in mice. Alligators have dark-colored, dome-shaped ISOs to detect this sense. One animal has two "rays," or foveas of this sense, made of 25,000 Eimer's organs each. Superficial neuromasts, which are located in lateral line organs, are dedicated to this sense in fish and amphibians. Unmyelinated vesicle chain receptors are inside the (*)** "push-rods" that detect this sense in the bills of platypi and the snouts of echidnas. Pacinian corpuscles and Merkel cells are ways to detect this sense, which mammalian follicle-sinus complexes contain vibrissae for sensing. The adhesive removal test and paw whisker test measure this sense. Sentry hairs on naked mole rats and "star noses" are ways, for 10 points, to transduce which sense?
ANSWER: **touch** [or **somatosensation** or **vibration**; prompt on "**mechanosensation**" or "**feeling**"; do not accept "proprioception"]

9. **The Euclidean path integral formalism can be used to show that the action to transition between degenerate vacua is the same applying this method to the same potential with an opposite sign. Using this method for the "bouncing neutrons" problem gives an energy proportional to N minus one-fourth to the two-thirds. This method gives a solution that is equal to one over the square root of momentum times a complex exponential of the integral of the momentum. One part of this method involves patching together two areas with a linear potential and solving the Schrödinger equation in that region. The solutions are the (*)** Airy functions, and they occur at the turning points. This approximation was used to model the probability of escaping from an attractive strong force potential to a repulsive Coulomb potential in Gamow's theory of alpha decay. It can be used to find transition probabilities for tunnelling through a slowly-varying potential barrier. For 10 points, name this approximation used in quantum mechanics, named for three guys.
ANSWER: **WKB** approximation [accept answer with **Wentzel**, **Kramers**, and **Brillouin** in any order; accept it with Jeffreys; accept **semiclassical** approximation]

10. **This space is the classifying space of the group Z direct sum Z. When this space is embedded in S-3, it contains knots associated to any coprime pair of positive integers. The complement of this space in S-3 comprises two homeomorphic connected components. Every elliptic curve over the complex numbers is isomorphic to this space as a Riemann surface. Every closed orientable surface is a connect sum of zero or more copies of this surface, which has a (*)** flat geometry and Euler characteristic zero. This surface can be formed by attaching a single 2-cell to a wedge of two circles a and b along the path a b a-inverse b-inverse, or equivalently by gluing together the opposite edges of a rectangle in the same direction. This surface is produced by S-1 cross S-1. For 10 points, name this product of two circles.
ANSWER: **torus**

11. **A character protests that he should be excused from saving this entity because of his malformed public-duty gland and a natural deficiency in moral fibre. A theory about the nature of this entity was invented by a man in order to annoy his wife, and is able to deduce the nature of this entity from the composition of a piece of fairy cake. The only person to survive a certain "perspective vortex" that shows you all of this thing is a certain hoopy frood with two heads. According to one theory, this entity was sneezed out of the nose of the Great Green Arkleseizure. Another theory is that if anyone ever discovers the (*)** true nature of this entity it will immediately be replaced by something even weirder, and according to another theory, that has already happened. The creation of this entity "has made a lot of people very angry and has widely been regarded as a bad move." The restaurant Milliways exists at the end of this entity. For 10 points, name this place, which appears along with life and everything in the title of a Douglas Adams novel.
ANSWER: the **Universe**

12. **In functional programming, these structures have the advantage of being both incremental *and* parallelizable. By Eilenberg's theorem, varieties of these structures are in one-to-one correspondence with certain classes of recognizable languages. An example via Schützenberger's theorem is that star-free languages are exactly those with an aperiodic example of these structures. A language being recognized by a finite automaton is equivalent to being recognized by a finite one of these structures. The set of equivalence classes obtained by a syntactic congruence is used to define their syntactic example. When generated by an alphabet, a type of these structures is equivalent to the set of strings in the alphabet, has a "product" defined by string concatenation, and is the (*)** "free" type, of which formal languages are a subset. They're defined as a set with an associated binary operation that has an identity and obeys associativity. For 10 points, name these ubiquitous structures in computer science that differ from semigroups in that they have an identity element.
ANSWER: **monoid**s [or syntactic **monoid**; prompt on "**semigroup**s"; do not accept "monads"]

13. **When two benzenes, one of which is attached to six of these atoms, [face-to-face pi stack], their quadrupole moments invert. Alkanes with this element show charge-alternating inductive effects. This element's bonds with carbon have strong 1,3-dipolar repulsions with C–H bonds. In 1,2-disubstituted ethyl groups, this atom triggers a [LUMO-lowering gauche effect] when beta to a heteroatom. The "block effect" occurs when replacing [hydrogen in C–H bonds] with this element. This element weakly donates pi-electrons only to cations, but is a (*)** strong para-activator and withdraws sigma-electrons. This halogen's addition to alkenes gives a *syn* product. It has a "mimic effect" for hydrogen and is a "superhalogen." This halogen has the strongest charge-shift bonding properties. Its bond to carbon is the strongest in organic chemistry. For 10 points, name this most electronegative halogen.
ANSWER: **fluorine** [or **F**]

14. **Assays of this structure's activity use succinyl-LLVY motifs bound to 7-Amino-4-methylcoumarin. PA700 unfolds its substrates, which obey the "N-end rule" and often have high PEST content. [CHIP's U-box binding to HSP70] and HSP90 inhibitors both promote this complex's activity. Type I interferon-induced ISG15ylation indirectly, and (*)** SUMOylation directly, send substrates here. With an E4-like factor, Parkin activates it. In making isopeptide bonds with lysine-29s or 48s, E1 activating-, E2 conjugating-, and E3 ligases target substrates thrice or more to send them to this complex. It has a barrel-like 20S core particle with two 19S lid-like regulatory particles in humans. An alpha-ring tops this gate-and-latch complex where substrate carbonyls are hydrolyzed. For 10 points, name this human 26S complex that degrades polyubiquitinated proteins.
ANSWER: **proteasome**

15. **In 1969, Taylor and Spinrad used spectra of K giants to argue for the existence of objects with a "super" high value for this quantity. Stars with a low value of this quantity called CEMPs have strong CH bands. Researchers at ESO discovered that the galaxy COSMOS Redshift 7 has an excitingly low value for this quantity. Lequeux's 1979 study of irregular and blue compact galaxies has led to the realization of the correlation of mass and this quantity. This value is denoted by an X over H inside square brackets, and a value of one means that the object has a (*)** value 10 times higher than in the sun. It's not age, but this quantity is now used to classify stars into populations I, II, and III, and it's commonly measured as the log of the ratio of iron atoms to hydrogen atoms. For 10 points, name this quantity which measures the amount of elements which are not hydrogen or helium.
ANSWER: **metallicity** [or **Z**]

16. **Bergman and Graham used an iridium atom bonded to two hydrogen atoms, a Cp* ("C-P-star") ring, and one of these ligands to perform the first photochemical intermolecular C–H bond activation. The rate of the Murai reaction is inversely proportional to the concentration of these compounds, since a free one is formed during the generation of the active species. One of these compounds was replaced with an N-heterocyclic (*)** carbene ligand in the second generation of Grubbs' catalysts. A 14-electron active species for alkene hydrogenation is formed by the dissociation of one of these ligands from Wilkinson's catalyst. One of these compounds reduces azides to amines in the Staudinger reaction; that compound can also react with an alkyl bromide to generate an ylide in the Wittig reaction. For 10 points, name these compounds which have general formula PR3.
ANSWER: **phosphines** [accept any specific phosphines like tricyclohexyl**phosphine** or triphenyl**phosphine**; do not accept "phosphites"]

17. **In a discourse on these entities, Kenelm Digby denied the importance of a "vis formatrix" while noting the subsistence of a "balsamick Saline juyce." Abu Hanifa compiled Bedouin knowledge on these entities in his most famous work. A book by Andrea Cesalpino on these entities notably contains no illustrations, and Cesalpino was one of the first people to collect them. Michael Marder runs a Los Angeles Review of Books blog on the phenomenology of these entities. Goethe searched for an archetypal (*)** design of these entities in a book on their metamorphosis and in his *Italian Journey*. A scientific poem by Erasmus Darwin on these entities was the first English-language work to use the word "oxygen." Theophrastus carried out a detailed classification of these entities and their uses at the behest of Aristotle, who in *De Anima* wrote that these entities have only a nutritive soul. For 10 points, name these living things, usually sessile, that Aristotle distinguished from animals.
ANSWER: **plant**s [or obvious equivalents, such as **vegetation** or **flora**]

18. **A good scoring system for this disease is the Shwachman–Kulczycki one. To check for steatorrhea in this disease, 72-hour fecal fat balance tests are used. After isoproterenol is added, two electrodes measure amiloride-dependent sodium absorption in the nasal potential difference test for this disease. "Linear markings" in this disease are one of four categories measured by its age-old radiographic Brasfield scoring system. Heel prick tests for it give Guthrie cards with high (*)** immunoreactive trypsinogen levels in neonates. In a marker perfusion technique for this disease, CCK and secretin are added to the duodenum. To check for this disease with pancreatic sufficient and insufficient forms, a Gibson–Cooke apparatus can do a quantitative pilocarpine iontophoresis, or sweat, test. For 10 points, name this disease often caused by a delta-F508 mutation in a chloride transporter, in which lung mucus builds up.
ANSWER: **cystic fibrosis** [accept **CF** or **mucoviscidosis**]

19. **In a 2016 paper in *Science*, Pazos-Outón et al. demonstrated that using a lead-iodide form of these minerals allows for photon recycling leading to increased characteristic length of energy transport and efficiency. The simplest layered phase of this mineral is named for Ruddlesden and Popper and its intruding layer is composed of an alkali metal in its Dion–Jacobson phase. A crystal structure named for this mineral has general formula (*)** ABX3, where A is a larger cation than B and X is an anion. A phase change from minerals of this type to a similarly-named form is thought to be the cause of the seismic discontinuities at the D double prime layer. Many high-temperature superconductors adopt a structure named for this mineral and have copper-oxide layers, like YBCO. Along the core-mantle boundary is a high-pressure magnesium silicate known as its "post" form. For 10 points, name this mineral composed of calcium titanium oxide and named for a Russian mineralogist.
ANSWER: **perovskite**

20. **One part of these devices has types including "box and grid," "circular cage," "linear-focused," and "venetian blind." The radiant sensitivity of these devices is equal to quantum sensitivity times wavelength divided by 1.24. Bialkali or multialkalis are commonly used for another part of these devices. Varieties of them which are "side-on" usually have a reflective cathode, compared to the transparent cathode of the "head on" variety. Like CCDs, these devices can experience dark current when thermal fluctuations allow electrons' energy to exceed their (*)** work function. These devices consist of a photocathode, several dynodes which are each at a higher voltage than the previous one, and an anode to collect signal, which is a result of secondary emission. These devices are often coupled to scintillators to detect ionizing radiation. For 10 points, name these devices which, as their name suggests, amplify the signal of an incoming photon.
ANSWER: **photomultiplier** tube [or **PMT**; prompt on "**phototube**" or "**vacuum tube**"]

21. **The "threshold" denoted by this term is less than one for all problems that can be reduced to a search for a structure S such that a maximal number of tuples x fulfill phi of S comma x, where phi must be a quantifier-free term of first-order logic. A class of reductions that is "preserving" of this term includes L-reductions. To be useful, algorithms denoted by this term should have an epsilon value less than one, which is true for problems in MAXSNP. The performance of this process is bounded by a constant for problems in the class APX. A time complexity that is polynomial in the input size is required for polynomial time "schemes" denoted by this term. The** (*) **PCP theorem is used to determine the "hardness of" this term. This type of algorithm** is often used for NP-hard optimization problems because a polynomial-time exact algorithm doesn't exist. For 10 points, identify this type of algorithm that finds a near-optimal solution to a problem.
ANSWER: **approximation** algorithms [accept word forms, such as **approximability**; prompt on "**heuristic**" or "**near-optimal**"; <u>do not accept</u> "optimal"]

22. *Note to all: the answerline is quite broad.*

The Albertsson equation determines one protein behavior in this type of system. Their formation is described by the Cahn-Hilliard equation. In these systems, complex coacervation results in the formation of structures like microcapsules. Spinodal decomposition, which is a form of demixing, results in this systems. Metastable extensions to (*) **tie lines extend into regions with these conditions. The lever rule is used in these systems to** determine their components' ratios. Measuring the binodals of these systems after the "cloud point" is reached is done in turbidimetric titrations. Hofmeister effects alter solubility in these systems, which have miscibility gaps. PEG and dextran are commonly used in extractions of this type. Eutectic solids and colloids are this type of system. A metric called logP is measured in octanol and water, which is this type of system. For 10 points, what systems have their phases combine at the critical point?
ANSWER: **biphase**/**ic** or **two-phase** systems [accept **liquid-liquid**, **liquid-gas**, **solid-solid**, **ABS**, **ATPS**, **alloys**, **colloids**, **eutectic solids** or anything indicating that two phases of matter are present before mentioned]

23. **The Kadowaki–Woods ratio equals one of the terms in a metal's resistivity over the square of a term in the expansion for this quantity. In 1975, Anres, Graeber, and Ott discovered that $CeAl_3$ forms a metal whose values for magnetic susceptibility and this quantity were about 1000 times higher than conventional metals and speculated that this was due to "heavy f-electrons." Those electrons are said to have a high effective mass because the Sommerfeld coefficient for this quantity is proportional to mass and is anomalously high. For a Bose–Einstein condensate, this quantity has a numerical coefficient of 15 times the Riemann zeta function of five-halves over 4 times the zeta function of three-halves, or about 1.93. For an** (*) **ideal gas, one may compute** this quantity by differentiating both sides of the equipartition theorem. This quantity is proportional to the cube of temperature in a model that treats vibrations as phonons named for Debye, and it's about a 3 times the gas constant per mole according to the Dulong–Petit law. For 10 points, name this quantity which measures how much energy is needed to increase the temperature.
ANSWER: specific **heat capacity** [or **specific heat**; prompt on "**C**"]

24. **H. Allen Orr proposed a sign test to determine occurrences of this phenomenon using QTL data. This phenomenon can be inferred from a value of F-st that deviates strongly from its phenotypic analogue, Q-st. Fay and Wu's H improves over Tajima's D's ability to detect this phenomenon from the frequency spectrum of alleles. Pleiotropy can cause correlated responses to this phenomenon. A ratio of nonsynonymous to synonymous substitutions that is much** (*) **greater or less than one is a signature of this phenomenon. According** to the breeder's equation, the trait response equals narrow-sense heritability times the strength of this phenomenon. Genetic hitchhiking due to linkage occurs as a result of "sweeps" caused by this phenomenon. This effect of this process can be disruptive, directional, or stabilizing. For 10 points, name this phenomenon in which phenotypic differences cause variation in reproduction, the core of Darwin's theory of evolution.

ANSWER: natural **selection** [accept any specific kind of selection]