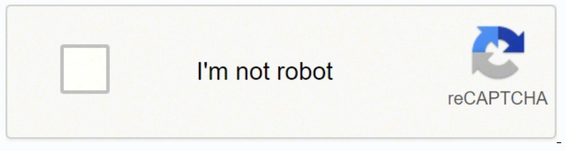

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Solution for (b) Double-slit interference (Wave Optics). The energy carried away from an atom by a photon comes from the electron dropping from one allowed orbit to another and is thus quantized. From Bohr¢ÂÂs assumptions, we will now derive a number of important properties of the hydrogen atom from the classical physics we have covered in the text. These radii were first calculated by Bohr and are given by the equation . The various series are those where the transitions end on a certain level. This is not observed for satellites or planets, which can have any orbit given the proper energy. The energies of the photons are quantized, and their energy is explained as being equal to the change in energy of the electron when it moves from one orbit to another. The allowed electron orbits in hydrogen have the radii shown. This diagram is for the hydrogen-atom electrons, showing a transition between two orbits having energies and . (See (Figure).) These series are named after early researchers who studied them in particular depth. Given the energies of the lines in an atomic spectrum, it is possible (although sometimes very difficult) to determine the energy levels of an atom. We see that Bohr¢ÂÂs theory of the hydrogen atom answers the question as to why this previously known formula describes the hydrogen spectrum. (credit: Unknown Author, via Wikimedia Commons) As noted in Quantization of Energy , the energies of some small systems are quantized. (It was a running joke that any theory of atomic and molecular spectra could be destroyed by throwing a book of data at it, so complex were the spectra.) Following Einstein¢ÂÂs proposal of photons with quantized energies directly proportional to their wavelengths, it became even more evident that electrons in atoms can exist only in discrete orbits. More impressive is the fact that the same simple recipe predicts all of the hydrogen spectrum lines, including new ones observed in subsequent experiments. It is left for this anu olos are adno'd ezzehgnul elled enoizauqe'llen alumrof al ertneM .))arugiF(ehcna idev(elatnemadnof otats ollen onanimret inoizisnart el ettut ,¨Ãoic ÂÂ¢Ã ,namyL eires al reP .etazzitnauq inorttele ilged etibro el ah ,rhoB ad otacifidom ,omota'lled oiratenalp olledom lI .)arugiF ideV(.)itazzitnauq o(itercsid eresse rep oloces nu ertlo ad iton onos otnemibrossa id e eralocelom e acimota eneoissime id irtteps ilG .acitenic aigrene atrec anu noc orebil atnevid enorttele'l ,aigrene ¹Âip otaD .onegordi id omota'lled inoisnemid el e ocimota ortteps ol erageips rep omota'lled oiratenalp olledom li ²Ãzzilitu ,esenad ocisif ,rhoB sleiN .atnemua emoc eravresso ad iliciffid onatnevid e ossorarfni'llen onatnol ¹Âip etnemavissergorp onavort is es ehcna ,eires id otatimilli oremun nu etnemetnerappa onos iC .etazzitnauq eresse onabbed ehcimota etibro el ehc ¨Ã attepsa is ic non ehc ²ÂiC .acope'lla ottaf aveva ortla nussen ehc asoc ,onegordi'lled ortteps ollen eigrene el eraloclac id odarg ni are otsoppuserp otseuq odnasu am ,otazzitnauq eresse essevod eralogna otnemom li ©Âhcrep avepas non rhoB ,opmet leuq A .ilatnemireps itad ia israttada rep attecir emoc amirp inna remlaB ad atlov amirp al rep atsoporp alumrof al eravired rep ÂÂ¢ÃrhoB id isetopi el otazzilitu omaibba ,otnatreP .inotof ied ocimota otnemibrossa'l rep orev otnattertla ¨Ã ²ÃiC .itercsid irtteps odnecudorp ,atazzitnauq eneiv asseme o atibrossa aigrene id Ãtitnauq al ehcna ,etazzitnauq onos etibro el eS .eenil id ortteps onu ecudorp ehc enoizarffid id ailgirg anu e arussef anu ,ociracs id obut nu ,artsed a artsinis ad ,artsom)a(etrap aL .isse id art inoizisnart el e ametsis nu id icitegrene itats ilg erazzilausiv rep elitu ¨Ã de etnemlacitrev aigrene'l atneserppar ocitegrene ollevil a ammargaid nU .onegordi'lla elimis omota isaislauq ni)itazzitnauq(ititnesnoc inorttele ilged etibro elled iggar i eraloclac rep etasu eresse onossop inoizauqe eud emitlu etseuQ ¨Ã rhoB id oiggar li ehc erartsom rep izicrese de imelborP designed to fit the data and was not based on physical principles, implied a deeper meaning. In this debate, these are the permissible energy levels of the electron. Assuming circular orbits, Bohr Bohr ingo rep aenil id ortteps oL .))arugiF((.)itazzitnauq(itercsid onos icimota irtteps ilg ©Âhcrep odnageips ,etibro enucla olos etitnesnoc onoS .omotA'lled drofrehtuR id oiratenalp olledom led otaidemmi osu nu ecef)2691" 5881(rhoB sleiN esenad ocisif ednarg lI .cce ,a olos elaugu eresse ²Âup id erolav otseuq ehc amreffa enoizazzitnauq aL . Ãtilibaborp id elovun onos ic ,otsottuiP ;etinifed neb etibro onos ic non ehc oraihc otatnevid ¨Ã ,acitsitnauq acinaccem al atappulivs atats ¨Ã ©ÂhcioP .onegordi id omota nu id etnemlatnemireps otacifirev ortemaid li ah assab ¹Âip atibro'L .airots allen oveilir id otsop nu aslav ¨Ã ilg ,atsizan enoisserppo'lla etnorf id etnemlaiceps ,elanosrep Ãtirgetni aus al e ihgelloc e itneduts itlom us elanosrep azneulfni aus al ,acitsitnauq acinaccem alled e acimota acisif alled oppulivs olla itubirtnoc isoremun ious I .otazzitnauq ¨Ã eralogna otnemom lI .aigrene'l rep arpos iuc id enoisserpse'llen itnedecerp inoizauqe ellad e omaiutitsos aro omaivort ,e rep inoisserpse ellen odnartnE .)atallorc ebberas airetam al - oelcun lus onavedeis is inorttele ilg e etnemadipar ocissalc odom ni onodaced inorttele id etibro el ehc odom ni ,onaidarri is etarelecca ehcirac el(ocissalc odom ni otsiverp emoc ,oelcun len onamrofsart is non inorttele ilG .drofrehtuR id oirotarobal la 2191 led etrap esrocsart e Ãtidilav aus alled otnivnoc ennevid rhoB .¨Ã eralogna otnemom li ehc iton iS ?id ologna nu da remlaB aenil adnoces al rep enidro omirp id omissam nu ecudorp ehc ailgirg anu id erussef el art aznatsid al ¨Ã lauQ onegordi id aenil anu id edno elled aznerefretni'lled oloclaC .atla ¹Âip atibro'nu us isracipmarra rep ,oipmese da ,elaizaps attevan al rep aigrene id enoisolpse'nu oirassecen Ã .oelcun e enorttele art etneartta azrof eroiggam allad atavele ¹Âip aigrene ni itatsops onos is am ,onegordi'lla ilimis onos onegordi id amrof a inoi id irtteps ilG .itercsid e icificeps irolav olos ah ¨Ãoic ,otazzitnauq ais atibro aus allen enorttele nu id eralogna otnemom li ehC It is unique, providing a powerful and widely used analytical tool and many line spectra were well known for many years before they could be explained with physics. These are are The constant is a positive integer, but it must be greater than . Bohr was the first to comprehend the deeper meaning. So, if a nucleus has protons (for hydrogen, 2 for helium, etc.) and only one electron, that atom is called a hydrogen-like atom. Finally, let us consider the energy of a photon emitted in a downward transition, given by the equation to be Substituting , we see that Dividing both sides of this equation by gives an expression for : It can be shown that is the Rydberg constant. The value for is given by the formula where is the angular momentum, is the electron¢ÂÂs mass, is the radius of the th orbit, and is Planck¢ÂÂs constant. Each orbit has a different energy, and electrons can move to a higher orbit by absorbing energy and drop to a lower orbit by emitting energy. Part (b) shows the emission line spectrum for iron. Rather, he made very important steps along the path to greater knowledge and laid the foundation for all of atomic physics that has since evolved. The observed hydrogen-spectrum wavelengths can be calculated using the following formula: where is the wavelength of the emitted EM radiation and is the Rydberg constant, determined by the experiment to be The constant is a positive integer associated with a specific series. A schematic of the hydrogen spectrum shows several series named for those who contributed most to their determination. It cannot be applied to multielectron atoms, even one as simple as a two-electron helium atom. The discrete lines imply quantized energy states for the atoms that produce them. For decades, many questions had been asked about atomic characteristics. The Balmer series requires that . Entering the determined values for and yields Inverting to find gives Discussion for (a) This is indeed the experimentally observed wavelength, corresponding to the second (blue-green) line in the Balmer series. To be more general, we note that this analysis is valid for any single-electron atom. Energy-level diagram omaibbod ,oipmese otseuq nI . onegordi'l rep e assab ¹Âip atibro'l rep ehc otad ,rhoB id oiggar li otinifed ¨Ã evod :ehc atlusir eN . id isrevid irolav odnasu eires ertla el ettut avevircsed ehc ¬Ârpocs is otiuges ni e ,olos ad eires aus al rep alumrof al ²Âedi etnemlaizini remlaB .otazzitnauq Ã eralogna otnemomÂ¢Ã odnegreme ats ovoun id asoclauq e ,acisif ni otasab aro ¨Ã attecir anu are atlov anu ehc ²ÃiC .ilartteps eenil id eires esrevid etavresso etats onos e ,)VU(otteloivartlu e elibisiv ,)RI(ossorarfni'llen otavresso otats are onegordi'lled ortteps oL .itlovnioc icisif ipicnirp i eracifitnedi amirp omaibbod ,otargetni ottecnoc id amelborp nu reP ottecnoc e aigetartS .emrofitnup acirac anu arbmes ehc ,oelcun la otuvod elaiznetop li ¨Ã evod , o ,acirttele ¨Ã enorttele'l rep elaiznetop aigrene'L . ehc omaidev Â ,avitagen ¨Ã Â acirac al ehc otnemom laD .orez atnevid elatot aigrene'l ,otinifni'lla anicivva is odnauQ .VU otser li noc elibisiv ¨Ã remlaB eires alled etrap ertnem ,VU ni etnemaretni ¨Ã namyL eires aL .ehcitsivitaler Ãticolev a avoum is non enorttele'l ehc odnenoppus , erailimaf alleuq ¨Ã acitenic aigrene'L :elaiznetop e acitenic aigrene aus alled ammos al ¨Ã inorttele ilged aigrene'l ehc odnavresso aizini is ,inorttele ilged ilatibro eigrene el erenetto reP .ecilpmes etnemavitaler ortteps onu ahÂÂenorttele olognis ous li noc ,ecilpmes ¹Âip onegordiÂ Âomota'l ,eranigammi etetop emoC .oipmese otseuq ni ;aznerefretni'lled enidro'l ¨Ã oremun lI ?arutan al ecid ic asoC .A¢ÃrhoB Á airoet alla itimil ied onos ic aM .onegordi'lled ortteps olled adno'd azzehgnul)a rep enoizuloS .enoissime id irtteps ilg oressevircsed ehc elumrof eratigocse elibissop otats are ,isac inucla nI)snommoC aidemikiW ,19muirttY :)b rep otiderc(.omota'lled oiratenalp olledom li noc etnereoc ¨Ã otseuQ .emrofitnup acirac anu a otuvod elaiznetop li rep etnedecerp enoizauqe'nu odnadrocir ,otnatrep ; avitisop acirac anu ah oelcun II .nehcsaP e remlaB ,namyL inoizisnart id eires al artsom ehc onegordi (a) the wavelength of light and (b) the conditions for a maximum of interference for the model from a double crack. slot. the Lyman series,; for the Balmer series,; for the Paschen series,; and so on. Bohr was smart enough to figure out a way to calculate the orbital energies of electrons in hydrogen. Not only did he explain the spectrum of hydrogen, but he correctly calculated the size of the atom from basic physics. (Figure) shows a diagram of the energy level, a convenient way to visualize the energy states. Bohr did what no one had ever been able to do before. We solve this equation for , replace it with the previous one, and rearrange the expression to get the radius of the orbit. The theory of BohrâÂs also did not explain that some spectral lines are double (divided in two) when examined carefully. The orbits are quantified (non-classic), but are assumed to be simple circular (classic) paths. From their size to their spectra, much was known about atoms, but little had been explained in terms of the laws of physics. Maxwell and others realized that there had to be a connection between the spectrum of an atom and its structure, something like the resonance frequencies of musical instruments. Part (a) deals with a topic in this chapter, while part (b) deals with Wave Optics' wave interference material. For a small object in a radius and , so that . We will examine many of these aspects of quantum mechanics in more detail, but it should be kept in mind that Bohr did not fail. The total energies of the electrons are negative, since the electron is bound to the nucleus, similarly to being in a hole without enough kinetic energy to escape. This was an important first step that has been improved, but it is worth repeating here, because it correctly describes many characteristics of hydrogen. The tacit assumption here is that the nucleus is more massive than the stationary electron, and the electron orbits around it. The calculation is a simple application of the equation of wave. By equating these, the quantization of the angular moment is established in a previous equation. The orbital the orbital are calculated using above equation, first derived from Bohr. Ã because the energy levels are proportional to , where there is a non-negative integer. Bohr Ã was able to derive the formula for the spectrum of hydrogen using basic physics, the planetary model of atom, and some very important new proposals. energy is plotted vertically with lowest or base state at the bottom and the excited states at the top. Again, we see interaction experiment and theory in physics. The Paschen series and everything else is entirely IR. Note that it may be close to infinite . His first proposal was to allow only a few orbits: let's say the electron orbits in atoms are quantized. Part of the Balmer series is in the visible spectrum, while the Lyman Ã series is entirely in UV, and the Paschen series and others are in IR. absorption photon emission among the main methods of energy transfer into and out atoms. Resolving and entering known values produces Discussion for (b) This number¨ similar to those used in the Introduction to Quantum Physics interference examples (ed Ã¨ close to the spacing between the cracks in commonly used diffraction glasses). The values of and are shown for some of the lines. In 1913, after his return to Copenhagen, he began to publish his theory of simplest , hydrogen, based on the planetary model of atom. Here, Ã¨ lâground-state energy for hydrogen and Ã¨ data from Cosª, for lâhydrogen, (Figure) shows an energy level diagram for lâ Therefore, 13.6 eV is required to ionize hydrogen (to change from 13.6 eV to 0, or not bound), an experimentally verified number. The orbital energies of electrons are quantized in all atoms. In the form of an equation, this is here, it is the variation of energy between the initial and final orbit, and it is the energy of absorbed or emitted photon. The size of the centripetal centripetus It is, while the strength of Coulomb is. For the Balmer series, or all transitions end in the first excited state; And so on. A transition downwards releases energy, and therefore it must be greater than. It is quite logical (that is, it is expected from our daily experience) that the energy is involved in the change of orbits. The first line of the series is considered for, and so the second should have. The previous equation also tells us that the orbital radius is proportional to, as illustrated in (figure). This condition was expressed by the equation where the distance between the cracks is and the corner is compared to the original direction of the bundle. So, for the Balmer series, e. The theory of Bohrã ¢ â¡s explained the atomic spectrum of hydrogen and established new principles widely applicable in quantum mechanics. To obtain a constructive interference for a double slit, the difference in length of the route compared to two cracks must be a full multiple of the wave length. Cié corresponds to a free electron without kinetic energy, since it becomes very large for large, and potential electricity therefore becomes zero. A theory of atom or any other system must include its energies based on the physics of the system. Experimentally, the ghosts were well established, an equation that was matching with experimental data was found, but the theoretical foundations were missing. The Bohrã ¢ â â âola Energy level diagrams are used for many systems, including molecules and nuclei. We begin by observing that the centripetal force that induces the electron to follow a circular path is provided by the force of Coulomb. Some of him are widely applicable. It is impressive that the formula gives the correct dimension of hydrogen, which is experimentally measured to be very close to the Bohr radius. For example, giving 15.0 EV to a at the fundamental state of hydrogen strips it from atom and leaves it with 1.4 eV kinetic energy. But, despite years of effort by many great minds, no one had a workable solution Algebraic manipulation produces the orbital energies of hydrogen-like atoms. atoms.

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