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, the free encyclopedia that anyone can edit. 109,638 active editors 7,015,183 articles in English Magic tablet from Pergamon The Orphic Hymns are a collection of 87 hymns in ancient Greek, addressed to various deities. Attributed in antiquity to the mythical poet Orpheus, they were composed in Asia Minor (in modern-day Turkey), most likely around the 2nd or 3rd centuries AD, and seem to have belonged to a cult community which used them in ritual. The collection is preceded by a proem (or prologue) in which Orpheus addresses the legendary poet Musaeus. The hymns in the collection, all of which are brief, typically call for the attention of the deity they address, describing them and their divinity, and appealing to them with a request. The first codex containing the Orphic Hymns to reach Western Europe arrived in Italy in the first half of the 15th century, and in 1500 the first printed edition of the Hymns was published in Florence. During the Renaissance, some scholars believed that the hymns were a genuine work of Orpheus; later, a more sceptical wave of scholarship argued for a dating in late antiquity. (Full article...) Recently featured: HMS Neptune (1909) Nominative determinism Donkey Kong Land Archive By email More featured articles About Forrest modeling in 2018 ... that Diandra Forrest (pictured) was bullied for her white skin before becoming a professional model? ... that the Savannah River Site was where the neutrino was discovered? ... that one of the earliest Ukrainian science fiction novels, written in 1918 by Mykola Chaikovsky, features solar power and a radiotelephone? ... that the Philadelphia School of Anatomy began as a private dissection room? ... that having been elected to Indonesia's House of Representatives five times, Muhidin Mohamad Said is its longest-serving incumbent member? ... that Horvat Mazad's walls, which also functioned as storage rooms, were likely a revival of centuries-old military architecture? ... that despite never having visited China, cyclist Howard Wing competed for it at the 1936 Summer Olympics? ... that a leader of a terrorist group in the Russian Empire was revealed in 1908 to have been a police agent for 15 years? ... that Ben Lashes is a talent manager for cat memes? Archive Start a new article Nominate an article Trifid and Lagoon nebulae The Vera C. Rubin Observatory in Chile releases the first light images (example shown) from its new 8.4-metre (28 ft) telescope. In basketball, the Oklahoma City Thunder defeat the Indiana Pacers to win the NBA Finals. An attack on a Greek Orthodox church in Damascus, Syria, kills at least 25 people. The United States conducts military strikes on three nuclear facilities in Iran. In rugby union, the Crusaders defeat the Chiefs to win the Super Rugby Pacific final. Ongoing: Gaza war Iran–Israel war Russian invasion of Ukraine timeline Sudanese civil war timeline Recent deaths: Gérard Lefranc Takutai Tarsh Kemp Arnaldo Pomodoro Mikayla Raines John R. Casani Richard Gerald Jordan Nominate an article June 29: Feast of Saints Peter and Paul (Western Christianity) Jayne Mansfield 1613 – The original Globe Theatre in London burned to the ground after a cannon employed for special effects misfired during a performance of Henry VIII and ignited the roof. 1764 – One of the strongest tornadoes in history struck Woldegk in present-day northeastern Germany, killing one person. 1950 – The United States defeated England during the FIFA World Cup in one of the greatest upsets in the competition's history. 1967 – Actress Jayne Mansfield (pictured), her boyfriend Sam Brody, and their driver were killed in a car accident outside of New Orleans, while her children Miklós, Zoltán, and Mariska Hargitay escaped with only minor injuries. 2020 – Reddit banned r/The_Donald, a pro-Trump subreddit, for rule violations and antagonizing the company. Ernest Fanelli (b. 1860)Ludwig Beck (b. 1880)Paul Klee (d. 1940)Nestor Binabo (d. 2023) More anniversaries: June 28 June 29 June 30 Archive By email List of days of the year About The thousand-yard stare (also referred to as the two-thousand-yard stare) is the blank, unfocused gaze of people experiencing dissociation due to acute stress or traumatic events. The phrase was originally used to describe war combatants and the post-traumatic stress they exhibited but is now also used to refer to an unfocused gaze observed in people under any stressful situation, or in people with certain mental health conditions. The thousand-yard stare is sometimes described as an effect of shell shock or combat stress reaction, along with other mental health conditions. However, it is not a formal medical term. This painting by the war artist Thomas C. Lea III, titled Marines Call It That 2,000 Yard Stare, popularized the term after it was published in Life in 1945. It depicts an unnamed US Marine at the Battle of Peleliu, which took place in 1944. Painting credit: Thomas C. Lea III Recently featured: Myosotis scorpioides Whitehead's trogon Atacamite Archive More featured pictures Community portal – The central hub for editors, with resources, links, tasks, and announcements. Village pump – Forum for discussions about Wikipedia itself, including policies and technical issues. Site news – Sources of news about Wikipedia and the broader Wikimedia movement. Teahouse – Ask basic questions about using or editing Wikipedia. Help desk – Ask questions about using or editing Wikipedia. Reference desk – Ask research questions about encyclopedic topics. Content portals – A unique way to navigate the encyclopedia. Wikipedia is written by volunteer editors and hosted by the Wikimedia Foundation, a non-profit organization that also hosts a range of other volunteer projects: CommonsFree media repository MediaWikiWiki software development Meta-WikiWikimedia project coordination WikibooksFree textbooks and manuals WikidataFree knowledge base WikinewsFree-content news WikiquoteCollection of quotations WikisourceFree-content library WikispeciesDirectory of species WikiversityFree learning tools WikivoyageFree travel guide WiktionaryDictionary and thesaurus This Wikipedia is written in English. Many other Wikipedias are available; some of the largest are listed below. 1,000,000+ articles العربية Deutsch Español فارسی Français Italiano Nederlands 日本語 Polski Português Русский Svenska Українська Tiếng Việt 中文 250,000+ articles Bahasa Indonesia Bahasa Melayu Bân-lâm-gú Български Català Čeština Dansk Eesti Ελληνικά Esperanto Euskara עברית Հայերեն Magyar Norsk bokmål Română Simple English Slovenčina Srpski Srpskohrvatski Suomi Türkçe O’zbekcha 50,000+ articles Asturianu Azərbaycanca [illegible] Bosanski کوردی Frysk Gaeilge Galego Hrvatski ქართული Kurdî Latviešu Lietuvių [illegible] Македонски [illegible] Norsk nynorsk [illegible] Shqip Slovenščina [illegible] اردو Retrieved from " 2 Calendar year Years Millennium 2nd millennium Centuries 16th century 17th century 18th century Decades 1590s 1600s 1610s 1620s 1630s Years 1610 1611 1612 1613 1614 1615 1616 vte August 29: The Battle of Cape Corvo is fought between Sicily and the Ottoman Empire 1613 by topic Arts and science Architecture Art Literature Music Science Leaders State leaders Colonial governors Religious leaders Birth and death categories Births – Deaths Establishments and disestablishments categories Establishments – Disestablishments Works category Works vte 1613 in various calendarsGregorian calendar1613MDCXIIIAb urbe condita2366Armenian calendar1062ԹՎ ՌԿԲAssyrian calendar6363Balinese saka calendar1534–1535Bengali calendar1019–1020Berber calendar2563English Regnal year10 Ja. 1 – 11 Ja. 1Buddhist calendar2157Burmese calendar975Byzantine calendar7121–7122Chinese calendar壬子年 (Water Rat)4310 or 4103 — to 癸丑年 (Water Ox)4311 or 4104Coptic calendar1329–1330Discordian calendar2779Ethiopian calendar1605–1606Hebrew calendar5373–5374Hindu calendars - Vikram Samvat1669–1670 - Shaka Samvat1534–1535 - Kali Yuga4713–4714Holocene calendar11613Igbo calendar613–614Iranian calendar991–992Islamic calendar1021–1022Japanese calendarKeichō 18(慶長１８年)Javanese calendar1533–1534Julian calendarGregorian minus 10 daysKorean calendar3946Minguo calendar299 before ROC民前299年Nanakshahi calendar145Thai solar calendar2155–2156Tibetan calendar阳水鼠年(male Water-Rat)1739 or 1358 or 586 — to 阴水牛年(female Water-Ox)1740 or 1359 or 587 1613 (MDCXIII) was a common year starting on Tuesday of the Gregorian calendar and a common year starting on Friday of the Julian calendar, the 1613th year of the Common Era (CE) and Anno Domini (AD) designations, the 613th year of the 2nd millennium, the 13th year of the 17th century, and the 4th year of the 1610s decade. As of the start of 1613, the Gregorian calendar was 10 days ahead of the Julian calendar, which remained in localized use until 1923. Calendar year January 11 – Workers in a sandpit in the Dauphiné region of France discover the skeleton of what is alleged to be a 30-foot tall man (the remains, it is supposed, of the giant Teutobochus, a legendary Gallic king who fought the Romans).[1] January 20 – King James I of England successfully mediates the Treaty of Knäred between Denmark and Sweden.[2] February 14 – Elizabeth, daughter of King James I of England, marries Frederick V, Elector Palatine.[3] February 24 – King Anaukpetlun of Burma blockades the Portuguese port at Syriam with 80 warships and 3,000 men, then sets about to tunnel into the city. March 3 (February 21 O.S.) – An assembly of the Russian Empire elects Mikhail Romanov Tsar of Russia, ending the Time of Troubles. The House of Romanov will remain a ruling dynasty until 1917. March 27 – The first English child is born in Canada at Cuper's Cove, Newfoundland to Nicholas Guy. March 29 Explorer Samuel de Champlain becomes the first unofficial Governor of New France in Canada. Burmese soldiers, tunneling under the walls of the Portuguese colonial fortress at Syriam (now Thanlyin), bring down a section of the walls and sack the city. Portuguese Governor Filipe de Brito e Nicote and rebel Burmese General Natshinnaung are captured, and executed by impalement on April 9. April 13 – Samuel Argall captures Algonquian princess Pocahontas in Passapatanzy, Virginia, to ransom her for some English prisoners held by her father, Chief Powhatan. She is brought to Henricus as a hostage.[4] May 12 – Mikhail Romanov arrives in Moscow to begin his reign as Tsar of Russia, after having been elected on March 3. May 14 The city of Hanthawaddy (now Bago) is restored as the capital of Burma by King Anaukpetlun, who relocates the government from Ava (now Inwa). The ruler of the principality of Martaban, Binnya Dala, surrenders to the armies of King Anaukpetlun of Burma. May 23 – War of the Montferrat Succession: The defenders of the Italian city of Nizza Monferrato successfully resist a nine-day siege by the troops of Charles Emmanuel I, Duke of Savoy. May 27 – After getting an official proclamation that he is the French Governor of New France, explorer Samuel de Champlain begins exploration of the area westward from Quebec, traveling along the Ottawa River. June 28 (July 8 N.S.) – From Jamestown, John Rolfe makes the first shipment to England of tobacco grown in Virginia, dispatching it on the ship The Elizabeth. [5] The tobacco arrives in England after a voyage of three weeks. June 29 – Fire destroys London's famed Globe Theatre, during a performance of Shakespeare's Henry VIII.[6] July 20 (July 30 N.S.) – The first American-grown tobacco, produced in the British colony of Virginia, arrives in England after being dispatched 22 days earlier by John Rolfe. [5] July 26 – Diego Marín de Negron, the Spanish Governor of Rio de la Plata y Paraguay, is assassinated by poisoning at his palace in Buenos Aires.C. Antonio Zinny, History of the governors of the Argentine provinces from 1810 to the present (Editoriales Huemul, 1941) p.105 July 28 – Gregor Richter, the chief pastor of Görlitz, denounces Jacob Boehme as a heretic, in his Sunday sermon. August 29 – The Sicilians under de Aragon defeat the trade fleet of the Ottoman Empire, ending the Battle of Cape Corvo. September 29 – The New River is opened, to supply London with drinking water from Hertfordshire. October 21 – Gabriel Bathory, ruler of the Principality of Transylvania, is removed from office by vote of the nobles meeting at Gyulafehérvár (now Alba Iulia in Romania).[7]:279 Bathory refuses to vacate the palace at the Transylvanian capital at Várad, (now Oradea in Romania), and is murdered on October 27.[7] October 23 – Gabriel Bethlen is elected as the new Prince of Transylvania.[8] October 28 – Keichō embassy: Hasekura Tsunenaga departs Japan in the Date Maru with a Japanese diplomatic mission to the Holy See, scheduled to first travel to Acapulco in New Spain, with a goal of concluding an agreement between Tokugawa Ieyasu and the East India Company, permitting English merchants to live and trade in Japan. November 3 – English royal favourite Robert Carr is created 1st Earl of Somerset. November 30 – King Anaukpetlun of Burma sends an army of 4,000 troops to drive the Siamese occupiers from the Tenasserim coast. December 26 – The Date Maru, carrying the Japanese diplomatic mission commanded Hasekura Tsunenaga, reaches North America, sighting Cape Mendocino on the California coast.[9] The Earl of Somerset marries Frances Howard, following the September 25 annulment of her marriage to Robert Devereux, 3rd Earl of Essex; the event is the inspiration for John Donne's Eclogue.[10] December 26 – The Burmese Army defeats the Siamese Army at Tavoy. The city is now part of Myanmar as Dawei. December 27 – Mateo Leal de Ayala becomes the new Governor of Rio de la Plata y Paraguay, covering what will become the nations of Argentina, Chile and Paraguay. He succeeds Diego Marín de Negron, who was poisoned on July 26. A locust swarm destroys La Camarque, France. Kuwait City is founded. Sultan Agung of Mataram takes the throne of the kingdom of Mataram in Java. Near Jamestown, Virginia, Sir Thomas Dale starts a settlement called Bermuda City, which later becomes part of Hopewell, Virginia. Mattia Preti Stjepan Gradić André Le Nôtre Empress Dowager Xiaozhuang Claude Perrault January 14 – Pier Martire Armani, Italian painter (d. 1699) January 15 – Giovanni Pietro Bellori, Italian art historian (d. 1696) January 21 – George Gillespie, Scottish theologian (d. 1648) February 2 Noël Chabanel, French Jesuit missionary at Sainte-Marie among the Hurons (d. 1649) William Thomas, Welsh Anglican bishop (d. 1689) February 7 – Johannes Musaeus, German theologian (d. 1681) February 24 – Mattia Preti, Italian painter (d. 1699) February 28 – John Pearson, English theologian and scholar (d. 1686) March 6 Stjepan Gradić, Croatian philosopher and scientist (d. 1683) Anna Moroni, Italian educator (d. 1675) March 11 – Francesco Caetani, 8th Duke of Sermoneta, Governor of the Duchy of Milan (d. 1683) March 12 – André Le Nôtre, French landscape and garden designer (d. 1700)[11] March 19 – John Swinfen, English politician (d. 1694) March 24 – Antonia of Württemberg, princess, literary figure, patron and Christian Kabbalist (d. 1679) March 28 – Empress Dowager Xiaozhuang, concubine of Qing dynasty ruler Hong Taiji (d. 1688)[12] March 29 – Louis-Isaac Lemaistre de Sacy, French Bible translator (d. 1684) April 1 Giulio Bartolocci, Italian Biblical scholar (d. 1687) Charles de Saint-Évremond, French soldier and writer (d. 1703) April 7 – Gerrit Dou, Dutch painter (d. 1675) April 18 – Philip Wharton, 4th Baron Wharton, English soldier (d. 1696) April 21 – Franciscus Plante, Dutch painter, chaplain (d. 1690) April 29 – Christoph Bach, German musician (d. 1661) May 9 – Mattias de' Medici, Italian noble (d. 1667) May 10 – François Chauveau, French painter (d. 1676) May 15 – George Seton, Lord Seton, Scottish noble (d. 1648) May 31 – John George II, Elector of Saxony (1656–1680) (d. 1680) June 1 – William Wirich, Count of Daun-Falkenstein, German nobleman (d. 1682) June 13 – Johann Ernst, Count of Hanau-Münzenberg (1641–1642) (d. 1642) June 16 – John Cleveland, English poet (d. 1658) July 15 – Gu Yanwu, Chinese philologist and geographer (d. 1682) July 16 – Alderano Cybo, Catholic cardinal (d. 1700) August 7 – William Frederick, Prince of Nassau-Dietz, Dutch stadtholder (d. 1664) August 15 – Gilles Ménage, French scholar (d. 1692) August 18 – Sir Thomas Peyton, 2nd Baronet, English politician (d. 1684) August 20 – Duchess Elisabeth Sophie of Mecklenburg, German poet composer and (by marriage) Duchess of Brunswick-Lüneburg (d. 1676) August 24 – Bartholomew Holzhauser, German priest, founder of a religious community, visionary, writer of prophecies (d. 1658) August 29 – John Jolliffe, English politician and businessman (d. 1680) September 8 – Henri Albert de La Grange d'Arquien, Catholic cardinal (d. 1707) September 15 – François de La Rochefoucauld, French writer (d. 1680)[13] September 19 – Sir John Norwich, 1st Baronet, English Member of Parliament (d. 1661) September 25 – Claude Perrault, French architect (d. 1688) October 3 – Marion Delorme, French courtesan known for her relationships with the important men of her time (d. 1650) October 12 – Jacques d'Arthois, Flemish painter (d. 1686) October 13 Luisa de Guzmán, Duchess of Braganza, queen consort of Portugal (d. 1666) Adriaan Heereboord, Dutch philosopher (d. 1661) October 19 – Charles of Sezze, Italian Franciscan friar and saint (d. 1670) October 28 – Edmund Bowyer, English politician (d. 1681) November 5 – Isaac de Benserade, French poet (d. 1691)[14] November 12 – Sir Ralph Verney, 1st Baronet, of Middle Claydon, English Baronet (d. 1696) November 16 – Frederick, Prince of Anhalt-Harzgerode (1635–1670) (d. 1670) November 20 – Tyman Oosdorp, Dutch Golden Age brewer and magistrate of Haarlem (d. 1668) November 24 – John Knight, Member of the Parliament of England (d. 1683) November 25 – Philip VII, Count of Waldeck-Wildungen (1638–1645) (d. 1645) December 4 (bapt.) – Samuel Butler, English satirist (d. 1680) December 10 – Izaak van Oosten, Flemish painter (d. 1661) December 11 – Amar Singh Rathore, Rajput nobleman affiliated with the royal house of Marwar (d. 1644) December 23 – Carl Gustaf Wrangel, Field Marshal of Sweden (d. 1676) December 28 – Bullen Reymes, English courtier, diplomat and politician (d. 1672) Henry Vane, English politician (d. 1662) Khushal Khan Khattak, Afghan poet (d. 1690) Richard Crashaw, English poet (d. 1649) Juan García López-Rico Ikeda Terumasa Sigismund Báthory January 2 – Salima Sultan Begum, Empress of the Mughal Empire (b. 1539) January 12 – George Blackwell, English Catholic archpriest (b. 1545) January 18 – Antoon Claeissens, Flemish Baroque painter (b. 1536) January 27 – Anna of Saxony, German noblewoman (b. 1567) January 28 – Thomas Bodley, English diplomat and library founder (b. 1545)[15] February 14 – Juan García López-Rico, Spanish Catholic priest from the Trinitarian Order, founded the Order of Discalced Carmelites (b. 1561) February 16 – Johannes Letzner, German Protestant priest and historian (b. 1531) February 27 – Pietro Facchetti, Italian painter (b. 1539) March 2 – Rudolph Snellius, Dutch linguist and mathematician (b. 1546) March 13 – Giovanni Battista Caccini, Italian artist (b. 1556) March 16 Sigrid Sture, Swedish Governor (b. 1538) Ikeda Terumasa, Japanese daimyō (b. 1565) March 23 – Jerónimo de Ayanz y Beaumont, Spanish inventor (b. 1553) March 27 – Sigismund Báthory, Prince of Transylvania (b. 1572) April 27 – Robert Abercromby, Scottish Jesuit missionary (b. 1532) June 3 – Allahverdi Khan, Georgian-born Iranian general (b. 1590) June 8 – Cigoli, Italian painter (b. 1559) June 15 – Magdalena Moons, Dutch heroine (b. 1541) July 2 – Bartholomaeus Pitiscus, German astronomer and mathematician (b. 1561) July 19 – Nicolaus van Aelst, Flemish engraver (b. 1526) July 20 – Sebastian Lubomirski, Polish-Lithuanian nobleman (szlachcic) (b. c. 1546) July 30 – Henry Julius, Duke of Brunswick-Lüneburg (b. 1564) August 1 Francesco Grimaldi, Italian architect (b. 1543) Thomas Twyne, English actor (b. 1543) August 7 – Thomas Fleming, English judge (b. 1544) August 14 – David Lindsay, Scottish bishop (b. 1531) August 18 – Giovanni Artusi, Italian composer (b. c. 1540) August 22 – Dominicus Baudius, Dutch historian and poet (b. 1561) August 25 – William Waldegrave, English Member of Parliament (b. 1540) September 8 Carlo Gesualdo, Italian composer (b. 1566)[16] James Pemberton, British goldsmith (b. 1550) September 14 – Thomas Overbury, English poet and essayist (murdered) (b. 1581) October 9 – Henry Constable, English poet (b. 1562) October 11 – John Petre, 1st Baron Petre, English politician (b. 1549) October 22 – Mathurin Régnier, French satirist (b. 1573) October 26 – Johann Bauhin, Swiss botanist (b. 1541) October 27 – Gabriel Báthory, Prince of Transylvania (b. 1589) November 4 – Cristóbal Rodríguez Juárez, Spanish Catholic archbishop (b. 1547) November 16 – Trajano Boccalini, Italian satirist (b. 1556) November 21 – Rose Lok, English Marian exile (b. 1526) November 23 – Charles Philippe de Croÿ, Marquis d’Havré, Belgian noble and politician (b. 1549) November 26 – Henry Berkeley, 7th Baron Berkeley, English politician (b. 1534) December 6 – Anton Praetorius, German pastor (b. 1560) December 7 – Simon VI, Count of Lippe, imperial count and ruler of the County of Lippe (Germany) since 1563 (b. 1554) date unknown Phùng Khắc Khoan, Vietnamese military strategist, politician, diplomat and poet (b. 1528) Beatrice Michiel, Venetian spy (b. 1553) ^ W.A. 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ISBN 978-0-404-60195-9. {{cite book}}: ISBN / Date incompatibility (help) ^ Church Monuments: Journal of the Church Monuments Society. The Society. 1993. p. 61. ^ David Mason Greene; Constance Green (1985). Greene's Biographical Encyclopedia of Composers. Reproducing Piano Roll Fnd. p. 81. ISBN 978-0-385-14278-6. Retrieved from " 3One hundred years, from 1501 to 1600 This article needs additional citations for verification. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed.Find sources: "16th century" – news · newspapers · books · scholar · JSTOR (September 2022) (Learn how and when to remove this message) Millennia 2nd millennium Centuries 15th century 16th century 17th century Timelines 15th century 16th century 17th century State leaders 15th century 16th century 17th century Decades 1500s 1510s 1520s 1530s 1540s 1550s 1560s 1570s 1580s 1590s Categories: Births – Deaths Establishments – Disestablishments vte The world map by the Italian Amerigo Vespucci (from whose name the word America is derived) and Belgian Gerardus Mercator shows (besides the classical continents Europe, Africa, and Asia) the Americas as America sive India Nova', New Guinea, and other islands of Southeast Asia, as well as a hypothetical Arctic continent and a yet undetermined Terra Australis.[1]The 16th century began with the Julian year 1501 (represented by the Roman numerals MDI) and ended with either the Julian or the Gregorian year 1600 (MDC), depending on the reckoning used (the Gregorian calendar introduced a lapse of 10 days in October 1582).[1] The Renaissance in Italy and Europe saw the emergence of important artists, authors and scientists, and led to the foundation of important subjects which include accounting and political science. Copernicus proposed the heliocentric universe, which was met with strong resistance, and Tycho Brahe refuted the theory of celestial spheres through observational measurement of the 1572 appearance of a Milky Way supernova. These events directly challenged the long-held notion of an immutable universe supported by Ptolemy and Aristotle, and led to major revolutions in astronomy and science. Galileo Galilei became a champion of the new sciences, invented the first thermometer and made substantial contributions in the fields of physics and astronomy, becoming a major figure in the Scientific Revolution in Europe. Spain and Portugal colonized large parts of Central and South America, followed by France and England in Northern America and the Lesser Antilles. The Portuguese became the masters of trade between Brazil, the coasts of Africa, and their possessions in the Indies, whereas the Spanish came to dominate the Greater Antilles, Mexico, Peru, and opened trade across the Pacific Ocean, linking the Americas with the Indies. English and French privateers began to practice persistent theft of Spanish and Portuguese treasures. This era of colonialism established mercantilism as the leading school of economic thought, where the economic system was viewed as a zero-sum game in which any gain by one party required a loss by another. The mercantilist doctrine encouraged the many intra-European wars of the period and arguably fueled European expansion and imperialism throughout the world until the 19th century or early 20th century. The Reformation in central and northern Europe gave a major blow to the authority of the papacy and the Catholic Church. In England, the British-Italian Alberico Gentili wrote the first book on public international law and divided secularism from canon law and Catholic theology. European politics became dominated by religious conflicts, with the groundwork for the epochal Thirty Years' War being laid towards the end of the century. In the Middle East, the Ottoman Empire continued to expand, with the sultan taking the title of caliph, while dealing with a resurgent Persia. Iran and Iraq were caught by a major popularity of the Shia sect of Islam under the rule of the Safavid dynasty of warrior-mystics, providing grounds for a Persia independent of the majority-Sunni Muslim world.[2] In the Indian subcontinent, following the defeat of the Delhi Sultanate and Vijayanagara Empire, new powers emerged, the Sur Empire founded by Sher Shah Suri, Deccan sultanates, Rajput states, and the Mughal Empire[3] by Emperor Babur, a direct descendant of Timur and Genghis Khan.[4] His successors Humayun and Akbar, enlarged the empire to include most of South Asia. Japan suffered a severe civil war at this time, known as the Sengoku period, and emerged from it as a unified nation under Toyotomi Hideyoshi. China was ruled by the Ming dynasty, which was becoming increasingly isolationist, coming into conflict with Japan over the control of Korea as well as Japanese pirates. In Africa, Christianity had begun to spread in Central Africa and Southern Africa. Until the Scramble for Africa in the late 19th century, most of Africa was left uncolonized. For timelines of earlier events, see 15th century and Timeline of the Middle Ages. Main article: 1500s Mona Lisa, by Leonardo da Vinci, c. 1503–1506, one of the world's best-known paintings 1501: Michelangelo returns to his native Florence to begin work on the statue David. 1501: Safavid dynasty reunifies Iran and rules over it until 1736. Safavids adopt a Shia branch of Islam.[5] 1501: First Battle of Cannanore between the Third Portuguese Armada and Kingdom of Cochin under João da Nova and Zamorin of Kozhikode's navy marks the beginning of Portuguese conflicts in the Indian Ocean. 1502: First reported African slaves in the New World 1502: The Crimean Khanate sacks Sarai in the Golden Horde, ending its existence. 1503: Spain defeats France at the Battle of Cerignola. Considered to be the first battle in history won by gunpowder small arms. 1503: Leonardo da Vinci begins painting the Mona Lisa and completes it three years later. 1503: Nostradamus is born on either December 14 or December 21. 1504: A period of drought, with famine in all of Spain. 1504: Death of Isabella I of Castile; Joanna of Castile becomes the Queen. 1504: Foundation of the Sultanate of Sennar by Amara Dunqas, in what is modern Sudan 1505: Zhengde Emperor ascends the throne of Ming dynasty. 1505: Martin Luther enters St. Augustine's Monastery at Erfurt, Germany, on 17 July and begins his journey to instigating the Reformation. 1505: Sultan Trenggono builds the first Muslim kingdom in Java, called Demak, in Indonesia. Many other small kingdoms were established in other islands to fight against Portuguese. Each kingdom introduced local language as a way of communication and unity. 1506: Leonardo da Vinci completes the Mona Lisa. 1506: King Afonso I of Kongo wins the battle of Mbanza Kongo, resulting in Catholicism becoming Kongo's state religion.Battle of Cerignola: El Gran Capitan finds the corpse of Louis d'Armagnac, Duke of Nemours 1506: At least two thousand converted Jews are massacred in a Lisbon riot, Portugal. 1506: Christopher Columbus dies in Valladolid, Spain. 1506: Poland is invaded by Tatars from the Crimean Khanate. 1507: The first recorded epidemic of smallpox in the New World on the island of Hispaniola. It devastates the native Taíno population.[6] 1507: Afonso de Albuquerque conquered Hormuz and Muscat, among other bases in the Persian Gulf, taking control of the region at the entrance of the Gulf. 1508: The Christian-Islamic power struggle in Europe and West Asia spills over into the Indian Ocean as Battle of Chaul during the Portuguese-Mamluk War 1508–1512: Michelangelo paints the Sistine Chapel ceiling. 1509: The defeat of joint fleet of the Sultan of Gujarat, the Mamlûk Burji Sultanate of Egypt, and the Zamorin of Calicut with support of the Republic of Venice and the Ottoman Empire in Battle of Diu marks the beginning of Portuguese dominance of the Spice trade and the Indian Ocean. 1509: The Portuguese king sends Diogo Lopes de Sequeira to find Malacca, the eastern terminus of Asian trade. After initially receiving Sequeira, Sultan Mahmud Shah captures and/or kills several of his men and attempts an assault on the four Portuguese ships, which escape.[7] The Javanese fleet is also destroyed in Malacca. 1509: Krishnadevaraya ascends the throne of Vijayanagara Empire. Main article: 1510s Afonso de Albuquerque 1509–1510: The 'great plague' in various parts of Tudor England.[8] 1510: Afonso de Albuquerque of Portugal conquers Goa in India. 1511: Afonso de Albuquerque of Portugal conquers Malacca, the capital of the Sultanate of Malacca in present-day Malaysia. 1512: Copernicus writes Commentariolus, and proclaims the Sun the center of the Solar System. 1512: The southern part (historical core) of the Kingdom of Navarre is invaded by Castile and Aragon. 1512: Qutb Shahi dynasty, founded by Quli Qutb Mulk, rules Golconda Sultanate until 1687. 1512: The first Portuguese exploratory expedition was sent eastward from Malacca (in present-day Malaysia) to search for the 'Spice Islands' (Maluku) led by Francisco Serrão. Serrão is shipwrecked but struggles on to Hitu (northern Ambon) and wins the favour of the local rulers.[9] 1513: Machiavelli writes The Prince, a treatise about political philosophy 1513: The Portuguese mariner Jorge Álvares lands at Macau, China, during the Ming dynasty. 1513: Henry VIII defeats the French at the Battle of the Spurs. 1513: The Battle of Flodden Field in which invading Scots are defeated by Henry VIII's forces. 1513: Sultan Selim I ("The Grim") orders the massacre of Shia Muslims in Anatolia (present-day Turkey). 1513: Vasco Núñez de Balboa, in service of Spain arrives at the Pacific Ocean (which he called Mar del Sur) across the Isthmus of Panama. He was the first European to do so. 1514: The Battle of Orsha halts Muscovy's expansion into Eastern Europe. 1514: Dózsa rebellion (peasant revolt) in Hungary.Martin Luther initiated the Reformation with his Ninety-five Theses in 1517. 1514: The Battle of Chaldiran, the Ottoman Empire gains decisive victory against Safavid dynasty. 1515: Ascension of Francis I of France as King of France following the death of Louis XII. 1515: The Ottoman Empire wrests Eastern Anatolia from the Safavids after the Battle of Chaldiran. 1515: The Ottomans conquer the last beyliks of Anatolia, the Dulkadirs and the Ramadanids. 1516–1517: The Ottomans defeat the Mamluks and gain control of Egypt, Arabia, and the Levant. 1517: The Sweating sickness epidemic in Tudor England.[10] 1517: The Reformation begins when Martin Luther posts his Ninety-five Theses in Saxony. 1518: The Treaty of London was a non-aggression pact between the major European nations. The signatories were Burgundy, France, England, the Holy Roman Empire, the Netherlands, the Papal States and Spain, all of whom agreed not to attack one another and to come to the aid of any that were under attack. 1518: Mir Chakar Khan Rind leaves Baluchistan and settles in Punjab. 1518: Leo Africanus, also known as al-Hasan ibn Muhammad al-Wazzan al-Fasi, an Andalusian Berber diplomat who is best known for his book Descrittione dell’Africa (Description of Africa), is captured by Spanish pirates; he is taken to Rome and presented to Pope Leo X. 1518: The dancing plague of 1518 begins in Strasbourg, lasting for about one month. 1519: Leonardo da Vinci dies of natural causes on May 2.Europe at the time of the accession of Charles V in 1519 1519: Wang Yangming, the Chinese philosopher and governor of Jiangxi province, describes his intent to use the firepower of the fo-lang-ji, a breech-loading Portuguese culverin, in order to suppress the rebellion of Prince Zhu Chenhao. 1519: Barbary pirates led by Hayreddin Barbarossa, a Turk appointed to ruling position in Algiers by the Ottoman Empire, raid Provence and Toulon in southern France. 1519: Death of Emperor Maximilian; Charles I of Austria, Spain, and the Low Countries becomes Emperor of Holy Roman Empire as Charles V, Holy Roman Emperor (ruled until 1556). 1519–1522: Spanish expedition commanded by Magellan and Elcano are the first to Circumnavigate the Earth. 1519–1521: Hernán Cortés leads the Spanish conquest of the Aztec Empire. Main article: 1520s Ferdinand Magellan led the first expedition that circumnavigated the globe in 1519–1522. 1520–1566: The reign of Suleiman the Magnificent marks the zenith of the Ottoman Empire. 1520: The first European diplomatic mission to Ethiopia, sent by the Portuguese, arrives at Massawa 9 April, and reaches the imperial encampment of Emperor Dawit II in Shewa 9 October. 1520: Vijayanagara Empire forces under Krishnadevaraya defeat the Adil Shahi under at the Battle of Raichur 1520: Sultan Ali Mughayat Shah of Aceh begins an expansionist campaign capturing Daya on the west Sumatran coast (in present-day Indonesia), and the pepper and gold producing lands on the east coast. 1520: The Portuguese established a trading post in the village of Lamakera on the eastern side of Solor (in present-day Indonesia) as a transit harbour between Maluku and Malacca. 1521: Belgrade (in present-day Serbia) is captured by the Ottoman Empire. 1521: After building fortifications at Tuen Mun, the Portuguese attempt to invade Ming dynasty China, but are expelled by Chinese naval forces. 1521: Philippines encountered by Ferdinand Magellan. He was later killed in the Battle of Mactan in central Philippines in the same year. 1521: Jiajing Emperor ascended the throne of Ming dynasty, China. 1521: November, Ferdinand Magellan's expedition reaches Maluku (in present-day Indonesia) and after trade with Ternate returns to Europe with a load of cloves. 1521: Pati Unus leads the invasion of Malacca (in present-day Malaysia) against the Portuguese occupation. Pati Unus was killed in this battle, and was succeeded by his brother, sultan Trenggana. 1522: Rhodes falls to the Ottomans of Suleiman the Magnificent.[11]Sack of Rome of 1527 by Charles V's forces (painting by Johannes Lingelbach) 1522: The Portuguese ally themselves with the rulers of Ternate (in present-day Indonesia) and begin construction of a fort.[9] 1522: August, Luso-Sundanese Treaty signed between Portugal and Sunda Kingdom granted Portuguese permit to build fortress in Sunda Kelapa. 1523: Sweden gains independence from the Kalmar Union. 1523: The Cacao bean is introduced to Spain by Hernán Cortés 1524–1525: German Peasants' War in the Holy Roman Empire. 1524: Giovanni da Verrazzano is the first European to explore the Atlantic coast of North America between South Carolina and Newfoundland. 1524: Ismail I, the founder of Safavid dynasty, dies and Tahmasp I becomes king.Gun-wielding Ottoman Janissaries and defending Knights of Saint John at the siege of Rhodes in 1522, from an Ottoman manuscript 1525: Timurid Empire forces under Babur defeat the Lodi dynasty at the First Battle of Panipat, end of the Delhi Sultanate. 1525: German and Spanish forces defeat France at the Battle of Pavia, Francis I of France is captured. 1526: The Ottomans defeat the Kingdom of Hungary at the Battle of Mohács. 1526: Mughal Empire, founded by Babur. 1527: Sack of Rome with Pope Clement VII escaping and the Swiss Guards defending the Vatican being killed. The sack of the city of Rome considered the end of the Italian Renaissance. 1527: Protestant

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An Encyclopedia of World History (5th ed. 1973); highly detailed outline of events online free Media related to 16th century at Wikimedia Commons Timelines of 16th century events, science, culture and persons Retrieved from " 4 The following pages link to 16th century External tools (link count transclusion count sorted list) · See help page for transcluding these entries Showing 50 items. View (previous 50 | next 50) (20 | 50 | 100 | 250 | 500)Bagpipes (links | edit) List of decades, centuries, and millennia (links | edit) Fashion (links | edit) Giovanni Boccaccio (links | edit) History of Mali (links | edit) History of Mauritius (links | edit) Post office (links | edit) Snare drum (links | edit) Republican Party (United States) (links | edit) 20th century (links | edit) 15th century (links | edit) 17th century (links | edit) 18th century (links | edit) 1624 (links | edit) 1626 (links | edit) 1642 (links | edit) 1661 (links | edit) 1608 (links | edit) 1492 (links | edit) 14th century (links | edit) 1st century (links | edit) 13th century (links | edit) 4th century (links | edit) 12th century (links | edit) 11th century (links | edit) 1564 (links | edit) 1648 (links | edit) 1572 (links | edit) 1623 (links | edit) 1662 (links | edit) 1490s (links | edit) 1640s (links | edit) 1597 (links | edit) 1690 (links | edit) 1688 (links | edit) 7th century (links | edit) 10th century (links | edit) 9th century (links | edit) 8th century (links | edit) 6th century (links | edit) 5th century (links | edit) 3rd century (links | edit) 2nd century (links | edit) 1573 (links | edit) 1570s (links | edit) 1574 (links | edit) 1436 (links | edit) 1476 (links | edit) 1542 (links | edit) 1540s (links | edit) View (previous 50 | next 50) (20 | 50 | 100 | 250 | 500) Retrieved from " WhatLinksHere/16th_century" The emission of electrons from a metallic surface when irradiated by electromagnetic radiation is called the phenomenon of photoelectric effect. The emitted electrons are called as photoelectrons. For the investigation of the photoelectric effect a schematic diagram of the apparatus as used by Lenord (1902) is shown in the fig.(16.14). Monochromatic light from the lamp L illuminates a plate P in an evacuated glass enclosure. A battery maintains a potential difference between P and a metal cylinder C, which collects the photoelectrons. The potential C can be varied to be either positive or negative relative to P. When the collector is positive with respect to the plate, the electrons are attracted to it and the ammeter (A) registers a current. Lenard studied the dependence of photoelectric current on the following factors. (i) Intensity of incident radiation (ii) Potential difference between the plate and the collector (iii) Frequency of the incident radiation The result of observations are as follows: When the collector is positive relative to the plate and the potential difference is kept fixed, then for a given frequency of radiation, the photoelectric current is proportional to the intensity of the light, as shown in fig.(16.15). It shows that the number of emitted photoelectrons is proportional to the light intensity. Furthermore, there is no threshold intensity. Effect of Potential Difference When the frequency and intensity of radiation are kept constant and the positive potential of collector relative to plate is gradually increased, then the photoelectric current i increases with the potential difference V. At some value of the potential difference, when all the emitted electrons are collected, thus increasing potential difference has no effect on the current. The current has reached its maximum value, called the saturation current. When the polarity of the battery is reversed, the electrons are repelled and only the most energetic ones reach the collector, so the current falls. When the retarding potential difference reaches a critical value, the current drops to zero. At this stopping potential Vo, only those electrons with the maximum kinetic energy are able to reach the collector. eVo = 1/2 mv2 max (16.29) For a given frequency of light, the saturation current depends on the intensity of light. Larger the intensity; higher the saturation current. However, the stopping potential does not change with the intensity. It is clearly shown in fig. (16.16). Effect of frequency For a given intensity of radiation, the stopping potential depends on the frequency. Higher the frequency, higher the value of stopping potential. The maximum kinetic energy of the electrons depends on the light source and the plate material, but not on the intensity of the source. Certain combinations of light sources and plate materials exhibit no photoelectric effect. For a metal plate there exists a minimum frequency called threshold frequency (fo) below which no electron is emitted however large the light intensity may be. The threshold frequency is a characteristic of the metal plate. Einstein's Theory of Photoelectric Effect According to Einstein, the experimental results of photoelectric effect can be explained by applying the quantum theory of light. He assumed that light of frequency f contain packets or quanta of energy E = hf. On this basis, light consists of particles, and these are called photons. The number of photons per unit area of cross-section of the beam of light per second is proportional to its intensity. But the energy of photon is proportional to its frequency and is independent of the light intensity. In the process of photo emission a single photon gives up all its energy to a single electron. As a result, the electron is ejected instantaneously. Since the intensity of light is determined by the number of photons incident, therefore, increasing the intensity will increase the number of ejected electrons. The maximum possible kinetic energy (1/2 mv2 max) of the photoelectrons is determined by the energy of each photon (hf) according to the Einstein equation (16.30) 1/2 mv2 max = hf - W(16.30) where the work function, (W), is the minimum energy needed to extract an electron from the surface of the material. In terms of threshold frequency, it is given by W = hfo (16.31) Using equation (16.31), we may write equation (16.30) as 1/2 mv2 max = hf – hfo = h(f – fo) (16.32) Also, in terms of stopping potential, eVo = h(f – fo) (16.33) Example 16.22 Ultraviolet light of wavelength 2000Å causes photoemission from a surface. The stopping potential is 2V. (a) Find the work function in eV (b) Find the maximum speed of the photoelectrons. Solution (a) Using Einstein relation W = hc/λ - eVo or W = 12400/2000 - 2 = 4.2eV (b) Since 1/2 mv2 max = eVo ∴ vmax = or vmax = 8.4 × 105 m/s How to determine the photoelectric current? Let P be the power of a point source of electromagnetic radiations, then intensity I at a distance r from the source is given by I = P/4πr2 (W/m2) (16.34) If A is the area of a metal surface on which radiations are incident, then the power received by the plate is P′ = IA = (P/4πr2)A (W) (16.35) If f is the frequency of radiation, then the energy of photon is given by E = hf The number of photons incident on the plate per second (called photon flux) is given by Φ = (16.36) If f > fo (threshold frequency) and photon efficiency of the metal plate is η%, then the number of photoelectrons emitted per second is given by n = (16.37) Finally, the photocurrent i is given by i = ne (16.38) where e is the charge of an electron (e = 1.6 × 10-19 J) Example 16.23 The intensity of sunlight on the surface of earth is 1400 W/m2. Assuming the mean wavelength of sunlight to be 6000Å, calculate (a) the photon flux arriving at 1 m2 area on earth perpendicular to light radiations, and (b) the number of photons emitted from the sun per second assuming the average radius of Earth's orbit is 1.49 × 1011 m. Solution (a) Energy of a photon E = hc/λ = 12400/6000 = 2.06eV = 3.3 x 10-19J Photon flux = IA/E = (1400)(1)/3.3 x 10-19= 4.22 × 1021 (b) n = P/E = I(4πR2)/E or n = (1400)(4π)(1.49 x 1011)2/3.3 x 10-19 = 1.18 × 1045 85%(13)85% found this document useful (13 votes)82K viewsThe document is a project report on the photoelectric effect submitted by Maidam Vedha Vyas for their class 12 physics project. The 3-page report includes an index, acknowledgements, and sec...SaveSave Physics Project 12th For Later85%85% found this document useful, undefined Everything learned in classical physics was turned on its head as physicists explored ever smaller realms and discovered quantum effects. Among the first of these discoveries was the photoelectric effect. In the early 1900s, the results of this effect failed to match classical predictions and were only explainable with quantum theory, opening up a whole new world for physicists. Today, the photoelectric effect has many practical applications as well. From medical imaging to the production of clean energy, the discovery and application of this effect now has implications that go well beyond simply understanding the science. When light, or electromagnetic radiation, hits a material such as a metal surface, that material sometimes emits electrons, called photoelectrons. This is essentially because the atoms in the material are absorbing the radiation as energy. Electrons in atoms absorb radiation by jumping to higher energy levels. If the energy absorbed is high enough, the electrons leave their home atom entirely. This process is sometimes also called photoemission because incident photons (another name for particles of light) are the direct cause of the emission of electrons. Because electrons have a negative charge, the metal plate from which they were emitted is left ionized. What was most special about the photoelectric effect, however, was that it did not follow classical predictions. The way in which the electrons were emitted, the number that were emitted and how this changed with intensity of light all left scientists scratching their heads initially. The original predictions as to the results of the photoelectric effect made from classical physics included the following: 1. Energy transfers from incident radiation to the electrons. It was assumed that whatever energy is incident upon the material would be directly absorbed by the electrons in the atoms, regardless of wavelength. This makes sense in the classical mechanics paradigm: Whatever you pour into the bucket fills the bucket by that amount. 2. Changes in light intensity should yield changes in kinetic energy of electrons. If it is assumed that electrons are absorbing whatever radiation is incident upon them, then more of the same radiation should give them more energy accordingly. Once the electrons have left the bounds of their atoms, that energy is seen in the form of kinetic energy. 3. Very low-intensity light should yield a time lag between light absorption and emission of electrons. This would be because it was assumed that electrons must gain enough energy to leave their home atom, and low-intensity light is like adding energy to their energy "bucket" more slowly. It takes longer to fill, and hence it should take longer before the electrons have enough energy to be emitted. The actual results were not at all consistent with the predictions. This included the following: 1. Electrons were released only when the incident light reached or exceeded a threshold frequency. No emission occurred below that frequency. It didn't matter if the intensity was high or low. For some reason, the frequency, or wavelength of the light itself, was much more important. 2. Changes in intensity did not yield changes in kinetic energy of electrons. They changed only the number of electrons emitted. Once the threshold frequency was reached, increasing the intensity did not add more energy to each emitted electron at all. Instead, they all ended up with the same kinetic energy; there were just more of them. 3. There was no time lag at low intensities. There seemed to be no time required to "fill the energy bucket" of any given electron. If an electron was to be emitted, it was emitted immediately. Lower intensity had no effect on kinetic energy or lag time; it simply resulted in fewer electrons being emitted. The only way to explain this phenomenon was to invoke quantum mechanics. Think of a beam of light not as a wave, but as a collection of discrete wave packets called photons. The photons all have distinct energy values that correspond to the frequency and wavelength of the light, as explained by wave-particle duality. In addition, consider that the electrons are only able to jump between discrete energy states. They can only have specific energy values, but never any values in between. Now the observed phenomena can be explained as follows: 1. Electrons are released only when they absorb very specific sufficient energy values. Any electron that gets the right energy packet (photon energy) will be released. None are released if the frequency of the incident light is too low regardless of intensity because none of the energy packets are individually big enough. 2. Once the threshold frequency is exceeded, increasing intensity only increases the number of electrons released and not the energy of the electrons themselves because each emitted electron absorbs one discrete photon. Greater intensity means more photons, and hence more photoelectrons. 3. There is no time delay even at low intensity as long as the frequency is high enough because as soon as an electron gets the right energy packet, it is released. Low intensity only results in fewer electrons. One important concept related to the photoelectric effect is the work function. Also known as electron-binding energy, it is the minimum energy needed to remove an electron from a solid. The formula for the work function is given by: \(W = -e\phi – E\) Where -e is the electron charge, ϕ is the electrostatic potential in the vacuum nearby the surface and E is the Fermi level of electrons in the material. Electrostatic potential is measured in volts and is a measure of the electric potential energy per unit charge. Hence the first term in the expression, -eϕ, is the electric potential energy of an electron near the surface of the material. The Fermi level can be thought of as the energy of the outermost electron when the atom is in its ground state. Closely related to the work function is the threshold frequency. This is the minimum frequency at which incident photons will cause the emission of electrons. Frequency is directly related to energy (higher frequency corresponds to higher energy), hence why a minimum frequency must be reached. Above the threshold frequency, the kinetic energy of the electrons depends on the frequency and not the intensity of the light. Basically the energy of a single photon will be transferred entirely to a single electron. A certain amount of that energy is used to eject the electron, and the remainder is its kinetic energy. Again, a greater intensity just means more electrons will be emitted, not that those emitted will have any more energy. The maximum kinetic energy of emitted electrons can be found via the following equation: \(K_{max} = h(f – f_0)\) Where _Kmax_ is the maximum kinetic energy of the photoelectron, h is Planck's constant = 6.62607004 ×10-34 m2kg/s, f is the frequency of the light and _f0_ is the threshold frequency. You can think of the discovery of the photoelectric effect as happening in two stages. First, the discovery of the emission of photoelectrons from certain materials as a result of incident light, and second, the determination that this effect does not obey classical physics at all, which led to many important underpinnings of our understanding of quantum mechanics. Heinrich Hertz first observed the photoelectric effect in 1887 while performing experiments with a spark gap generator. The setup involved two pairs of metal spheres. Sparks generated between the first set of spheres would induce sparks to jump between the second set, thus acting as transducer and receiver. Hertz was able to increase the sensitivity of the setup by shining light on it. Years later, J.J. Thompson discovered that the increased sensitivity resulted from the light causing the electrons to be ejected. While Hertz's assistant Phillip Lenard determined that the intensity did not affect the kinetic energy of the photoelectrons, it was Robert Millikan who discovered the threshold frequency. Later, Einstein was able to explain the strange phenomenon by assuming the quantization of energy. Albert Einstein was awarded the Nobel Prize in 1921 for his discovery of the law of the photoelectric effect, and Millikan won the Nobel Prize in 1923 also for work related to understanding the photoelectric effect. The photoelectric effect has many uses. One of those is that it allows scientists to probe the electron energy levels in matter by determining the threshold frequency at which incident light causes emission. Photomultiplier tubes making use of this effect were also used in older television cameras. A very useful application of the photoelectric effect is in the construction of solar panels. Solar panels are arrays of photovoltaic cells, which are cells that make use of electrons ejected from metals by solar radiation to generate current. As of 2018, nearly 3 percent of the world's energy is generated by solar panels, but this number is expected to grow considerably over the next several years, especially as the efficiency of such panels increases. But most important of all, the discovery and understanding of the photoelectric effect laid the groundwork for the field of quantum mechanics and a better understanding of the nature of light. There are many experiments that can be performed in an introductory physics lab to demonstrate the photoelectric effect. Some of these are more complicated than others. A simple experiment demonstrates the photoelectric effect with an electroscope and a UV-C lamp providing ultraviolet light. Place negative charge on the electroscope so that the needle deflects. Then, shine the UV-C lamp. Light from the lamp will release electrons from the electroscope and discharge it. You can tell this happens by seeing the needle's deflection reducing. Note, however, that if you tried the same experiment with a positively charged electroscope, it wouldn't work. There are many other possible ways to experiment with the photoelectric effect. Several setups involve a photocell consisting of a large anode that, when hit with incident light, will release electrons that are picked up by a cathode. If this setup is connected to a voltmeter, for example, the photoelectric effect will become apparent when shining the light creates a voltage. More complex setups allow for more accurate measurement and even allow you to determine the work function and threshold frequencies for different materials. See the Resources section for links. TOWELL, GAYLE. "Photoelectric Effect: Definition, Equation & Experiment" sciencing.com, . 28 December 2020. APA TOWELL, GAYLE. (2020, December 28). Photoelectric Effect: Definition, Equation & Experiment. sciencing.com. Retrieved from Chicago TOWELL, GAYLE. Photoelectric Effect: Definition, Equation & Experiment last modified August 30, 2022. Emission of electrons when electromagnetic radiation hits a material Not to be confused with Photovoltaic effect. This article relies excessively on references to primary sources. Please improve this article by adding secondary or tertiary sources. Find sources: "Photoelectric effect" – news · newspapers · books · scholar · JSTOR (July 2024) (Learn how and when to remove this message) Photoemission of electrons from a metal plate accompanied by the absorption of light quanta – photons The photoelectric effect is the emission of electrons from a material caused by electromagnetic radiation such as ultraviolet light. Electrons emitted in this manner are called photoelectrons. The phenomenon is studied in condensed matter physics, solid state, and quantum chemistry to draw inferences about the properties of atoms, molecules and solids. The effect has found use in electronic devices specialized for light detection and precisely timed electron emission. The experimental results disagree with classical electromagnetism, which predicts that continuous light waves transfer energy to electrons, which would then be emitted when they accumulate enough energy. An alteration in the intensity of light would theoretically change the kinetic energy of the emitted electrons, with sufficiently dim light resulting in a delayed emission. The experimental results instead show that electrons are dislodged only when the light exceeds a certain frequency—regardless of the light's intensity or duration of exposure. Because a low-frequency beam at a high intensity does not build up the energy required to produce photoelectrons, as would be the case if light's energy accumulated over time from a continuous wave, Albert Einstein proposed that a beam of light is not a wave propagating through space, but discrete energy packets, which were later popularised as photons by Gilbert N. Lewis since he coined the term 'photon' in his letter "The Conservation of Photons" to Nature published in 18 December 1926.[1][2] Emission of conduction electrons from typical metals requires a few electron-volt (eV) light quanta, corresponding to short-wavelength visible or ultraviolet light. In extreme cases, emissions are induced with photons approaching zero energy, like in systems with negative electron affinity and the emission from excited states, or a few hundred keV photons for core electrons in elements with a high atomic number.[3] Study of the photoelectric effect led to important steps in understanding the quantum nature of light and electrons and influenced the formation of the concept of wave–particle duality.[4] Other phenomena where light affects the movement of electric charges include the photoconductive effect, the photovoltaic effect, and the photoelectrochemical effect. The photons of a light beam have a characteristic energy, called photon energy, which is proportional to the frequency of the light. In the photoemission process, when an electron within some material absorbs the energy of a photon and acquires more energy than its binding energy, it is likely to be ejected. If the photon energy is too low, the electron is unable to escape the material. Since an increase in the intensity of low-frequency light will only increase the number of low-energy photons, this change in intensity will not create any single photon with enough energy to dislodge an electron. Moreover, the energy of the emitted electrons will not depend on the intensity of the incoming light of a given frequency, but only on the energy of the individual photons.[5] While free electrons can absorb any energy when irradiated as long as this is followed by an immediate re-emission, like in the Compton effect, in quantum systems all of the energy from one photon is absorbed—if the process is allowed by quantum mechanics—or none at all. Part of the acquired energy is used to liberate the electron from its atomic binding, and the rest contributes to the electron's kinetic energy as a free particle.[6][7][8] Because electrons in a material occupy many different quantum states with different binding energies, and because they can sustain energy losses on their way out of the material, the emitted electrons will have a range of kinetic energies. The electrons from the highest occupied states will have the highest kinetic energy. In metals, those electrons will be emitted from the Fermi level. When the photoelectron is emitted into a solid rather than into a vacuum, the term internal photoemission is often used, and emission into a vacuum is distinguished as external photoemission. Even though photoemission can occur from any material, it is most readily observed from metals and other conductors. This is because the process produces a charge imbalance which, if not neutralized by current flow, results in the increasing potential barrier until the emission completely ceases. The energy barrier to photoemission is usually increased by nonconductive oxide layers on metal surfaces, so most practical experiments and devices based on the photoelectric effect use clean metal surfaces in evacuated tubes. Vacuum also helps observing the electrons since it prevents gases from impeding their flow between the electrodes.[citation needed] Sunlight is an inconsistent and variable source of ultraviolet light. Cloud cover, ozone concentration, altitude, and surface reflection all alter the amount of UV. Laboratory sources of UV are based on xenon arc lamps or, for more uniform but weaker light, fluorescent lamps.[9] More specialized sources include ultraviolet lasers[10] and synchrotron radiation.[11] Schematic of the experiment to demonstrate the photoelectric effect. Filtered, monochromatic light of a certain wavelength strikes the emitting electrode (E) inside a vacuum tube. The collector electrode (C) is biased to a voltage VC that can be set to attract the emitted electrons, when positive, or prevent any of them from reaching the collector when negative. The classical setup to observe the photoelectric effect includes a light source, a set of filters to monochromatize the light, a vacuum tube transparent to ultraviolet light, an emitting electrode (E) exposed to the light, and a collector (C) whose voltage VC can be externally controlled.[citation needed] A positive external voltage is used to direct the photoemitted electrons onto the collector. If the frequency and the intensity of the incident radiation are fixed, the photoelectric current I increases with an increase in the positive voltage, as more and more electrons are directed onto the electrode. When no additional photoelectrons can be collected, the photoelectric current attains a saturation value. This current can only increase with the increase of the intensity of light.[citation needed] An increasing negative voltage prevents all but the highest-energy electrons from reaching the collector. When no current is observed through the tube, the negative voltage has reached the value that is high enough to slow down and stop the most energetic photoelectrons of kinetic energy Kmax. This value of the retarding voltage is called the stopping potential or cut off potential Vo.[12] Since the work done by the retarding potential in stopping the electron of charge e is eVo, the following must hold eVo = Kmax. The current-voltage curve is sigmoidal, but its exact shape depends on the experimental geometry and the electrode material properties. For a given metal surface, there exists a certain minimum frequency of incident radiation below which no photoelectrons are emitted. This frequency is called the threshold frequency. Increasing the frequency of the incident beam increases the maximum kinetic energy of the emitted photoelectrons, and the stopping voltage has to increase. The number of emitted electrons may also change because the probability that each photon results in an emitted electron is a function of photon energy[citation needed]. An increase in the intensity of the same monochromatic light (so long as the intensity is not too high[13]), which is proportional to the number of photons impinging on the surface in a given time, increases the rate at which electrons are ejected—the photoelectric current I—but the kinetic energy of the photoelectrons and the stopping voltage remain the same. For a given metal and frequency of incident radiation, the rate at which photoelectrons are ejected is directly proportional to the intensity of the incident light. The time lag between the incidence of radiation and the emission of a photoelectron is very small, less than 10−9 second. Angular distribution of the photoelectrons is highly dependent on polarization (the direction of the electric field) of the incident light, as well as the emitting material's quantum properties such as atomic and molecular orbital symmetries and the electronic band structure of crystalline solids. In materials without macroscopic order, the distribution of electrons tends to peak in the direction of polarization of linearly polarized light.[14] The experimental technique that can measure these distributions to infer the material's properties is angle-resolved photoemission spectroscopy. Diagram of the maximum kinetic energy as a function of the frequency of light on zinc In 1905, Einstein proposed a theory of the photoelectric effect using a concept that light consists of tiny packets of energy known as photons or light quanta. Each packet carries energy h ν {\displaystyle hu } that is proportional to the frequency ν {\displaystyle u } of the corresponding electromagnetic wave. The proportionality constant h {\displaystyle h} has become known as the Planck constant. In the range of kinetic energies of the electrons that are removed from their varying atomic bindings by the absorption of a photon of energy h ν {\displaystyle hu } , the highest kinetic energy K max {\displaystyle K_{\max }} is K max = h ν − W . {\displaystyle K_{\max }=h\,u -W.} Here, W {\displaystyle W} is the minimum energy required to remove an electron from the surface of the material. It is called the work function of the surface and is sometimes denoted Φ {\displaystyle \Phi } or φ {\displaystyle \varphi } .[15] If the work function is written as W = h ν o , {\displaystyle W=h\,u _{o},} the formula for the maximum kinetic energy of the ejected electrons becomes K max = h (ν − ν o) . {\displaystyle K_{\max }=h\left(u -u _{o}\right).} Kinetic energy is positive, and ν > ν o {\displaystyle u >u _{o}} is required for the photoelectric effect to occur.[16] The frequency ν o {\displaystyle u _{o}} is the threshold frequency for the given material. Above that frequency, the maximum kinetic energy of the photoelectrons as well as the stopping voltage in the experiment V o = h e (ν − ν o) {\textstyle V_{o}={\frac {h}{e}}\left(u -u _{o}\right)} rise linearly with the frequency, and have no dependence on the number of photons and the intensity of the impinging monochromatic light. Einstein's formula, however simple, explained all the phenomenology of the photoelectric effect, and had far-reaching consequences in the development of quantum mechanics. Electrons that are bound in atoms, molecules and solids each occupy distinct states of well-defined binding energies. When light quanta deliver more than this amount of energy to an individual electron, the electron may be emitted into free space with excess (kinetic) energy that is h ν {\displaystyle hu } higher than the electron's binding energy. The distribution of kinetic energies thus reflects the distribution of the binding energies of the electrons in the atomic, molecular or crystalline system: an electron emitted from the state at binding energy E B {\displaystyle E_{B}} is found at kinetic energy E k = h ν − E B {\displaystyle E_{k}=hu -E_{B}} . This distribution is one of the main characteristics of the quantum system, and can be used for further studies in quantum chemistry and quantum physics.[citation needed] The electronic properties of ordered, crystalline solids are determined by the distribution of the electronic states with respect to energy and momentum—the electronic band structure of the solid. Theoretical models of photoemission from solids show that this distribution is, for the most part, preserved in the photoelectric effect. The phenomenological three-step model[17] for ultraviolet and soft X-ray excitation decomposes the effect into these steps:[18][19][20] Inner photoelectric effect in the bulk of the material that is a direct optical transition between an occupied and an unoccupied electronic state. This effect is subject to quantum-mechanical selection rules for dipole transitions. The hole left behind the electron can give rise to secondary electron emission, or the so-called Auger effect, which may be visible even when the primary photoelectron does not leave the material. In molecular solids phonons are excited in this step and may be visible as satellite lines in the final electron energy. Electron propagation to the surface in which some electrons may be scattered because of interactions with other constituents of the solid. Electrons that originate deeper in the solid are much more likely to suffer collisions and emerge with altered energy and momentum. Their mean-free path is a universal curve dependent on electron's energy. Electron escape through the surface barrier into free-electron-like states of the vacuum. In this step the electron loses energy in the amount of the work function of the surface, and suffers from the momentum loss in the direction perpendicular to the surface. Because the binding energy of electrons in solids is conveniently expressed with respect to the highest occupied state at the Fermi energy E F {\displaystyle E_{F}} , and the difference to the free-space (vacuum) energy is the work function of the surface, the kinetic energy of the electrons emitted from solids is usually written as E k = h ν − W − E B {\displaystyle E_{k}=hu -W-E_{B}} . There are cases where the three-step model fails to explain peculiarities of the photoelectron intensity distributions. The more elaborate one-step model[21] treats the effect as a coherent process of photoexcitation into the final state of a finite crystal for which the wave function is free-electron-like outside of the crystal, but has a decaying envelope inside.[20] In 1839, Alexandre Edmond Becquerel discovered the related photovoltaic effect while studying the effect of light on electrolytic cells.[22] Though not equivalent to the photoelectric effect, his work on photovoltaics was instrumental in showing a strong relationship between light and electronic properties of materials. In 1873, Willoughby Smith discovered photoconductivity in selenium while testing the metal for its high resistance properties in conjunction with his work involving submarine telegraph cables.[23] Johann Elster (1854–1920) and Hans Geitel (1855–1923), students in Heidelberg, investigated the effects produced by light on electrified bodies and developed the first practical photoelectric cells that could be used to measure the intensity of light.[24][25]:458 They arranged metals with respect to their power of discharging negative electricity: rubidium, potassium, alloy of potassium and sodium, sodium, lithium, magnesium, thallium and zinc; for copper, platinum, lead, iron, cadmium, carbon, and mercury the effects with ordinary light were too small to be measurable. The order of the metals for this effect was the same as in Volta's series for contact-electricity, the most electropositive metals giving the largest photo-electric effect. Gold leaf electroscope demonstrating the photoelectric effect. When the electroscope disk is negatively charged with excess electrons, the gold leaves mutually repel. If high-energy light (such as ultraviolet) is then shone on the disk, electrons are emitted by the photoelectric effect and the leaf repulsion ceases. But if the light used has insufficient energy to stimulate electron emission, the leaves stay separated regardless of duration. In 1887, Heinrich Hertz observed the photoelectric effect[26] and reported on the production and reception[27] of electromagnetic waves.[28] The receiver in his apparatus consisted of a coil with a spark gap, where a spark would be seen upon detection of electromagnetic waves. He placed the apparatus in a darkened box to see the spark better. However, he noticed that the maximum spark length was reduced when inside the box. A glass panel placed between the source of electromagnetic waves and the receiver absorbed ultraviolet radiation that assisted the electrons in jumping across the gap. When removed, the spark length would increase. He observed no decrease in spark length when he replaced the glass with quartz, as quartz does not absorb UV radiation.[citation needed] The discoveries by Hertz led to a series of investigations by Wilhelm Hallwachs,[29][30] Hoor,[31] Augusto Righi[32] and Aleksander Stoletov[33][34] on the effect of light, and especially of ultraviolet light, on charged bodies. Hallwachs connected a zinc plate to an electroscope. He allowed ultraviolet light to fall on a freshly cleaned zinc plate and observed that the zinc plate became uncharged if initially negatively charged, positively charged if initially uncharged, and more positively charged if initially positively charged. From these observations he concluded that some negatively charged particles were emitted by the zinc plate when exposed to ultraviolet light. With regard to the Hertz effect, the researchers from the start showed the complexity of the phenomenon of photoelectric fatigue—the progressive diminution of the effect observed upon fresh metallic surfaces. According to Hallwachs, ozone played an important part in the phenomenon,[35] and the emission was influenced by oxidation, humidity, and the degree of polishing of the surface. It was at the time unclear whether fatigue is absent in a vacuum.[citation needed] In the period from 1888 until 1891, a detailed analysis of the photoeffect was performed by Aleksandr Stoletov with results reported in six publications.[34] Stoletov invented a new experimental setup which was more suitable for a quantitative analysis of the photoeffect. He discovered a direct proportionality between the intensity of light and the induced photoelectric current (the first law of photoeffect or Stoletov's law). He measured the dependence of the intensity of the photo electric current on the gas pressure, where he found the existence of an optimal gas pressure corresponding to a maximum photocurrent; this property was used for the creation of solar cells.[citation needed] Many substances besides metals discharge negative electricity under the action of ultraviolet light. G. C. Schmidt[36] and O. Knoblauch[37] compiled a list of these substances. In 1897, J. J. Thomson investigated ultraviolet light in Crookes tubes.[38] Thomson deduced that the ejected particles, which he called corpuscles, were of the same nature as cathode rays. These particles later became known as the electrons. Thomson enclosed a metal plate (a cathode) in a vacuum tube, and exposed it to high-frequency radiation.[39] It was thought that the oscillating electromagnetic fields caused the atoms' field to resonate and, after reaching a certain amplitude, caused subatomic corpuscles to be emitted, and current to be detected. The amount of this current varied with the intensity and color of the radiation. Larger radiation intensity or frequency would produce more current.[citation needed] During the years 1886–1902, Wilhelm Hallwachs and Philipp Lenard investigated the phenomenon of photoelectric emission in detail. Lenard observed that a current flows through an evacuated glass tube enclosing two electrodes when ultraviolet radiation falls on one of them. As soon as ultraviolet radiation is stopped, the current also stops. This initiated the concept of photoelectric emission. The discovery of the ionization of gases by ultraviolet light was made by Philipp Lenard in 1900. As the effect was produced across several centimeters of air and yielded a greater number of positive ions than negative, it was natural to interpret the phenomenon, as J. J. Thomson did, as a Hertz effect upon the particles present in the gas.[28] In 1902, Lenard observed that the energy of individual emitted electrons was independent of the applied light intensity.[6][40] This appeared to be at odds with Maxwell's wave theory of light, which predicted that the electron energy would be proportional to the intensity of the radiation. Lenard observed the variation in electron energy with light frequency using a powerful electric arc lamp which enabled him to investigate large changes in intensity. However, Lenard's results were qualitative rather than quantitative because of the difficulty in performing the experiments: the experiments needed to be done on freshly cut metal so that the pure metal was observed, but it oxidized in a matter of minutes even in the partial vacuums he used. The current emitted by the surface was determined by the light's intensity, or brightness: doubling the intensity of the light doubled the number of electrons emitted from the surface.[citation needed] Initial investigation of the photoelectric effect in gasses by Lenard[41] were followed up by J. J. Thomson[42] and then more decisively by Frederic Palmer Jr.[43][44] The gas photoemission was studied and showed very different characteristics than those at first attributed to it by Lenard.[28] In 1900, while studying black-body radiation, the German physicist Max Planck suggested in his "On the Law of Distribution of Energy in the Normal Spectrum"[45] paper that the energy carried by electromagnetic waves could only be released in packets of energy. In 1905, Albert Einstein published a paper advancing the hypothesis that light energy is carried in discrete quantized packets to explain experimental data from the photoelectric effect. Einstein theorized that the energy in each quantum of light was equal to the frequency of light multiplied by a constant, later called the Planck constant. A photon above a threshold frequency has the required energy to eject a single electron, creating the observed effect. This was a step in the development of quantum mechanics. In 1914, Robert A. Millikan's highly accurate measurements of the Planck constant from the photoelectric effect supported Einstein's model, even though a corpuscular theory of light was for Millikan, at the time, "quite unthinkable".[46] Einstein was awarded the 1921 Nobel Prize in Physics for "his discovery of the law of the photoelectric effect",[47] and Millikan was awarded the Nobel Prize in 1923 for "his work on the elementary charge of electricity and on the photoelectric effect".[48] In quantum perturbation theory of atoms and solids acted upon by electromagnetic radiation, the photoelectric effect is still commonly analyzed in terms of waves; the two approaches are equivalent because photon or wave absorption can only happen between quantized energy levels whose energy difference is that of the energy of photon.[49][18] Albert Einstein's mathematical description of how the photoelectric effect was caused by absorption of quanta of light was in one of his Annus Mirabilis papers, named "On a Heuristic Viewpoint Concerning the Production and Transformation of Light".[50] The paper proposed a simple description of energy quanta, and showed how they explained the blackbody radiation spectrum. His explanation in terms of absorption of discrete quanta of light agreed with experimental results. It explained why the energy of photoelectrons was not dependent on incident light intensity. This was a theoretical leap, but the concept was strongly resisted at first because it contradicted the wave theory of light that followed naturally from James Clerk Maxwell's equations of electromagnetism, and more generally, the assumption of infinite divisibility of energy in physical systems. Einstein's work predicted that the energy of individual ejected electrons increases linearly with the frequency of the light. The precise relationship had not at that time been tested. By 1905 it was known that the energy of photoelectrons increases with increasing frequency of incident light and is independent of the intensity of the light. However, the manner of the increase was not experimentally determined until 1914 when Millikan showed that Einstein's prediction was correct.[7] The photoelectric effect helped to propel the then-emerging concept of wave–particle duality in the nature of light. Light simultaneously possesses the characteristics of both waves and particles, each being manifested according to the circumstances. The effect was impossible to understand in terms of the classical wave description of light,[51][52][53] as the energy of the emitted electrons did not depend on the intensity of the incident radiation. Classical theory predicted that the electrons would 'gather up' energy over a period of time, and then be emitted.[52][54] Research in recent years on the photoelectric effect has been focused on measurements on emission time of photoelectrons. For long, it was believed that photoemission is an instantaneous process. However, a seminal role in this field was played by experimental techniques on attosecond generation of pulses of light for studies on electron dynamics, which was recognised through the 2023 Nobel Prize in physics to Pierre Agostini, Ferenc Krausz and Anne L'Huillier.[55] For example, in 2010, it was discovered that electron emission takes 20 attoseconds and that photoemission is associated with complex multielectron correlations and is not a single-electron process.[56] In a more recent work in the context of tungsten, measurements on photoelectron emission indicated that around 100 attoseconds are required to liberate an electron.[57] In another research, the value was found to be 45 attoseconds.[58] A broad consensus is emerging towards the fact that photoemission is not instantaneous and involves finite time. The role of electric field in photoelectric effect has also been empirically studied and it was found that electromagnetic radiation with a specific orientation of electric field can excite electrons leading to enhanced emission in the Terahertz range.[59] Main article: Photomultiplier Photomultiplier These are extremely light-sensitive vacuum tubes with a coated photocathode inside the envelope. The photo cathode contains combinations of materials such as cesium, rubidium, and antimony specially selected to provide a low work function, so when illuminated even by very low levels of light, the photocathode readily releases electrons. By means of a series of electrodes (dynodes) at ever-higher potentials, these electrons are accelerated and substantially increased in number through secondary emission to provide a readily detectable output current. Photomultipliers are still commonly used wherever low levels of light must be detected.[60] Video camera tubes in the early days of television used the photoelectric effect. For example, Philo Farnsworth's "Image dissector" used a screen charged by the photoelectric effect to transform an optical image into a scanned electronic signal.[61] Main articles: Photoemission spectroscopy, Angle-resolved photoemission spectroscopy, and X-ray photoelectron spectroscopy Angle-resolved photoemission spectroscopy (ARPES) experiment. Helium discharge lamp shines ultraviolet light onto the sample in ultra-high vacuum. Hemispherical electron analyzer measures the distribution of ejected electrons with respect to energy and momentum. Because the kinetic energy of the emitted electrons is exactly the energy of the incident photon minus the energy of the electron's binding within an atom, molecule or solid, the binding energy can be determined by shining a monochromatic X-ray or UV light of a known energy and measuring the kin

metallic substances are usually very high. Einstein’s Contributions towards the Photoelectric Effect The photoelectric effect is the process that involves the ejection or release of electrons from the surface of materials (generally a metal) when light falls on them. The photoelectric effect is an important concept that enables us to clearly understand the quantum nature of light and electrons. After continuous research in this field, the explanation for the photoelectric effect was successfully explained by Albert Einstein. He concluded that this effect occurred as a result of light energy being carried in discrete quantised packets. For this excellent work, he was honoured with the Nobel Prize in 1921. According to Einstein, each photon of energy E is E = hν Where E = Energy of the photon in joule h = Plank’s constant (6.626 × 10-34 J.s) ν = Frequency of photon in Hz Properties of the Photon For a photon, all the quantum numbers are zero. A photon does not have any mass or charge, and they are not reflected in a magnetic and electric field. The photon moves at the speed of light in empty space. During the interaction of matter with radiation, radiation behaves as it is made up of small particles called photons. Photons are virtual particles. The photon energy is directly proportional to its frequency and inversely proportional to its wavelength. The momentum and energy of the photons are related, as given below E = p.c where p = Magnitude of the momentum c = Speed of light Definition of the Photoelectric Effect The phenomenon of metals releasing electrons when they are exposed to light of the appropriate frequency is called the photoelectric effect, and the electrons emitted during the process are called photoelectrons. Principle of the Photoelectric Effect The law of conservation of energy forms the basis for the photoelectric effect. Minimum Condition for Photoelectric Effect Threshold Frequency (γth) It is the minimum frequency of the incident light or radiation that will produce a photoelectric effect, i.e., the ejection of photoelectrons from a metal surface is known as the threshold frequency for the metal. It is constant for a specific metal but may be different for different metals. If γ = Frequency of the incident photon and γth= Threshold frequency, then, If γ < γTh, there will be no ejection of photoelectron and, therefore, no photoelectric effect. If γ = γTh, photoelectrons are just ejected from the metal surface; in this case, the kinetic energy of the electron is zero. If γ > γTh, then photoelectrons will come out of the surface, along with kinetic energy. Threshold Wavelength (λth) During the emission of electrons, a metal surface corresponding to the greatest wavelength to incident light is known as threshold wavelength. λth = c/γth For wavelengths above this threshold, there will be no photoelectron emission. For λ = wavelength of the incident photon, then If λ < λTh, then the photoelectric effect will take place, and ejected electron will possess kinetic energy. If λ = λTh, then just the photoelectric effect will take place, and the kinetic energy of ejected photoelectron will be zero. If λ > λTh, there will be no photoelectric effect. Work Function or Threshold Energy (Φ) The minimal energy of thermodynamic work that is needed to remove an electron from a conductor to a point in the vacuum immediately outside the surface of the conductor is known as work function/threshold energy. Φ = hγth = hc/λth The work function is the characteristic of a given metal. If E = energy of an incident photon, then If E photoelectron will be zero If E > Φ, the photoelectric effect will take place along with the possession of the kinetic energy by the ejected electron. Photoelectric Effect Formula According to Einstein’s explanation of the photoelectric effect, The energy of photon = Energy needed to remove an electron + Kinetic energy of the emitted electron i.e., hν = W + E Where, h is Planck’s constant ν is the frequency of the incident photon W is a work function E is the maximum kinetic energy of ejected electrons: 1/2 mv² Laws Governing the Photoelectric Effect For a light of any given frequency,; (γ > γ Th), the photoelectric current is directly proportional to the intensity of light. For any given material, there is a certain minimum (energy) frequency, called threshold frequency, below which the emission of photoelectrons stops completely, no matter how high the intensity of incident light is. The maximum kinetic energy of the photoelectrons is found to increase with the increase in the frequency of incident light, provided the frequency (γ > γ Th) exceeds the threshold limit. The maximum kinetic energy is independent of the intensity of light. The photo-emission is an instantaneous process. Experimental Study of the Photoelectric Effect Photoelectric Effect: Experimental Setup The given experiment is used to study the photoelectric effect experimentally. In an evacuated glass tube, two zinc plates, C and D, are enclosed. Plates C acts as an anode, and D acts as a photosensitive plate. Two plates are connected to battery B and ammeter A. If the radiation is incident on plate D through a quartz window, W electrons are ejected out of the plate, and current flows in the circuit. This is known as photocurrent. Plate C can be maintained at desired potential (+ve or – ve) with respect to plate D. Characteristics of the Photoelectric Effect The threshold frequency varies with the material, it is different for different materials. The photoelectric current is directly proportional to the light intensity. The kinetic energy of the photoelectrons is directly proportional to the light frequency. The stopping potential is directly proportional to the frequency, and the process is instantaneous. Factors Affecting the Photoelectric Effect With the help of this apparatus, we will now study the dependence of the photoelectric effect on the following factors: The intensity of incident radiation. A potential difference between the metal plate and collector. Frequency of incident radiation. Effects of Intensity of Incident Radiation on Photoelectric Effect The potential difference between the metal plate, collector and frequency of incident light is kept constant, and the intensity of light is varied. The electrode C, i.e., the collecting electrode, is made positive with respect to D (metal plate). For a fixed value of frequency and the potential between the metal plate and collector, the photoelectric current is noted in accordance with the intensity of incident radiation. It shows that photoelectric current and intensity of incident radiation both are proportional to each other. The photoelectric current gives an account of the number of photoelectrons ejected per sec. Effects of Potential Difference between the Metal Plate and the Collector on the Photoelectric Effect The frequency of incident light and intensity is kept constant, and the potential difference between the plates is varied. Keeping the intensity and frequency of light constant, the positive potential of C is increased gradually. Photoelectric current increases when there is a positive increase in the potential between the metal plate and the collector up to a characteristic value. There is no change in photoelectric current when the potential is increased higher than the characteristic value for any increase in the accelerating voltage. This maximum value of the current is called saturation current. Effect of Frequency on Photoelectric Effect The intensity of light is kept constant, and the frequency of light is varied. For a fixed intensity of incident light, variation in the frequency of incident light produces a linear variation of the cut-off potential/stopping potential of the metal. It is shown that the cut-off potential (Vc) is linearly proportional to the frequency of incident light. The kinetic energy of the photoelectrons increases directly proportionally to the frequency of incident light to completely stop the photoelectrons. We should reverse and increase the potential between the metal plate and collector in (negative value) so the emitted photoelectron can’t reach the collector. Einstein’s Photoelectric Equation According to Einstein’s theory of the photoelectric effect, when a photon collides inelastically with electrons, the photon is absorbed completely or partially by the electrons. So if an electron in a metal absorbs a photon of energy, it uses the energy in the following ways. Some energy Φ0 is used in making the surface electron free from the metal. It is known as the work function of the material. Rest energy will appear as kinetic energy (K) of the emitted photoelectrons. Einstein’s Photoelectric Equation Explains the Following Concepts The frequency of the incident light is directly proportional to the kinetic energy of the electrons, and the wavelengths of incident light are inversely proportional to the kinetic energy of the electrons. If γ = γth or λ =λth then vmax = 0 γ < γth or λ > λth: There will be no emission of photoelectrons. The intensity of the radiation or incident light refers to the number of photons in the light beam. More intensity means more photons and vice-versa. Intensity has nothing to do with the energy of the photon. Therefore, the intensity of the radiation is increased, and the rate of emission increases, but there will be no change in the kinetic energy of electrons. With an increasing number of emitted electrons, the value of the photoelectric current increases. Different Graphs of the Photoelectric Equation Photoelectric current vs Retarding potential for different voltages Photoelectric current vs Retarding potential for different intensities Electron current vs Light Intensity Stopping potential vs Frequency Electron current vs Light frequency Electron kinetic energy vs Light frequency Applications of the Photoelectric Effect Used to generate electricity in solar panels. These panels contain metal combinations that allow electricity generation from a wide range of wavelengths. Motion and Position Sensors: In this case, a photoelectric material is placed in front of a UV or IR LED. When an object is placed in between the Light-emitting diode (LED) and sensor, light is cut off, and the electronic circuit registers a change in potential difference Lighting sensors, such as the ones used in smartphones, enable automatic adjustment of screen brightness according to the lighting. This is because the amount of current generated via the photoelectric effect is dependent on the intensity of light hitting the sensor. Digital cameras can detect and record light because they have photoelectric sensors that respond to different colours of light. X-Ray Photoelectron Spectroscopy (XPS): This technique uses X-rays to irradiate a surface and measure the kinetic energies of the emitted electrons. Important aspects of the chemistry of a surface can be obtained, such as elemental composition, chemical composition, the empirical formula of compounds and chemical state. Photoelectric cells are used in burglar alarms. Used in photomultipliers to detect low levels of light. Used in video camera tubes in the early days of television. Night vision devices are based on this effect. The photoelectric effect also contributes to the study of certain nuclear processes. It takes part in the chemical analysis of materials since emitted electrons tend to carry specific energy that is characteristic of the atomic source. Photoelectric Effect – JEE Advanced Concepts and Problems Problems on the Photoelectric Effect 1. In a photoelectric effect experiment, the threshold wavelength of incident light is 260 nm and E (in eV) = 1237/λ (nm). Find the maximum kinetic energy of emitted electrons. Solution: Kmax = hc/λ – hc/λ0 = hc × [(λ0 – λ)/λλ0] ⇒ Kmax = (1237) × [(380 – 260)/380×260] = 1.5 eV Therefore, the maximum kinetic energy of emitted electrons in the photoelectric effect is 1.5 eV. 2. In a photoelectric experiment, the wavelength of the light incident on metal is changed from 300 nm to 400 nm and (hc/e = 1240 nm-V). Find the decrease in the stopping potential. Solution: hc/λ1 = ϕ + eV1 . . . . (i) hc/λ2 = ϕ + eV2 . . . . (ii) Equation (i) – (ii) hc(1/λ1 – 1/λ2) = e × (V1 – V2) ⇒V1 – V2 = (hc/e) × [(λ2 – λ1)/(λ1 λ2)] = (1240 nm V) × 100nm/(300nm × 400nm) =12.4/12 ≈ 1V Therefore, the decrease in the stopping potential during the photoelectric experiment is 1V. 3. When ultraviolet light with a wavelength of 230 nm shines on a particular metal plate, electrons are emitted from plate 1, crossing the gap to plate 2 and causing a current to flow through the wire connecting the two plates. The battery voltage is gradually increased until the current in the ammeter drops to zero, at which point the battery voltage is 1.30 V. a) What is the energy of the photons in the beam of light in eV? b) What is the maximum kinetic energy of the emitted electrons in eV? Solution: Assuming that the wavelength corresponds to the wavelength in the vacuum. \(\begin{array}{l}f = \frac{c}{\lambda }\end{array} \) \(\begin{array}{l}f = \frac{3\times 10^{8}}{2.40\times 10^{-7} }\end{array} \) f = 1.25 × 1015 Hz The energy of photon E = hf E = (4.136 × 10-15)(1.25 × 1015) Note: Planck’s constant in eV s = 4.136 × 10-15 eV s E = 5.17 eV. b) The maximum kinetic energy related to the emitted electron is stopping potential. In this case, the stopping potential is 1.30V. So the maximum kinetic energy of the electrons is 1.30V. Also Check out: JEE Main Photoelectric Effect Previous Year Questions with Solutions Important Points to Remember If we consider the light with any given frequency, the photoelectric current is generally directly proportional to the intensity of light. However, the frequency should be above the threshold frequency in such a case. Below threshold frequency, the emission of photoelectrons completely stops despite the high intensity of incident light. A photoelectron’s maximum kinetic energy increases with an increase in the frequency of incident light. In this case, the frequency should exceed the threshold limit. Maximum kinetic energy is not affected by the intensity of light. Stopping potential is the negative potential of the opposite electrode when the photo-electric current falls to zero. The threshold frequency is described as the frequency when the photoelectric current stops below a particular frequency of incident light. The photoelectric effect establishes the quantum nature of radiation. This has been taken into account to be proof in favour of the particle nature of light. Share — copy and redistribute the material in any medium or format for any purpose, even commercially. Adapt — remix, transform, and build upon the material for any purpose, even commercially. The licensor cannot revoke these freedoms as long as you follow the license terms. Attribution — You must give appropriate credit , provide a link to the license, and indicate if changes were made . You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use. ShareAlike — If you remix, transform, or build upon the material, you must distribute your contributions under the same license as the original. No additional restrictions — You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits. You do not have to comply with the license for elements of the material in the public domain or where your use is permitted by an applicable exception or limitation . No warranties are given. The license may not give you all of the permissions necessary for your intended use. For example, other rights such as publicity, privacy, or moral rights may limit how you use the material. German physicist Hertz conducted experiments to see if he could pull out the free electrons which were revolving in the outermost shells of an atom. By free electrons, we refer to those electrons inside a metal which are free to move. He observed that upon heating the surface of the metal to high temperatures, they were able to be ejected from the metal, a phenomenon called thermionic emission. Another way is to shine high frequency electromagnetic waves on them. This is what is used in the photoelectric effect. It proved that light has particle nature in addition to wave nature. Let’s see more about this here in this article! Table of contents Photoelectric effect Photoelectric effect experimental setup Effect of potential, intensity and frequency of incident radiation on photoelectrons Einstein’s photoelectric equation Practice problems FAQs Photoelectric effect The phenomenon of emission of photoelectrons from the surface of the metal when radiations of sufficient frequency (like ultraviolet ray) fall on it, is called photoelectric emission. The current produced in the process is called photocurrent. The incident radiation should have a high enough frequency (v) which is greater than the threshold frequency (v0) of the metal i.e. v > v0 Photoelectric effect experimental setup It consists of an evacuated glass tube with a photosensitive material as the cathode(C) and a collector plate acting as the anode(A). The incident light shines through a quartz window. A battery is connected to the cathode to facilitate evacuation of photoelectrons. The emitted photoelectrons strike the anode, upon which photocurrent is produced. A microammeter connected in series with the battery measures the photocurrent. Effect of potential, intensity and frequency of incident radiation on photoelectrons So now you have an understanding about photoelectrons and how instrumental they are in proving the particle nature of light. The intensity and frequency of the incident radiation play a vital role in photoelectric effect Effect of intensity on photoelectrons Keeping the frequency of incident radiation constant, if its intensity is increased, then the number of photoelectrons striking per second increases; increasing the photocurrent. Effect of potential on photocurrent The collector plate anode is initially kept positive with respect to the emitter plate. As the potential at the anode is increased, the photocurrent measured by the microammeter also increases. Even at zero potential, some photocurrent exists due to the already emitted electrons which move because of their kinetic energy. The photocurrent increases up to a certain level after which it becomes saturated since the number of electrons emitted remains constant. When the polarity is reversed, the photocurrent starts decreasing and becomes zero at a particular value of retarding potential known as stopping potential. When light rays of different intensities are made to fall on the emitter, it is observed that at high intensity, the value of saturation current increases, as shown in the figure. Effect of frequency of incident radiation With the increase in the frequency of the incident radiation, the value of saturation current remains constant whereas the magnitude of stopping potential increases and becomes more negative because the maximum kinetic energy of the photoelectrons increases. Einstein's photoelectric equation Einstein proposed that there is a certain minimum frequency below which the emission of electrons is not possible. This frequency is known as the threshold frequency or cut-off frequency(vo). So it can be deduced that the generation of photocurrent is only possible when the light of sufficient frequency is made to fall on the metal plate. Also there was no time lag between the emission of electrons and incidence of light. The electrons ejected can have the maximum kinetic energy given by Einstein's photoelectric equation, Kmax = hv - ϕo Where ϕo= hvo is the work function of the metal. It can be seen that the kinetic energy of the electrons emitted does not depend upon the intensity of incident light but its frequency instead. Also it is to be noted that there is zero chance of two photons hitting a single electron at a time. Practice problems Q. The work function ϕ of some metals is listed below. (Use hc=1240 eV nm) Metal Work function (ϕ eV) Li 2.4 Cu 4.8 Ag 4.3 W 4.75 Which of the given metal(s) will show photoelectric emission when illuminated by light of wavelength 300 nm? A. Photoelectric emission takes place when, Energyincident radiation > Work function(ϕ) Here, the energy of incident radiation (eV) is given by, Since only Therefore Li shows photoelectric emission. Q. A metal surface is illuminated by light of two different wavelengths 250 nm and 300 nm. The maximum speeds of ejected electrons corresponding to these wavelengths are v1 and v2 respectively. If the ratio of v1 : v2 = 2 : 1. Find the work function of the metal. (Use hc=1240 eV nm) A. Given, From Einstein's photoelectric equation, Q. The relationship between the maximum kinetic energy of electrons flying off the surface of a metal versus the frequency of light striking the metal surface as part of the photoelectric effect is shown in the graph below. According to this graph, what will happen when light of frequency 61014 Hz strikes the metal surface? A. From the figure, the threshold frequency of the metal, threshold=101014 Hz Photoelectrons are emitted only when light having a frequency larger than the threshold frequency is allowed to fall on a metal surface. As the light used has frequency, 61014 Hz which is less than the threshold frequency, no electrons will be emitted. Q. For photoelectric effect in a metal, the graph of stopping potential Vo (in V) versus frequency (in Hz) of the incident radiation is shown in the figure. From the graph, find the threshold frequency and work function of the metal. (Take h=6.6 10-34 Js) A. From Einstein's photoelectric equation, E=o+KEmax E-o=eVo Where o=Work function=ho From, the figure we get, the threshold frequency, o=4 1015 Hz o=ho=(6.6 10-34) (4 1015) =26.410-19 J =26.410-191.610-19=16.5 eV FAQs Q. Every metal has a definite work function. Why do all the photo-electrons not come out with the same energy, if incident radiation is monochromatic? A. An electron is bound with the nucleus of the metal atom and has different internal energy which depends on the orbit in which they are orbiting. When a photon is incident on the metal surface, some energy of the photon is used up to overcome the coulombic interaction, which is known as the work function of the metal, and the remaining energy of the photon becomes the kinetic energy of the emitted photoelectrons. Maximum kinetic energy of the photo electrons, Kmax = h -o Where, h is the energy of photons and o is the work function of metal. K.Emax λo, photoemission is not possible. Effect of intensity of light on the photoelectric currentThe collector plate A is kept at a positive potential in relation to the emitter plate C, attracting electrons emitted from C to A. The intensity of light is modified while the frequency of incident radiation and accelerating potential remains constant, and the resulting photoelectric current is monitored. Photoelectric current is observed to rise linearly with light intensity, as shown in the below image. Variation of photoelectric current with the intensity of lightThe number of photoelectrons emitted per second is exactly proportional to the photoelectric current. This means that the rate at which photoelectrons are emitted is proportional to the intensity of incident energy. Note: More photos, not more energetic photons, are produced by a brighter light. Effect of potential difference on photoelectric currentThe incident radiation threshold frequency and intensity are both kept constant at a reasonable value. Plate A's positive potential is steadily increased, and the resulting photoelectric current is measured each time. It has been discovered that as the positive (accelerating potential) grows, so does the photoelectric current. All of the released electrons are captured by plate A at some point for a particular positive potential, and photoelectric current peaks. The photoelectric current does not rise as the positive potential of plate A is increased further. Saturation current refers to the highest value of photoelectric current. The commutator key is now inverted, and plate A is given a negative (retarding) potential in relation to plate C. The negative potential of Plate A is gradually increased till the photoelectric current reduces to zero. The minimum negative potential V_{0} given to the plate A for which photoelectric current stops or becomes zero is called cut-off or stopping potential. Variation of photoelectric current with collector plate potential for different intensities of incident radiationThe energy of all photoelectrons released from a metal surface is not the same. When the stopping potential is adequate to reject even the most energetic photoelectrons with the highest kinetic energy, the photoelectric current becomes zero, and 1 / 2 mv2max = eV0. where vmax is the maximum velocity of the photoelectron, m is the mass of the electron, and e is the magnitude of the charge on the electron. When the incident radiation frequency is maintained constant and the experiment is repeated with varying strengths of the incident beam, it is discovered that V remains constant in all circumstances see above image. The stopping potential and maximum kinetic energy of photoelectrons are thus independent of incoming radiation intensity for a certain frequency of incident radiation. Variation of photoelectric current with collector plate potential for different frequencies of incident radiationAdjusting the same intensity of incoming radiation at various frequencies to study the fluctuation of photoelectric current with collector plate potential is illustrated in the figure. For incoming radiation of various frequencies, different values of stopping potential but the same values of saturation current are achieved. The energy of a photoelectron released is proportional to the frequency of incoming light. When the frequency of incoming radiation is increased, the stopping potential becomes more negative. As shown, the below graph between incoming radiation frequency and related stopping potential for various metals is made up of straight lines. Variation of stopping potential with the frequency of incident radiationsThe graph shows that, for a particular photosensitive material, the stopping potential varies linearly with the frequency of incoming radiation, and there is a minimum cut-off frequency v0 below which the stopping potential is zero. Sample QuestionsQuestion 1: Define threshold frequency and photoelectric work function? Answer: Threshold frequency: The threshold frequency is the lowest frequency of incoming radiation for which photoelectrons are merely released from photosensitive material. Photoelectric work function: The photoelectric work function is the threshold energy required by the radiation or photons that are incident on the surface of the metal. We can use the term radiation interchangeably with photons in this case. ϕ=hν0 where h is the Planck's constant and ν0 is the threshold frequency. Question 2: What is the photoelectric effect? State and explain its characteristics? Answer: The phenomenon of emission of electrons by certain substances (say metals), when exposed to radiations of suitable frequencies is called photoelectric effect and emitted electrons are called photoelectrons. The photoelectric effect is a one photon-one electron phenomenon. One photon cannot eject more than one photo-electron. Characteristics: For a given photosensitive material, there exists a certain minimum cut-off frequency of the incident radiation, called threshold frequency v0 below which no emission of photoelectrons takes place. The threshold frequency is different for different metals.For a given photosensitive material and frequency of incident radiation (above threshold frequency), the photoelectric current is directly proportional to the intensity of incident light.Above the threshold frequency v0, the maximum kinetic energy of the emitted photoelectrons increases linearly with the frequency of the incident radiation, but is independent of intensity of incident radiation. The emission of photo electron is an instantaneous process. There is no time lag between the irradiation of the metal surface and P emission of photoelectrons.Question 3: Define threshold wavelength? Answer: The wavelength (λ0) corresponding to the threshold frequency v0, is called the threshold wavelength. If c is the velocity of light, then v0 = ϕ / h For the photoelectric emission the wavelength of incident light must be less than λ0. Question 4: What is the mass of a photon? Answer: The photon’s rest mass is zero, which indicates that if the photon is moving, it will have some momentum, which is equivalent to mass, but at rest, the photon’s mass will be zero. Question 5: Define stopping potential? Answer: The magnitude of the retarding potential for which the photoelectric current is zero is called the stopping potential (Vs) The value of the stopping potential is a measure of the maximum kinetic energy for the photoelectrons. Work done on electron by, Vs = Max K.E. for the photoelectrons. eVs = 1/2 mv2max Question 6: What is the effect of kinetic energies on stopping potential in photoelectric emission? Answer: The value of the stopping potential is a measure of the maximum kinetic energy that can be possessed by a photoelectron. The different photoelectrons have different kinetic energies. At the stopping potential, the work done by the electron against the stopping potential V is equal to the K.E. of this electron having maximum K.E. eV = 1/2 mv2max where V max is the maximum velocity.