



ISSN 2211-3797

Results in
Physics



ScienceDirect®

[Submit your article](#)[Menu](#)[Search in this journal](#)

Volume 7

Pages 1-4458 (2017)

[← Previous vol/issue](#)[Next vol/issue >](#)

Receive an update when the latest issues in this journal are published

[Sign in to set up alerts](#)

Regular articles

Research article *Open access*

Numerical study for Darcy-Forchheimer flow due to a curved stretching surface with Cattaneo-Christov heat flux and homogeneous-heterogeneous reactions

Tasawar Hayat, Rai Sajjad Saif, Rahmat Ellahi, Taseer Muhammad, Bashir Ahmad

Pages 2886-2892

[Download PDF](#) [Article preview](#)

[FEEDBACK](#)

Results in Physics

Open access

Submit your article

Menu

Search in this journal

Research article *Open access*

Analysis of spectral chirps and intensities evolution of a spatiotemporally focused femtosecond laser beam

Gang Li, Feng Lu, Hongjie Liu, Bo Cui, ... Yuqiu Gu
Pages 2898-2906

[Download PDF](#) [Article preview](#) ✓

Research article *Open access*

Effect of metal ion Fe(III) on the performance of chlorophyll as photosensitizers on dye sensitized solar cell

Harsasi Setyawati, Handoko Darmokoesoemo, Anggy Tamara Ayu Ningtyas, Yassine Kadmi, ... Heri Septya Kusuma
Pages 2907-2918

[Download PDF](#) [Article preview](#) ✓

Research article *Open access*

Ultra-lightweight and highly porous carbon aerogels from bamboo pulp fibers as an effective sorbent for water treatment

Wei Yuan, Xiaofang Zhang, Jiangqi Zhao, Qingye Li, ... Canhui Lu
Pages 2919-2924

[Download PDF](#) [Article preview](#) ✓

Research article *Open access*

Study on precursory characteristics of granite failure based on infrasonic energy

Jian-ping Wei, Bing Jia, Zhi-hui Wen, Lin-xing Jia
Pages 2925-2932

[Download PDF](#) [Article preview](#) ✓

FEEDBACK 

Results in Physics

Open access

Submit your article

Menu

Search in this journal

Research article *Open access*

Eigenvalue approach to two dimensional coupled magneto-thermoelasticity in a rotating isotropic medium

F.S. Bayones, A.M. Abd-Alla
Pages 2941-2949

[Download PDF](#) [Article preview](#) 

Research article *Open access*

Metachronal wave analysis for non-Newtonian fluid under thermophoresis and Brownian motion effects

A. Shaheen, S. Nadeem
Pages 2950-2957

[Download PDF](#) [Article preview](#) 

Research article *Open access*

Effects of Y_2O_3 on crystallization kinetics of $SiO_2-Al_2O_3-CaO-CaF_2$ oxy-fluoride glass-ceramic system

M. Soleymani Zarabad, M. Rezvani
Pages 2958-2964

[Download PDF](#) [Article preview](#) 

Research article *Open access*

Random laser based on Rhodamine 6G (Rh6G) doped poly(methyl methacrylate) (PMMA) films coating on ZnO nanorods synthesized by hydrothermal oxidation

Hua Zhang, Guoying Feng, Hong Zhang, Chao Yang, ... Shouhuan Zhou
Pages 2968-2972

[Download PDF](#) [Article preview](#) 

FEEDBACK 

Results in Physics

Open access

Submit your article

Menu



Search in this journal

[Download PDF](#) [Article preview](#)

Research article *Open access*

Magneto-Thermo-Marangoni convective flow of Cu-H₂O nanoliquid past an infinite disk with particle shape and exponential space based heat source effects

B. Mahanthesh, B.J. Gireesha, B.C. Prasannakumara, P.B. Sampath Kumar
Pages 2990-2996

[Download PDF](#) [Article preview](#)

Research article *Open access*

Numerical study of double stratification in Casson fluid flow in the presence of mixed convection and chemical reaction

Khalil Ur Rehman, Aneeqa Ashfaq Malik, M.Y. Malik, N. Sandeep, Noor Ul Saba
Pages 2997-3006

[Download PDF](#) [Article preview](#)

Research article *Open access*

Control of the shape and size of iron oxide (α -Fe₂O₃) nanoparticles synthesized through the chemical precipitation method

Abdelmajid Lassoued, Brahim Dkhil, Abdellatif Gadri, Salah Ammar
Pages 3007-3015

[Download PDF](#) [Article preview](#)

Research article *Open access*

A mathematical model for mixed convective flow of chemically reactive Oldroyd-B fluid between isothermal stretching disks

M.S. Hashmi, N. Khan, Sami Ullah Khan, M.M. Rashidi
Pages 3016-3023

FEEDBACK

Results in Physics

Open access

Submit your article

Menu



Search in this journal

[Download PDF](#) Article preview

Research article Open access

An unsteady squeezed flow of a tangent hyperbolic fluid over a sensor surface in the presence of variable thermal conductivity

K. Ganesh Kumar, B.J. Gireesha, M.R. Krishnamurthy, N.G. Rudraswamy

Pages 3031-3036

[Download PDF](#) Article preview

Research article Open access

A numerical study of magnetohydrodynamics flow in Casson nanofluid combined with Joule heating and slip boundary conditions

A. Kamran, S. Hussain, M. Sagheer, N. Akmal

Pages 3037-3048

[Download PDF](#) Article preview

Research article Open access

Computational analysis for velocity slip and diffusion species with carbon nanotubes

T. Hayat, Zakir Hussain, A. Alsaedi, A. Hobiny

Pages 3049-3058

[Download PDF](#) Article preview

Research article Open access

Statistical study of hydromagnetic boundary layer flow of Williamson fluid regarding a radiative surface

Anum Shafiq, T.N. Sindhu

Pages 3059-3067

FEEDBACK

Results in Physics

Open access

Submit your article

Menu



Search in this journal

[Download PDF](#) Article preview

Research article *Open access*

Local similar solution of MHD stagnation point flow in Carreau fluid over a non-linear stretched surface with double stratified medium

M. Farooq, Qurat ul ain Anzar, T. Hayat, M. Ijaz Khan, A. Anjum
Pages 3078-3089

[Download PDF](#) Article preview

Research article *Open access*

Carreau nanofluid impinging over a stretching cylinder with generalized slip effects: Using finite difference scheme

T. Salahuddin, Arif Hussain, M.Y. Malik, M. Awais, Mair Khan
Pages 3090-3099

[Download PDF](#) Article preview

Research article *Open access*

Numerical study for nanofluid flow due to a nonlinear curved stretching surface with convective heat and mass conditions

Tasawar Hayat, Arsalan Aziz, Taseer Muhammad, Ahmed Alsaedi
Pages 3100-3106

[Download PDF](#) Article preview

Research article *Open access*

MHD convective flow of magnetite- Fe_3O_4 nanoparticles by curved stretching sheet

Tasawar Hayat, Madiha Rashid, Ahmed Alsaedi
Pages 3107-3115

FEEDBACK

Results in Physics

Open access

Submit your article

Menu

 Search in this journal


Yakup Yıldırım, Nisa Çelik, Emrullah Yaşar
Pages 3116-3123

 [Download PDF](#) Article preview 

Research article *Open access*

XPS and morphological properties of Cr₂O₃ thin films grown by thermal evaporation method


Ahmed Kadari, Tobias Schemme, Dahane Kadri, Joachim Wollschläger
Pages 3124-3129

 [Download PDF](#) Article preview 

Research article *Open access*

Controllable preparation and mechanism of nano-silver mediated by the microemulsion system of the clove oil

Hongfang Gao, Hui Yang, Chuang Wang
Pages 3130-3136

 [Download PDF](#) Article preview 

Research article *Open access*

Computations for nanofluid flow near a stretchable rotating disk with axial magnetic field and convective conditions

A. Mushtaq, M. Mustafa
Pages 3137-3144

 [Download PDF](#) Article preview 

Research article *Open access*

FEEDBACK 

Results in Physics

Open access

Submit your article


Menu

 Search in this journal

Research article *Open access*

Influence of thermal and concentration gradients on unsteady flow over a stretchable surface

Naveed Ahmed, Adnan, Umar Khan, Syed Tauseef Mohyud-Din, Vedat Suat Erturk
Pages 3153-3162

 [Download PDF](#) [Article preview](#) 

Research article *Open access*

Some axisymmetric equilibria for certain ideal and resistive magnetohydrodynamics with incompressible flows

S.M. Moawad, O.H. El-Kalaawy, H.M. Shaker
Pages 3163-3175

 [Download PDF](#) [Article preview](#) 

Research article *Open access*

Investigations of structural, morphological and optical properties of Cu:ZnO/TiO₂/ZnO and Cu:TiO₂/ZnO/TiO₂ thin films prepared by spray pyrolysis technique

M.I. Khan
Pages 3176-3180

 [Download PDF](#) [Article preview](#) 

Research article *Open access*

Stabilized approximation of steady flow of third grade fluid in presence of partial slip

Amer Rasheed, Azka Kausar, Abdul Wahab, Tanvir Akbar
Pages 3181-3189

 [Download PDF](#) [Article preview](#) 

FEEDBACK 

Results in Physics

Open access

Submit your article

Menu



Search in this journal

[Download PDF](#) [Article preview](#)

Research article *Open access*

Non linear thermal radiation effect on Williamson fluid with particle-liquid suspension past a stretching surface

K. Ganesh Kumar, N.G. Rudraswamy, B.J. Gireesha, S. Manjunatha

Pages 3196-3202

[Download PDF](#) [Article preview](#)

Research article *Open access*

Structural, morphological and magnetic properties of Eu-doped CoFe_2O_4 nano-ferrites

Aiman Zubair, Zahoor Ahmad, Azhar Mahmood, Weng-Chon Cheong, ... Muhammad Naeem Ashiq

Pages 3203-3208

[Download PDF](#) [Article preview](#)

Research article *Open access*

Effect of point defects on the electronic density states of SnC nanosheets: First-principles calculations

Soleyman Majidi, Amine Achour, D.P. Rai, Payman Nayebi, ... Seyed Mohammad Elahi

Pages 3209-3215

[Download PDF](#) [Article preview](#)

Research article *Open access*

Liquid-liquid phase separation and solidification behavior of Al-Bi-Sb immiscible alloys

Degang Zhao, Rongxue Liu, Di Wu, Lin Bo, Lin Wang

Pages 3216-3221

[Download PDF](#) [Article preview](#)

FEEDBACK

Results in Physics

Open access

Submit your article

Menu



Search in this journal

[Download PDF](#) [Article preview](#)

Research article *Open access*

Pyrolysis characteristics of typical biomass thermoplastic composites

Hongzhen Cai, Ziyu Ba, Keyan Yang, Qingfa Zhang, ... Shiyan Gu
Pages 3230-3235

[Download PDF](#) [Article preview](#)

Research article *Open access*

First-principles study on the dehydrogenation characteristics of LiBH₄ modified by Ti

Xiaohua Mo, Weiqing Jiang, Shilong Cao
Pages 3236-3242

[Download PDF](#) [Article preview](#)

Research article *Open access*

Detection the nonlinear ultrasonic signals based on modified Duffing equations

Yuhua Zhang, Hanling Mao, Hanying Mao, Zhenfeng Huang
Pages 3243-3250

[Download PDF](#) [Article preview](#)

Research article *Open access*

Free vibration and buckling analyses of a size-dependent axially functionally graded beam incorporating transverse shear deformation

Wanli Yang, Dan He
Pages 3251-3263

[Download PDF](#) [Article preview](#)

FEEDBACK

Results in Physics

Open access

Submit your article

Menu



Search in this journal

[Download PDF](#) [Article preview](#)

Research article *Open access*

Phase slip process and charge density wave dynamics in a one dimensional conductor

N. Habiballah, M. Zouadi, A. Arbaoui, M. Qjani, J. Dumas

Pages 3277-3280

[Download PDF](#) [Article preview](#)

Research article *Open access*

Consequences of non-Fourier's heat conduction relation and chemical processes for viscoelastic liquid

A. Sohail, W.A. Khan, M. Khan, S.I.A. Shah

Pages 3281-3286

[Download PDF](#) [Article preview](#)

Research article *Open access*

Absolute variation of the mechanical characteristics of halloysite reinforced polyurethane nanocomposites complemented by Taguchi and ANOVA approaches

Tayser Sumer Gaaz, Abu Bakar Sulong, Abdul Amir H. Kadhum, Mohamed H. Nassir, Ahmed A. Al-Amiery

Pages 3287-3300

[Download PDF](#) [Article preview](#)

Research article *Open access*

Effects of arbitrary shear stress on unsteady free convection flow of Casson fluid past a vertical plate

Arshad Khan, Ilyas Khan, Asma Khalid, Sharidan Shafie

Pages 3301-3306

FEEDBACK

Results in Physics

Open access

Submit your article

Menu



Search in this journal

[Download PDF](#) Article preview

Research article *Open access*

Numerical analysis of unsteady 3D flow of Carreau nanofluid with variable thermal conductivity and heat source/sink

M. Irfan, M. Khan, W.A. Khan

Pages 3315-3324

[Download PDF](#) Article preview

Research article *Open access*

Numerical modeling of time-dependent bio-convective stagnation flow of a nanofluid in slip regime

Rakesh Kumar, Shilpa Sood, Sabir Ali Shehzad, Mohsen Sheikholeslami

Pages 3325-3332

[Download PDF](#) Article preview

Research article *Open access*

On the MAF solution of the uniformly lengthening pendulum via change of independent variable in the Bessel's equation

Coşkun Deniz

Pages 3333-3343

[Download PDF](#) Article preview

Research article *Open access*

Influence of the oxygen partial pressure on the growth and optical properties of RF-sputtered anatase TiO₂ thin films

A.R. Grayeli Korpi, Sahare Rezaee, C. Luna, Ş. Tǎlu, ... A. Ahmadpourian

FEEDBACK

Results in Physics

Open access

Submit your article

Menu

 Search in this journal

A. Zeeshan, A. Majeed, C. Fetecau, S. Muhammad
Pages 3353-3360

 [Download PDF](#) Article preview 

Research article *Open access*

Effect of magnetic field on piezo-thermoelastic medium with three theories

Mohamed I.A. Othman, Yassmin D. Elmaklizi, Ethar A.A. Ahmed
Pages 3361-3368

 [Download PDF](#) Article preview 

Research article *Open access*

The rheological properties of shear thickening fluid reinforced with SiC nanowires

Jianhao Ge, Zhuhua Tan, Weihua Li, Hang Zhang
Pages 3369-3372

 [Download PDF](#) Article preview 

Research article *Open access*

Witnessing a Poincaré recurrence with Mathematica

J.M. Zhang, Y. Liu
Pages 3373-3379

 [Download PDF](#) Article preview 

Research article *Open access*

Structural, optical and electronic properties of indium sulfide compositions under influence of copper impurity produced by chemical method

Parisa Esmaili, Haleh Kangarlou, Hadi Savaloni, Mahmood Ghorannevis

FEEDBACK 

Results in Physics

Open access

Submit your article

Menu

 Search in this journal

T. Hayat, Faisal Shah, Muhammad Ijaz Khan, A. Alsaedi
Pages 3390-3395

 [Download PDF](#) Article preview 

Research article *Open access*

Radiative peristaltic flow of magneto nanofluid in a porous channel with thermal radiation

T. Hayat, Saima Rani, A. Alsaedi, M. Rafiq
Pages 3396-3407

 [Download PDF](#) Article preview 

Research article *Open access*

Adsorption and inhibitive properties of sildenafil (Viagra) for zinc in hydrochloric acid solution

A.S. Fouda, H. Ibrahim, M. Atef
Pages 3408-3418

 [Download PDF](#) Article preview 

Research article *Open access*

Non-Darcy Forchheimer flow of ferromagnetic second grade fluid

T. Hayat, Salman Ahmad, M. Ijaz Khan, A. Alsaedi
Pages 3419-3424

 [Download PDF](#) Article preview 

Research article *Open access*

FEEDBACK 

Results in Physics

Open access

Submit your article

Menu

 Search in this journal

Research article *Open access*

Adsorption and corrosion inhibition of mild steel in hydrochloric acid solution by S-allyl-O,O'-dialkyldithiophosphates

Chuan Lai, Bin Xie, Like Zou, Xingwen Zheng, ... Shasha Zhu
Pages 3434-3443

 [Download PDF](#) Article preview 

Research article *Open access*

The influence of annealing temperature and time on the efficiency of pentacene: PTCDI organic solar cells

Mehmet Biber, Şakir Aydoğan, Zakir Çaldıran, Bülent Çakmak, ... Abdulmecit Türüt
Pages 3444-3448

 [Download PDF](#) Article preview 

Research article *Open access*

CuO, MnO₂ and Fe₂O₃ doped biomass ash as silica source for glass production in Thailand

N. Srisittipokakun, Y. Ruangtaweep, W. Rachniyom, K. Boonin, J. Kaewkhao
Pages 3449-3454

 [Download PDF](#) Article preview 

Research article *Open access*

Effect of laser irradiation on the structural, morphological and electrical properties of polycrystalline TiO₂ thin films

M.I. Khan, Asghar Ali
Pages 3455-3458

FEEDBACK 

Results in Physics

Open access

Submit your article

Menu



Search in this journal

Lu Jiming, Wang Zhuqing, Liang Tongxiang, Suzuki Ken, Imura Hiroo

Pages 3459-3464

[Download PDF](#) Article preview

Research article *Open access*

Effects of mass transfer on MHD three dimensional flow of a Prandtl liquid over a flat plate in the presence of chemical reaction

K. Ganesh Kumar, Rizwan-ul-Haq, N.G. Rudraswamy, B.J. Gireesha

Pages 3465-3471

[Download PDF](#) Article preview

Research article *Open access*

The photoemission study of Sr-intercalated C₆₀

Peng Wang, Ateeq Rehman, Liang Meng, Wen-Jie Li, ... Jun-Fa Zhu

Pages 3472-3474

[Download PDF](#) Article preview

Research article *Open access*

Numerical tackling for viscoelastic fluid flow in rotating frame considering homogeneous-heterogeneous reactions

Najwa Maqsood, M. Mustafa, Junaid Ahmad Khan

Pages 3475-3481

[Download PDF](#) Article preview

Research article *Open access*

Evolution of on-axis intensity of anomalous hollow Gaussian beams in highly nonlocal nonlinear media

Xue-Song Jiang, Zhen-Jun Yang, Shuai Jia, Zhen-Feng Yang, ... Shu-Min Zhang

FEEDBACK

Results in Physics

Open access

Submit your article

Menu

Search in this journal

Khalil Ur Rehman, Abid Ali Khan, M.Y. Malik, R.K. Pradhan
Pages 3487-3496

[Download PDF](#) Article preview 

Research article *Open access*

Local accumulation times for spatial difference in morphogen concentration

Xiaoqing Wen, Hongwei Yin
Pages 3497-3501

[Download PDF](#) Article preview 

Research article *Open access*

Effects of viscous dissipation on MHD tangent hyperbolic fluid over a nonlinear stretching sheet with convective boundary conditions

Arif Hussain, M.Y. Malik, T. Salahuddin, A. Rubab, Mair Khan
Pages 3502-3509

[Download PDF](#) Article preview 

Research article *Open access*

Effects of Mg^{2+} concentration on the structure and optical properties of $Mg_xAl_{2-x}O_3 \cdot 0.88\% Cd^{2+}$ ($0.25 \leq x \leq 4.5$) nano-powders synthesized via citrate sol-gel

V.M. Maphiri, F.B. Dejene, S.V. Motloung
Pages 3510-3521

[Download PDF](#) Article preview 

Research article *Open access*

FEEDBACK 

Results in Physics

Open access

Submit your article

Menu

 Search in this journal

Research article *Open access*

Improvement of the frequency-doubling efficiency of high-average-power lasers using multicrystal scheme with opposite thermal properties

Ying Chen, Yuan Zhou, Zhiyou Wang

Pages 3530-3536

 [Download PDF](#) [Article preview](#) 

Research article *Open access*

Generalized Lie symmetry analysis for non-linear differential equations: A purely viscous fluid model

Khalil Ur Rehman, Aneeqa Ashfaq Malik, M.Y. Malik, T. Hayat

Pages 3537-3542


 [Download PDF](#) [Article preview](#) 

Research article *Open access*

An energy and cost efficient majority-based RAM cell in quantum-dot cellular automata

Milad Bagherian Khosroshahy, Mohammad Hossein Moaiyeri, Keivan Navi, Nader Bagherzadeh

Pages 3543-3551

 [Download PDF](#) [Article preview](#) 

Research article *Open access*

Synthesis and length dependent photoluminescence property of zinc oxide nanorods

Ishaq Musa, Naser Qamhie, Saleh Thaker Mahmoud

Pages 3552-3556

 [Download PDF](#) [Article preview](#) 

FEEDBACK 

Results in Physics

Open access

Submit your article

Menu



Search in this journal

[Download PDF](#) [Article preview](#)

Research article *Open access*

Flotation performances and surface properties of chalcopyrite with xanthate collector added before and after grinding

Huiqing Peng, Di Wu, Mohamed Abdelmonem

Pages 3567-3573

[Download PDF](#) [Article preview](#)

Research article *Open access*

Effect of homogeneous-heterogeneous reactions on ferrofluid in the presence of magnetic dipole along a stretching cylinder

Sohail Nadeem, Naeem Ullah, Arif Ullah Khan, Tanvir Akbar

Pages 3574-3582

[Download PDF](#) [Article preview](#)

Research article *Open access*

An improved heat conduction and mass diffusion models for rotating flow of an Oldroyd-B fluid

W.A. Khan, M. Irfan, M. Khan

Pages 3583-3589

[Download PDF](#) [Article preview](#)

Research article *Open access*

X-ray fluorescence analysis of Pb, Fe and Zn in kohl

Eman Daar, Abdullah Alsubaie, K.S. Almugren, S. Barnes, ... D.A. Bradley

Pages 3590-3595

[Download PDF](#) [Article preview](#)

FEEDBACK

Results in Physics

Open access

Submit your article

Menu



Search in this journal

[Download PDF](#) [Article preview](#)

Research article *Open access*

Turbulent heat transfer and nanofluid flow in a protruded ribbed square passage

Sunil Kumar, Alok Darshan Kothiyal, Mangal Singh Bisht, Anil Kumar
Pages 3603-3618

[Download PDF](#) [Article preview](#)

Research article *Open access*

Optical and dielectric properties of NiFe₂O₄ nanoparticles under different synthesized temperature

Marziye Parishani, Marzieh Nadafan, Zahra Dehghani, Rasoul Malekfar, G.H.H. Khorrami
Pages 3619-3623

[Download PDF](#) [Article preview](#)

Research article *Open access*

Polyacrylamide ferrogels with embedded maghemite nanoparticles for biomedical engineering

Felix A. Blyakhman, Alexander P. Safronov, Andrey Yu. Zubarev, Tatyana F. Shklyar, ... Galina V. Kurlyandskaya
Pages 3624-3633

[Download PDF](#) [Article preview](#)

Research article *Open access*

Elastic, thermodynamic and optical behavior of V₂AC (A = Al, Ga) MAX phases

M.R. Khatun, M.A. Ali, F. Parvin, A.K.M.A. Islam
Pages 3634-3639

[Download PDF](#) [Article preview](#)

FEEDBACK

Results in Physics

Open access

Submit your article

Menu

 Search in this journal

Research article *Open access*

Melting heat transport of nanofluidic problem over a Riga plate with erratic thickness: Use of Keller Box scheme


Z. Iqbal, Ehtsham Azhar, Zaffar Mehmood, E.N. Maraj
Pages 3648-3658

 [Download PDF](#) [Article preview](#) 

Research article *Open access*

Temperature and concentration stratification effects on non-Newtonian fluid flow past a cylindrical surface



Khalil Ur Rehman, Abid Ali Khan, M.Y. Malik, Iffat Zehra, Usman Ali
Pages 3659-3667

 [Download PDF](#) [Article preview](#) 

Research article *Open access*

Entropy generation impact on peristaltic motion in a rotating frame

H. Zahir, T. Hayat, A. Alsaedi, B. Ahmad
Pages 3668-3677

 [Download PDF](#) [Article preview](#) 

Research article *Open access*

An upwind space-time conservation element and solution element scheme for solving dusty gas flow model

Asad Rehman, Ishtiaq Ali, Shamsul Qamar
Pages 3678-3686

 [Download PDF](#) [Article preview](#) 

FEEDBACK 

Results in Physics

Open access

Submit your article

Menu

Search in this journal

Research article *Open access*

Comparative study of Sm³⁺ doped in Li₂O₃-RE₂O₃-B₂O₃ (RE = Y/La) glasses system for laser medium application

E. Kaewnuam, J. Kaewkhao, N. Wantana, W. Klysubun, ... N. Sangwaranatee
Pages 3698-3703

[Download PDF](#) [Article preview](#) 

  Page 5 of 6  

[< Previous vol/issue](#)

[Next vol/issue >](#)

ISSN: 2211-3797

Copyright © 2022 Elsevier B.V. All rights reserved



ELSEVIER

Copyright © 2022 Elsevier B.V. or its licensors or contributors.
ScienceDirect® is a registered trademark of Elsevier B.V.

RELX™

FEEDBACK 



ScienceDirect®

Results in Physics

Open access

7.6

CiteScore

4.565

Impact Factor

[Submit your article](#)

[Guide for authors](#)

Menu

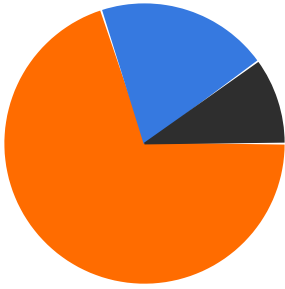


Search in this journal

- > [Aims and scope](#)
- > **[Editorial board](#)**
- > [Abstracting & indexing](#)
- > [Call for papers](#)
- > [News](#)
- > [Announcements](#)
- > [Highlighted Articles](#)
- > [Featured Articles](#)
- > [Watch the Video](#)

Gender diversity of editors

Based on 100.00% responding editors



70% man

20% woman

10% prefer not to disclose

0% non-binary or gender diverse

Editorial board by country

41 editors and editorial board members in 18 countries/regions

1 United States of America (7)

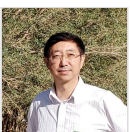
2 China (5)

3 Poland (4)

[> See more editors by country](#)

Editorial board

Editor-in-Chief



Cong-Feng Qiao, PhD

University of the Chinese Academy of Sciences, Beijing, China

Particle Physics, Quantum Theory

[> View full biography](#)

[Email this editor](#) ↗

Editors



Abdon Atangana

University of the Free State Faculty of Natural and Agricultural Sciences, Bloemfontein, South Africa

Methods and application of nonlinear equations, Fractional calculus and their applications to real world problems, Application of partial, ordinary and fractional differential equation to groundwater problems, Perturbation and asymptotic methods, Iteration methods for differential equations, Numerical method for partial differential equations, Numerical methods for ordinary differential equations, Analytical methods for partial differential equation, Analytical methods for ordinary differential equation, Integral transforms, Groundwater flow models, Groundwater transport models

[> View full biography](#)

[Email this editor](#) ↗



Fabio Baronio

University of Brescia, Brescia, Italy

Photonics; Optics; Nonlinear Optics, Optics, Nonlinear Optics, Nonlinear Physics, Solitons

[> View full biography](#)

[Email this editor](#) ↗



Amin Chabchoub

Kyoto University, Kyoto, Japan

Nonlinear Physics, Solitons, Fluid Dynamics, Physical Oceanography, Rogue Waves

[Email this editor](#) ↗



Shanshan Chen

Renmin University of China, Beijing, China

Low dimensional physics, Material Science

[Email this editor](#) ↗



Eugenio Del Re

University of Rome La Sapienza Department of Physics, Roma, Italy

Solid State Physics, Complex Systems, Functional Materials

[Email this editor](#) ↗



Vadim Markel

University of Pennsylvania, Philadelphia, Pennsylvania, United States of America

Optics, Atomic and Molecular Physics, Condensed Matter Physics, inverse problems, imaging

[> View full biography](#)

[Email this editor](#) ↗



Shuang-Yong Zhou

University of Science and Technology of China, Hefei, Anhui, China

Gravitation, Quantum Field Theory, Astrophysics and Cosmology

[Email this editor](#) ↗

Managing Editor

Eva Nováková

Den Haag, Netherlands

[> View full biography](#)

[Email this editor](#) ↗

Scientific Managing Editor'

Ali C. Basaran, PhD

University of California San Diego, La Jolla, United States of America

International Advisory Board



Omid Akhavan, PhD

Sharif University of Technology, Tehran, Iran

Bionanomaterials, Graphene, Photocatalysts, Antibacterial nanomaterials, Biosensors, Stem cell-based tissue engineering



Maxim Avdeev, PhD

Australian Nuclear Science and Technology Organisation, Kirrawee, Australia

Crystal and magnetic structure of inorganic materials; Neutron scattering; Classical and ab initio atomistic modelling; Data mining



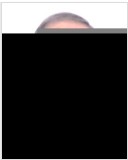
Michel Barsoum, PhD

Drexel University Department of Materials Science and Engineering, Philadelphia, Pennsylvania, United States of America

Ceramic materials; Ternary carbides and nitrides; MAX phases and their 2D derivatives; MXenes

Frank R. de Boer, PhD

University of Amsterdam Van der Waals-Zeeman Institute, Amsterdam, Netherlands



Boris Bokstein, D.Sc

National University of Science and Technology MISiS, Department of Physical Chemistry, Moscow, Russian Federation

Metals, Alloys, Diffusion, Phase transformations, Grain boundaries



Mikhail Brik, Dr. hab.

University of Tartu Institute of Physics, Tartu, Estonia

Crystal field theory, Calculations of energy levels of 3d and 4f ions in crystals, Ab initio calculations of physical properties of pure and doped crystals, Computational materials science

Ekkes Brück

Delft University of Technology, Delft, Netherlands



Charles Doering

University of Michigan, Ann Arbor, Michigan, United States of America

Nonlinear Science; Statistical Physics; Biological Physics; Plasma and Fluid Physics



William Fahrenholtz, PhD

Missouri University of Science and Technology, Rolla, Missouri, United States of America

Materials Science



Eric Gaffet, PhD, HDR

National Centre for Scientific Research, Paris, France

Nanomaterials: Synthesis and Characterization, Solid State Reaction, Mechanical alloying, Mechanochemistry / Ball Milling, Powder Metallurgy, Responsible Development of Nanomaterials, Safer by design / by process (nanomaterials), Chemistry, Physics

Manoj Gupta, PhD

National University of Singapore, Singapore, Singapore

Processing, microstructure and properties evaluation of advanced light weight structural materials inclusive of Al and Mg light-metal alloys/micro/nano/metastable-composites and lightweight high entropy alloys, Materials

Young-Woo Heo

Kyungpook National University, Daegu, South Korea

Azam Irajizad

Sharif University of Technology, Tehran, Iran

Ryosuke Kainuma

Tohoku University, Sendai, Japan

Materials science, phase diagrams, phase transformations, microstructure

Vladislav Kharton, PhD

Institute of Solid State Physics Russian Academy of Sciences, Chernogolovka, Russian Federation

Solid oxide fuel cells, Ceramic membranes, High-temperature electrochemistry and chemistry of solids, Electrocatalysis, Mixed ionic-electronic conductors, Solid electrolytes, Modeling of ionic and ambipolar transport processes, Ceramic technologies, Oxide and composite materials, Oxygen and hydrogen separation

Iwan Kityk†

Czestochowa Technical University, Faculty of Electrical Engineering, Institute of Optoelectronics and Measuring Systems, Częstochowa, Poland

Condensed Matter Physics, Spectroscopy of condensed matter, Nonlinear optical effects in solids, Band structure of crystals

Xiaoguang Li, PhD

University of Science and Technology of China Department of Physics, Hefei, Anhui, China

Research interests include the synthesis, microstructure, physical properties, and prototype devices of transitional metal oxides such as ferroelectric and multiferroic based electronic devices.

Zi-Kui Liu

The Pennsylvania State University Department of Materials Science and Engineering, University Park, Pennsylvania, United States of America

Jörg Löffler

ETH Zurich, Zurich, Switzerland

(1) Bulk metallic glasses , (2) Biodegradable metallic implants

Wilfrid Prellier, PhD

Laboratory of Crystallography and Materials Science, Caen, France

materials science, thin films, oxides, synthesis

Czesław Rudowicz, PhD

West Pomeranian University of Technology, Szczecin, Poland, and A. Mickiewicz University, Poznan, Poland

World-class expert in the areas, magnetism and optical & , EMR (EPR/ESR) spectroscopy of transition ions, ligand/crystal field theory, foundations of EMR, microscopic spin Hamiltonian theory, superposition model, low symmetry effects

David Schmool, DPhil

Versailles Saint-Quentin-en-Yvelines University, Versailles, France

Ferromagnetic resonance (FMR) and spin dynamics in nanoscale systems; Magneto-transport measurements; Magnetic thin films and multilayers; Magnetic oxides; Nanostructured magnetic materials and magnetic nanoparticles; Ultrafast magnetisation dynamics, Physics, Nanotechnology, Magnetism

Penelope Schobinger-Papamantellos

ETH Zurich, Zurich, Switzerland

Magnetic structures of Rare earth intermetallics and Boracites . I am basically a chemist and diffractionist (x-ray and neutron).

David Sellmyer

University of Nebraska-Lincoln, Lincoln, Nebraska, United States of America

Quantum and spin phenomena in nanomagnetic structures

Zbigniew Stadnik, PhD, BEd

University of Ottawa, Ottawa, Ontario, Canada

Magnetism, quasicrystals, high-Tc superconductors, novel compounds

Wieslaw Streck

Institute of Low Temperature and Structure Research Polish Academy of Sciences, Wroclaw, Poland

Rare earth ions and transition metal ions, doped sol-gel materials, photonic structures, nanomaterials, nanoceramics and crystals.

Andrez Wisniewski

Polish Academy of Sciences, Warszawa, Poland

Magnetism (Impact of pressure on magnetic properties; Magnetic nanoparticles; Magnetic properties of manganites and cobaltites) and Superconductivity (Impact of pressure on superconducting properties; Properties of vortex matter; Impact of irradiation defects and chemical substitutions on vortex lattice properties; High-Tc superconductors; Iron-based superconductors)

Thomas G. Woodcock, PhD

Leibniz Institute for Solid State and Materials Research Institute for Metallic Materials, Dresden, Germany

Electron microscopy; Electron backscatter diffraction; Magnetic materials; Microstructure

Chun-Liang Yeh, Ph.D.

Feng Chia University, Taichung, Taiwan

Self-propagating High-temperature Synthesis (SHS), Transition metal borides and nitrides, Intermetallics, MAX phases, Thermite Reaction

Yufeng Zheng, PhD

Peking University, Beijing, China

Biomaterials, Metals and alloys, Metallic biomaterials, Magnesium alloys, Zinc alloys, Iron-based alloys, Titanium alloys

Cordt Zollfrank, PhD

Technical University of Munich School of Life Sciences Weihenstephan, Freising, Germany

Biomimetics, Biomaterials

All members of the Editorial Board have identified their affiliated institutions or organizations, along with the corresponding country or geographic region. Elsevier remains neutral with regard to any jurisdictional claims.



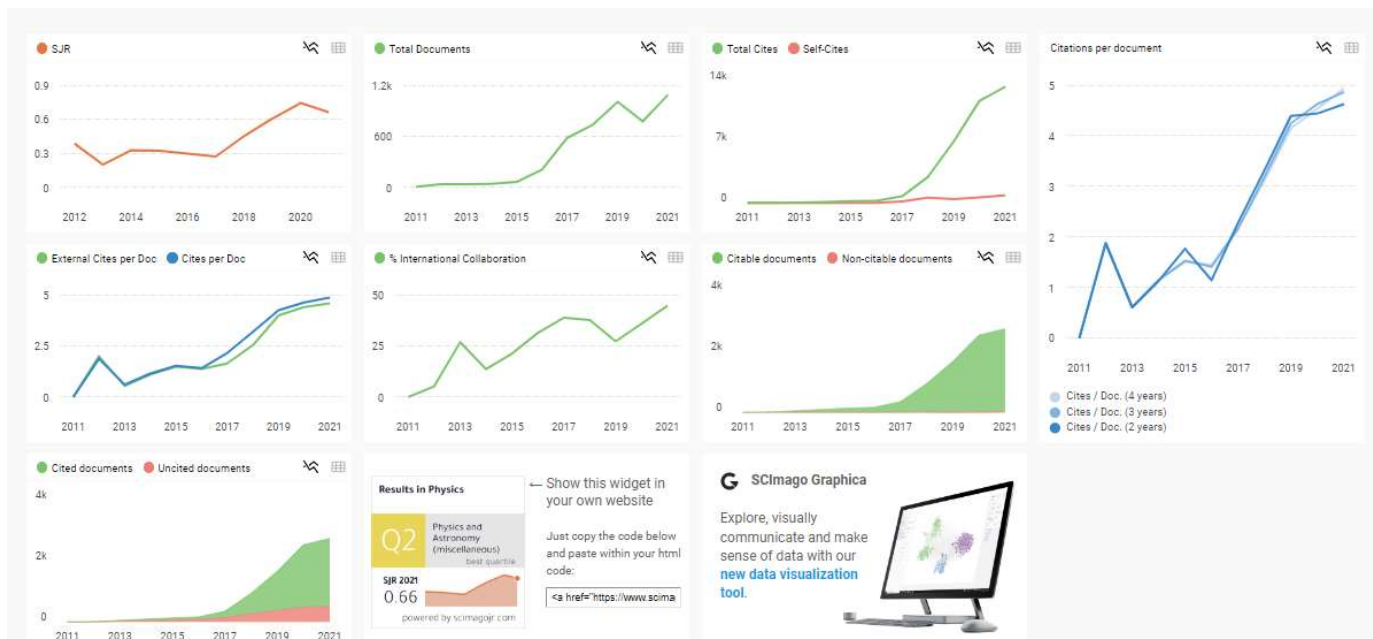
Copyright © 2022 Elsevier B.V. or its licensors or contributors.
ScienceDirect® is a registered trademark of Elsevier B.V.

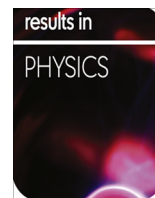


BUKTI SCOPUS

Results in Physics

COUNTRY Netherlands 	SUBJECT AREA AND CATEGORY Physics and Astronomy ↳ Physics and Astronomy (miscellaneous)	PUBLISHER Elsevier BV	H-INDEX <h1 style="font-size: 2em;">69</h1>
PUBLICATION TYPE Journals	ISSN 22113797	COVERAGE 2011-2021	INFORMATION Homepage How to publish in this journal Contact





Effect of metal ion Fe(III) on the performance of chlorophyll as photosensitizers on dye sensitized solar cell



Harsasi Setyawati^a, Handoko Darmokoesoemo^{a,*}, Anggy Tamara Ayu Ningtyas^a, Yassine Kadmi^{b,c,d,e}, Hicham Elmsellem^f, Heri Septya Kusuma^{g,*}

^a Department of Chemistry, Faculty of Science and Technology, Airlangga University, 60115, Indonesia

^b Université d'Artois, EA 7394, Institut Charles Viollette, Lens F-62300, France

^c ISA Lille, EA 7394, Institut Charles Viollette, Lille F-59000, France

^d Ulco, EA 7394, Institut Charles Viollette, Boulogne sur Mer F-62200, France

^e Université de Lille, EA 7394, Institut Charles Viollette, Lille F-59000, France

^f Laboratoire de chimie analytique appliquée, matériaux et environnement (LC2AME), Faculté des Sciences, B.P. 717, 60000 Oujda, Morocco

^g Department of Chemical Engineering, Faculty of Industrial Technology, Institut Teknologi Sepuluh Nopember, 60111, Indonesia

ARTICLE INFO

Article history:

Received 13 April 2017

Received in revised form 3 August 2017

Accepted 4 August 2017

Available online 9 August 2017

Keywords:

Fe(III)-chlorophyll

Dye sensitized solar cell

Metal ligand charge transfer

Photosensitizer

ABSTRACT

The energy crisis is a major problem facing the world today and will need a renewable energy source that is environmentally friendly; one of these is the dye sensitized solar cell (DSSC). DSSC is photochemical electric cell that can convert solar energy into electrical energy. This research aims to study the characteristics of chlorophyll compounds with the addition of metal ions Fe(III) and to determine the effect of Fe(III) on the performance of chlorophyll as a photosensitizer in the DSSC. The formation of complex compounds of Fe(III)-chlorophyll is shown by the phenomenon of metal ligand charge transfer (MLCT) at a wavelength of 263.00 nm and absorption transition d-d at 745.00 nm. Fourier transform infrared characterization of the binding of Fe-O complex compounds appears at 486.06 cm^{-1} . The complex compound of Fe(III)-chlorophyll has a magnetic moment value of 9.62 Bohr Magneton (BM). The existence of ion Fe(III) in chlorophyll can improve the performance of chlorophyll as a dye sensitizer with a maximum current of 4.00 mA/cm^2 , maximum voltage of 0.18 volts and efficiency values of 1.35%.

© 2017 The Author. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Energy is an essential requirement for human survival. Reliance on fossil fuels causes the supply of energy sources to dwindle while demand for energy increases [1]. The problems of the energy crisis have prompted many researchers to develop technologies that generate renewable energy. Solar energy is one type of renewable energy actively being developed at this time. Applications of dye sensitized solar cells (DSSC) using dye to capture sunlight have the potential to be developed because DSSC produces electricity and its applications can easily be applied to life [2].

DSSC technology is an attractive and economical source of renewable energy that converts solar energy into electrical energy. It was first discovered by Michael Grätzel and Brian O'Regan in 1991 [3]. DSSCs consist of semiconductors: photoanode, dye sensitizer, electrolyte and counter electrode [4]. DSSC performance is

very dependent on the material and the quality of the semiconductor electrode and the dye sensitizer used for the manufacture of the cells [5]. At the present time, the most efficient dye sensitizer used for photoinduction electron transfer in the DSSC is complex compound Ruthenium(II) polypyridyl, with an overall photovoltaic conversion efficiency of 10% [6]. However, because of the high costs and complicated synthesis process, researchers began developing dye sensitizers from transition metal that are cheaper to produce, yielding DSSCs that are more effective, environmentally friendly and low-cost [4].

DSSC utilizes the photoelectrochemical effects of dye in a number of materials, mainly organic materials. Dye used for sensitizer comes in synthetic and natural types. The use of natural dye as the sensitizer material has advantages including availability of abundant natural materials, low operating costs and a simple and easy to use extraction procedure that uses organic solvents without the need for high purity [7]. However, natural dye has the disadvantage of being easily degraded at high temperatures and less efficient when compared with synthetic dye. Previous studies have synthesized derivatives of 4,4'-dibenzodifuran-2,2'-bipyridine as

* Corresponding authors.

E-mail addresses: handokodarmokoesoemo@gmail.com (H. Darmokoesoemo), heriseptyakusuma@gmail.com (H.S. Kusuma).

a ligand for ruthenium dye, which, measured at AM 1.5G conditions, has a conversion efficiency of up to 21% [8]. In addition, it is known that if the produced current and voltage are high, the produced conversion efficiency is also higher.

A semiconductor material widely used in DSSC is TiO_2 (titanium oxide), which has a mesoporous structure [9]. Titanium semiconductors have an energy gap of 3.2 eV and absorb light in the ultraviolet region. For application in DSSC, TiO_2 is used commonly in the anatase phase because it has high photoactive ability. This material is chosen because it has advantages such as being inert, stable against photocorrosion, easily accessible, widely used and non-toxic [10]. TiO_2 is applied to the DSSC and should be prepared on broad surfaces so that more dye can be absorbed. TiO_2 is expected to increase the photocurrent. In addition, the use of a dye capable of absorbing a wide spectrum of light and in accordance with the energy band of TiO_2 [6]. One aspect that affects the performance of solar cell-based DSSC is the number of dye molecules that can be absorbed by the TiO_2 layer. More dye molecules be changed to adsorbed then causes greater absorption of photons and produces a higher efficiency value. The number of dye molecules adsorbed on the TiO_2 layer is influenced by the molarity of adsorbed dye solution when dipping the TiO_2 layers in dye solution [11].

The dye or plant pigment used as photosensitizer in this study is chlorophyll powder of classic mulberry powder (CMP). Researchers have proven that chlorophyll and xanthophyll can be excited by the exposure of the dye. As a result of its development, researchers have gained a better energy conversion efficiency on derivatives of chlorophyll dye because it has a carboxylic group [12]. Chlorophyll as a major pigment is effective as a photosensitizer in the photosynthesis process of green plants, which have maximum absorption at 670 nm; thus, chlorophyll is a compound that is suitable for use as a photosensitizer [6]. However, the stability of chlorophyll is weak, and it easily decomposes when exposed to heat, light and acidic and alkaline conditions [13]. The performance of a photosensitizer is influenced by the level of absorption peaks; if the absorption peak of a dye is high, it indicates that more photon energy can be absorbed and converted into electrical energy in solar cell applications. The produced current and voltage also affect the performance of the photosensitizer: The higher I-V indicates that the produced efficiencies have also increased [14].

Chlorophyll as a photosensitizer produces a strong absorption peak at a wavelength of 420 nm and 660 nm. The chlorophyll extract shows open circuit voltage (V_{oc}) of 0.585 mV, short circuit current (I_{sc}) around 1.96 mA, a fill factor (FF) around 47% and conversion efficiency of 0.538% [15]. This shows that the conversion efficiency in natural dye is much lower when compared with synthetic dye. One technique to improve the photostability of chlorophyll can be done through interaction with metals to form complex compounds [16]. The inspiration for this technique came from the use of mordant by craftsmen of batik in Indonesia to increase the brightness and color durability of batik using natural dyes. Several types of mordants used include salt, chalk, alum ($\text{Al}_2(\text{SO}_4)_3$) and FeSO_4 . The coloring of batik using mordant yields brighter colors and greater resistance to water and heat [17]. The increase in brightness and color durability is expected due to the formation of complex compounds between the mordant and natural dyes. Therefore, in this study, we will assess the addition of salt FeCl_3 on chlorophyll dye. In addition to increasing the stability of chlorophyll against light radiation, the addition of Fe(III) is expected to widen the light absorption area of natural dyes to the near-infrared spectrum region, which is the largest component of the sunlight spectrum.

Previous studies have addressed the formation of curcumin complex with Fe(III) and the antioxidant curcumin to improve photostability. Curcumin interacts with Fe(III) via the carbonyl group and provides better antioxidant photostability [16,18]. Interactions

that occur in complex molecules are characterized by the shift in wavelength bathochromic derived from electronic transition $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$. Chlorophyll also has a carbonyl group and is expected to have an interaction similar to curcumin when it binds to Fe(III).

This research studied the effect of ion Fe(III) on the performance of chlorophyll as a dye sensitizer in DSSC. Fe was selected because it is a transition metal in which the electron configuration d[6] is the same as ruthenium and osmium metals (used as dye solar cell), but ferrous metals are more easily obtained because of their abundance in nature when compared to other metals. It also has a quantum that is relatively high for producing sensitization on the nanocrystalline TiO_2 ; it is cheaper and can be obtained in Indonesia more easily than other metals and has been studied previously as a complex for solar cells; it is soluble in polar solvents; and its wavelength in the UV-Vis is 551 nm [19].

The formed complex compound of Fe(III)-chlorophyll will be characterized using UV-Vis spectrophotometer, Fourier transform infrared (FTIR), magnetic susceptibility balance (MSB) and the electrical conductivity test. The absorption of sunlight in the DSSC cells made by dyes that are coated on the surface of TiO_2 will be measured using the doctor blade technique, which is very simple and easy compared to other techniques. The doctor blade technique is a method of coating TiO_2 suspension on semiconductor glass using a rod stirrer by rolling the stirrer on the glass surface to flatten the suspension of TiO_2 that has been dropped [20]. The properties of the complex compound of Fe(III)-chlorophyll will be tested using measurements of produced current and voltage by multimeter when exposed to direct sunlight.

Materials and methods

Materials and chemicals

The chemicals used in this study have a purity degree of pro analysis and include, among others: sodium hydroxide (NaOH), ethanol ($\text{C}_2\text{H}_5\text{OH}$), hydrochloric acid (HCl), iron(III) chloride (FeCl_3), TiO_2 Degussa P25, acetonitrile, aquabidest, electrolite solution of I_2 in KI and chlorophyll powder CMP (PT. Health Wealth International).

Research procedure

Preparation of chlorophyll

A total of 1 g of chlorophyll powder was dissolved with aquabidest in a glass beaker, then transferred into a 10 mL volumetric flask up to the mark.

Saponification reaction of chlorophyll

A total of 2 g of NaOH were dissolved in 50 mL aquabidest. Five milliliters of NaOH solution then was diluted in 50 mL of aquabidest to obtain a concentration of 0.1 M NaOH solution. Two milliliters of this solution then were added to 8 mL ethanol to form ethanol-NaOH with total volume of 10 mL. As much as 5 mL of chlorophyll solution was added to the solution and homogenized for 2 h in a water bath at a temperature of 50 °C. The addition of NaOH formed a reaction with alkaline conditions. A total of 1 mL of chlorophyll was taken and dissolved in 50 mL aquabidest and then checked using the UV-Vis spectrophotometer 1800 Shimadzu at a wavelength of 639.00 nm [13].

The concentration optimization of complex compound Fe(III)-chlorophyll

The chlorophyll solution was combined with two concentrated drops of HCl to achieve a pH of 2–3. Furthermore, FeCl_3 solution

with concentrations of 5%, 10% and 20% were added to get the optimum concentration conditions. The solution with each concentration was homogenized at a temperature of 60–70 °C for 1 h; then the solution was evaporated to one-third part and reheated until the filtrate was exhausted. Next, the precipitate was heated in an oven at a temperature of 80 °C for 24 h to form the product Fe(III)-chlorophyll [13].

The characterization of complex compounds of Fe(III)-chlorophyll

The characterization of complex compounds of Fe(III)-chlorophyll using UV-Vis spectrophotometer

One milliliter of chlorophyll solution was dissolved by aquabidest in a 50 mL volumetric flask. The absorbance was measured at wavelengths between 200 and 800 nm using the UV-Vis spectrophotometer [21]. The solution from saponification of 1 mL chlorophyll was dissolved in a 50 mL volumetric flask with aquabidest. The absorbance in the region 200–800 nm then was measured.

The characterization of complex compounds of Fe(III)-chlorophyll using FTIR

The characterization using FTIR aims to observe the formation of bonds between the metal with ligands and to identify the functional groups on the compound formed [4]. The complex compound of Fe(III)-chlorophyll was mixed with KBr; then the mixture was made into pellets, and IR absorption at wave number 4000–300 cm^{-1} was measured [22].

The characterization of complex compounds of Fe(III)-chlorophyll using MSB

The characterization using MSB aims to determine the magnetic properties of complex compounds at room temperature. The empty MSB tube was weighed as m_0 , and then the tube was inserted in the MSB tool to obtain the value of R_0 . The MSB tube was filled with the formed compound and reweighed to obtain the value of m_1 . The greatest value of sample was given a value of 1. The MSB tube of the sample was put back in the tool to obtain the value R [23].

The characterization of electrical conductivity of complex compound of Fe(III)-chlorophyll

This characterization aims to determine the properties of complex compounds of Fe(III)-chlorophyll that are dissolved in dimethyl sulfoxide (DMSO) at a concentration of 10^{-4} M. The electrical conductivity of complex compounds will be compared with the electrical conductivity of DMSO using a conductometer.

Preparation of DSSC

Coating of TiO₂ on the glass plate

The glass plate was immersed in ethanol for 24 h to remove dirt. The glass plate then was dried. Compounds TiO₂ Degussa P 25, as much as 0.1 g, were suspended in 100 mL of 98% methanol. The suspension of TiO₂ was coated on the semiconductor glass measuring $2.5 \times 2.5 \text{ cm}^2$, and TiO₂ then was deposited with the help of scotch tape on the side of the glass that has resistivity, thus forming an area of $2 \times 2 \text{ cm}^2$. Scotch tape serves to control the thickness of the suspension of TiO₂. The suspension of TiO₂ was deposited over the place created by using the doctor blade method. The stirring rod or spatula was rolled on the surface of the glass to flatten the suspension of TiO₂ dripped until it reached a certain thickness. Glass that had been coated with TiO₂ was allowed to stand at room temperature for 45 min and then was heated at 450 °C for 30 min. It then was allowed to stand until the temperature reached 70 °C [11].

The characterization of TiO₂ bond and complex compounds of Fe(III)-chlorophyll using FTIR

The glass plate that had been coated with TiO₂ was soaked in the complex compound of Fe(III)-chlorophyll for 24 h. The glass plate was filed with another glass plate to obtain TiO₂ powder. The obtained powder was mixed with KBr to make pellets, and then IR absorption in the region of 4000–300 cm^{-1} was measured.

Preparation of electrolyte solution

The electrolyte solution was made with a concentration ratio of 0.5 M iodide salt and 0.05 M I₂. A total of 0.498 g of KI was dissolved in 6 mL of acetonitrile in a glass beaker. As much as 0.076 g of I₂ and 6 mL of acetonitrile were placed in another glass beaker, then stirred until homogeneous. The solution in both glass beakers was mixed and stirred [24].

Preparation of DSSC working electrode

The glass plate that had been coated with TiO₂ suspension was immersed in complex compound of Fe(III)-chlorophyll on a petri dish for 24 h. After coating, the glass plate is stored in dark glass bottles to avoid sunlight and ensure optimal absorption. For the use in the long term, the glass is stored in sealed glass bottles to avoid scratches that can damage the surface of TiO₂ [11].

Preparation of DSSC reference electrode

The glass plate was shaded evenly using a graphite pencil and then clamped and taped on the edges. It was then burned for 30 min using the flame from a candle to form a carbon layer [21]. The coating is intended as a catalyst to accelerate the reaction in the DSSC.

Preparation of DSSC tool

The working electrode that had been coated with TiO₂ and soaked with complex compounds was placed on the table with a layer of complex compound of Fe(III)-chlorophyll in the top position. The reference electrode was placed opposite to the working electrode, and the electrolyte solution of I₂ in KI was dripped between the two electrodes. The structure of the glass plate was clamped with binder clips on both ends of the part that was not coated to form a series of solar cells. The series of DSSC tools is shown in Fig. 1.

The measurements of current and voltage on the DSSC

DSSCs were connected by multimeter cables on both sides of the glass plate with the reference electrode at the positive pole and the working electrode at the negative pole. DSSCs that had been assembled were illuminated by direct sunlight with the

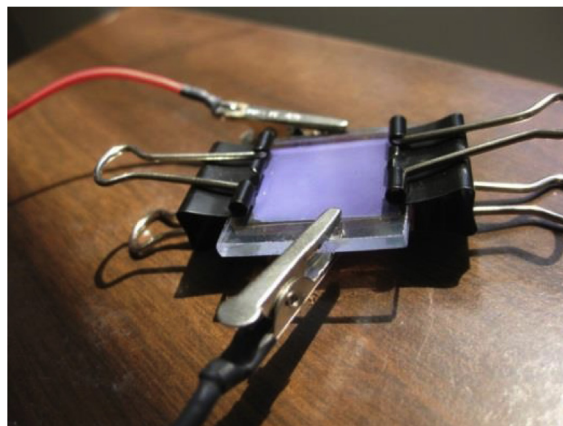


Fig. 1. The series of DSSC.

working electrode at the top; the maximum current and voltage then were measured. Output current was also measured by determining the active area of the solar cell [11]. The measurements of current and voltage are shown in Fig. 2.

The characterization of current and voltage on the DSSC using potentiometer

The characterization of current and voltage was done by connecting the DSSC and potentiometer that are adjusted in some way to determine the characteristics of current and voltage [21]. The measurement series of the I-V curve is shown in Fig. 3.

Results and discussion

In this study, we have investigated the characteristics of chlorophyll compounds that have been added to the metal ion Fe(III) and the effect of the presence of metal ion Fe(III) on the performance of chlorophyll, which is used as a photosensitizer in the DSSC. The complex compounds formed were characterized using UV-Vis spectrophotometer, FTIR, MSB and electrical conductivity test, which is measured with a conductometer. Furthermore, the performance of the photosensitizer was tested by measuring the current and voltage using a multimeter to better understand the effect of Fe(III) to the chlorophyll as ligand.

Saponification reaction of chlorophyll

The saponification reaction of chlorophyll, which aims to reduce the stability of chlorophyll to allow it to form bonds with other metals, was done by reacting chlorophyll that has been diluted with aquabidest with base. In the present study, the base used is ethanol-NaOH, which was homogenized in a water bath for 2 h [13]. The addition of bases aims to open the isocyclic ring on chlorophyll and remove the phytol group [25].

The determination of the optimum concentration of metal ion Fe(III) in complex compounds of Fe(III)-chlorophyll

The preparation of complex compounds of Fe(III)-chlorophyll was carried out by reacting Fe(III) derived from the compound $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ with chlorophyll solution that had been saponified with NaOH 0.1 M at a temperature of 50 °C. The various concentrations of metal ion Fe(III) used in this study were 5%, 10% and 20%.

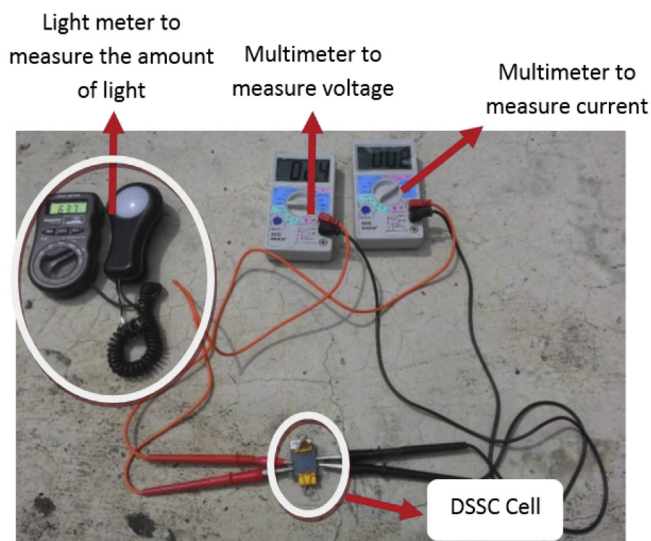


Fig. 2. The measurements series of current and voltage on the DSSC.

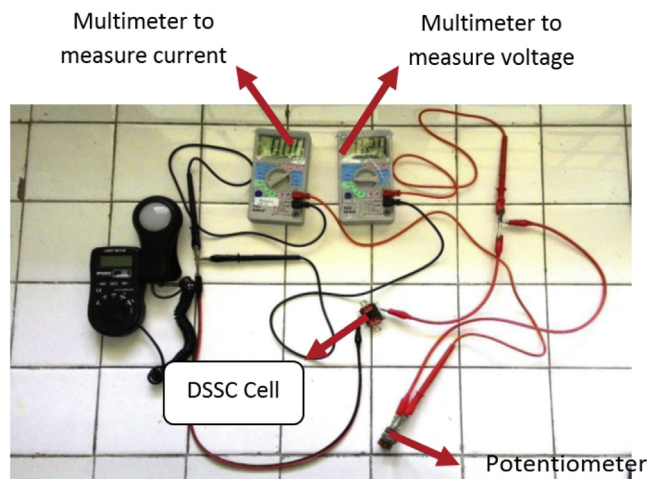


Fig. 3. The measurements series of I-V curve on the DSSC.

To 5 mL of saponified chlorophyll solution, we added 2 drops of HCl 37% to obtain pH 2–3. This is done to neutralize the saponified chlorophyll solution so that the metal ion Fe(III) is easily attached to the carbonyl group of the chlorophyll. Concentration optimization of the addition of metal ion Fe(III) was then conducted to obtain optimum results from the complex compounds formed. The 5 mL $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ solution with concentrations of 5%, 10% and 20%, respectively, were added to the saponification solution and heated at a temperature of 60–70 °C for 1 h. The filtrate was analyzed using UV-Vis spectrophotometer at a wavelength of 639 nm to analyze which concentration of metal ion Fe(III) is optimal.

Based on the absorbance data in Table 1, the optimum conditions for preparation of complex compounds is Fe(III) with a concentration of 10% because this concentration yielded the highest absorbance. In addition on the preparation of complex compounds can also be seen that Fe(III) with a concentration of 20% produces lower absorbance when compared with Fe(III) with a concentration of 10%. The reasons for this phenomenon may be a formation of complex with another composition or dimerization (aggregation) of reagent (ligand) or complex, high ionic strength can also influence on the activity of species or their electronic state, or will have dehydration and medium polarity effects. After obtaining the optimum concentration of Fe(III), filtrate of the solution was evaporated to one-third and then evaporated again until the entire filtrate turned into precipitate. The obtained precipitate then was put into an oven for 24 h at a temperature of 80 °C. After baking, the precipitate took the form of black powder. After the complex compound was successfully established, we then conducted characterization to determine the characteristics of the complex compounds. The solid of the complex compound of Fe(III)-chlorophyll is shown in Fig. 4.

The characterization of complex compound of Fe(III)-chlorophyll

The complex compounds that were made were characterized to determine their properties and characteristics. The characteriza-

Table 1

The absorbance data for determination of optimum concentration on metal ion Fe(III).

Concentrations of metal ion Fe(III)	Absorbance
5%	0.006
10%	0.061
20%	0.049



Fig. 4. The solid of complex compounds of Fe(III)-chlorophyll.

tion was conducted using UV–Vis spectrophotometer, FTIR, MSB and conductometer.

The characterization of complex compounds of Fe(III)-chlorophyll using UV–Vis

The characterization using UV–Vis spectrophotometer was conducted to determine the maximum absorption wavelength in the wavelength range of 200–800 nm. The characterization results with UV–Vis spectrophotometer are shown in Table 2.

Table 2 shows that there is a difference between the maximum wavelength of the complex compound of Fe(III)-chlorophyll and chlorophyll. The maximum wavelength of the complex compound of Fe(III)-chlorophyll in UV and the visible spectrum is 263 nm and 745 nm, respectively, while the maximum wavelength of chlorophyll is 404 nm and 628.50 nm, respectively. The difference in maximum wavelength that emerged shows that the complex compound of Fe(III)-chlorophyll has been formed. The maximum wavelength that appears in the region of 200–300 nm is due to the phenomenon of charge transfer in the form of Metal to ligand charge transfer (MLCT). In the complex compounds of Fe(III)-chlorophyll, this phenomenon occurred because metal ion Fe(III) has lower oxidation states [26]. The wavelength of MLCT on complex compounds of Fe(III)-chlorophyll can be used as a dye sensitizer in DSSC due to the phenomenon of charge transfer. The maximum wavelength of the compound is also influenced by the transition d-d that appears in visible areas [27]. This transition changes the distribution of metal-ligand charge because the electron density shifts from orbitals with high metal character to high ligand orbitals. This phenomenon is included in the phenomenon of MLCT [28]. The MLCT phenomenon occurs because the ligand has orbital π^* with low energy, and the presence of MLCT phenomenon in the complex compound makes it very useful as a dye sensitizer because it can optimally absorb light for conversion into electrical energy. When a compound has many electrons in d orbitals and the ligand is abundant, it causes the compound to undergo the MLCT phenomenon [28].

Table 2

The characterization result of complex compounds of Fe(III)-chlorophyll and chlorophyll.

Compounds	Maximum wavelength (nm)			
Fe(III)-chlorophyll	263.00	–	–	745.00
chlorophyll	–	404.00	–	628.50

In this study, Fe(III)-chlorophyll was dissolved in dimethyl sulfoxide (DMSO) as a solvent because this solvent has a high degree of polarity. In addition, DMSO does not liberate hydrogen when met with very electropositive metal [29].

The characterization of complex compounds of Fe(III)-chlorophyll using FTIR

The characterization of complex compounds of Fe(III)-chlorophyll by FTIR determines the functional groups and the bond formed between metal and ligands. The differences in the FTIR spectra between chlorophyll as ligand and the complex compound of Fe(III)-chlorophyll indicates that the compound has been successfully synthesized. The characterization results of chlorophyll as ligand and complex compound Fe(III)-chlorophyll can be seen in Fig. 5; the FTIR data can be seen in Table 3.

Based on the FTIR spectra from Fig. 5 and FTIR data from Table 3, there is bonding between the metal Fe(III) and chlorophyll as ligand. This can be determined from the formation of Fe-O bond, so it can be concluded that the complex compound of Fe(III)-chlorophyll has been formed. The prediction bonding between the metal Fe(III) with chlorophyll as ligand is shown in Fig. 6.

The characterization of complex compound of Fe(III)-chlorophyll using MSB

The complex compound of Fe(III)-chlorophyll is characterized using MSB to determine its magnetism properties by measuring the magnetic moment of the complex compound. Based on Table 4, the complex compound of Fe(III)-chlorophyll has a magnetic moment of 9.62 Bohr Magnetron (BM). When viewed from the perspective of valence bonds, chlorophyll ligands are weak and cannot urge the electrons in the d orbitals of Fe(III) to pair [30]. In this study, chlorophyll used as ligand donated six lone pair electrons, which are unpaired in metal Fe(III) in orbitals s, p and d; the hybridization formed therefore is sp^3d^2 with an octahedral shape. The magnetic properties of complex compounds of Fe(III)-chlorophyll-based valence bond theory is shown in Fig. 7.

Based on Table 4, complex compounds of Fe(III)-chlorophyll have a magnetic moment of 9.62 BM, which indicates that there are nine unpaired electrons, but Fig. 7 shows that there are only five unpaired electrons. This is because the chlorophyll as a ligand that is bound by metal also contributed to increase the magnetic properties, which also increases the magnetic value.

The electrical conductivity characterization of complex compound of Fe(III)-chlorophyll using conductometer

The characterization of the electrical conductivity of complex compounds via conductometer aims to determine whether the complex compound is molecular or ionic. Measurements of the electrical conductivity of the complex compounds are then compared with the electrical conductivity of DMSO, the solvent used. If the conductivity value of the complex compounds of Fe(III)-chlorophyll is higher than that of the solvent (DMSO), this indicates that the complex compound is an ionic compound. If the conductivity value of the solvent (DMSO) is higher than that of the complex compound, this indicates that the complex compound is

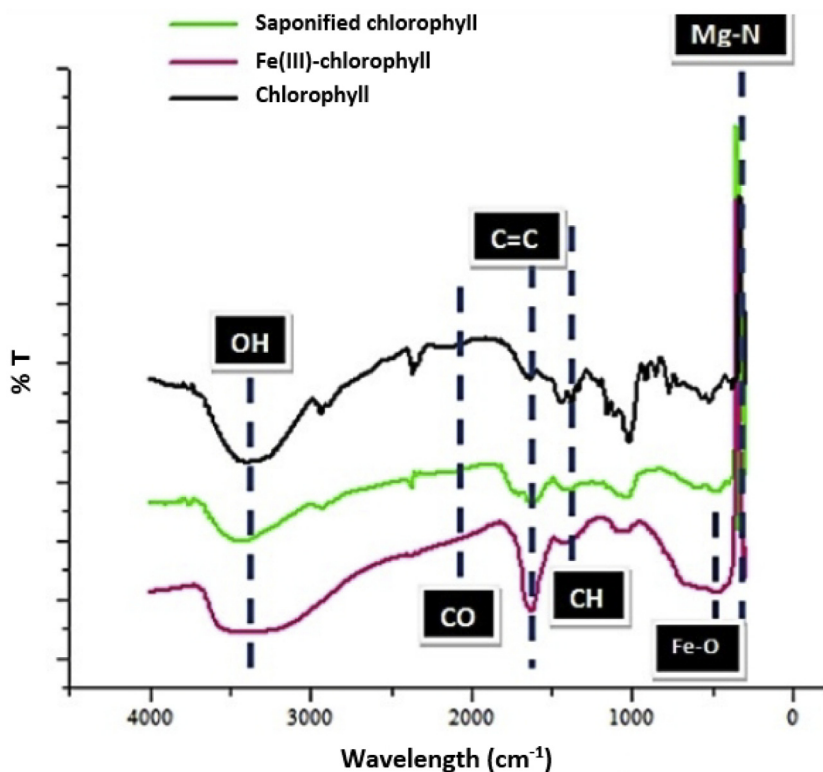


Fig. 5. FTIR spectra of chlorophyll, saponified chlorophyll and complex compounds of Fe(III)-chlorophyll.

Table 3
The FTIR data of ligand and complex compound.

Bond	Wavelength of ligand (cm ⁻¹)	Wavelength of complex compound (cm ⁻¹)	Wavelength Theoretically (cm ⁻¹)	References
Fe-O		486.06	430–480	Martak 2011
Mg-N	300.9	308.61	242–310	Mojumdar et al., 1998
OH	3394.72	3402	3362–3421	Ahmed et al., 2014
CO	2167.99	2167.99	2150–2200	Chakarova et al., 2011
CH	1381	1381	1350–1400	Bodirlau et al., 2007
C=C aromatic	1635	1620	1619–1640	Ahmed et al., 2014

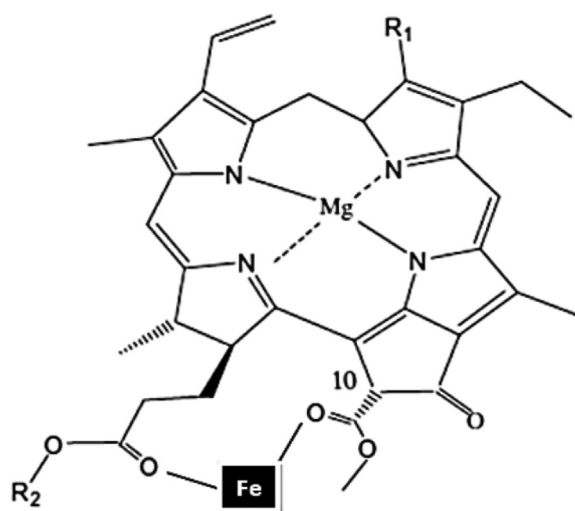


Fig. 6. The prediction bonding between the metal Fe(III) with chlorophyll as ligand.

a molecular compound. The conductivity values are shown in Table 5.

Based on Table 5, it can be seen that the conductivity of the complex compound of Fe(III)-chlorophyll is higher than that of

Table 4
The magnetic moment of FeCl₃·6H₂O, chlorophyll as ligand and Fe(III)-chlorophyll.

Compounds	Magnetic moment (BM)
FeCl ₃ ·6H ₂ O	5.13
Chlorophyll as ligand	0.81
Fe(III)-chlorophyll	9.62

the solvent (DMSO), indicating that the complex compounds are ionic. Ionic compounds easily conduct electricity because they have a high boiling point and melting point. Moreover, ionic compounds are easy to break down into ions because the electron transfer process can take place continuously. Ionic compounds are therefore good in DSSC applications [31].

Application of complex compounds of Fe(III)-chlorophyll in DSSC

In this study, before the complex compounds of Fe(III)-chlorophyll applied to DSSC, it needs to do some preparation. The preparation that has been done in this study such as: preparation of TiO₂ suspension, coating of TiO₂ on glass plate with doctor blade method, preparation of working electrode, preparation of reference electrode, and preparation of electrolyte solution. In the prepara-

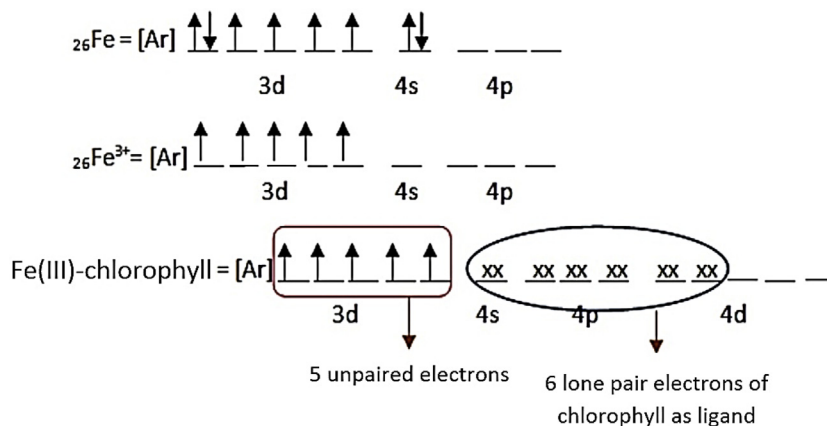


Fig. 7. The formation prediction of complex compounds of Fe(III)-chlorophyll.

Table 5

The conductivity value of complex compounds and DMSO.

Compounds	Conductivity (μs)
Solvent (DMSO)	0.08
Fe(III)-chlorophyll in the solvent (DMSO)	2.05



Fig. 8. The coating results of TiO₂ on the glass plate with doctor blade method.

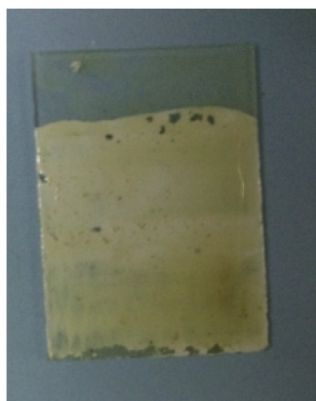


Fig. 9. The working electrode.

the glass plate onto which TiO₂ will be deposited first must be sanded to increase the glass surface so that the TiO₂ can attach optimally [21]. The coating results of TiO₂ on the glass plate can be seen in Fig. 8.

Before the complex compounds of Fe(III)-chlorophyll applied to DSSC, it also needs to prepare the working electrode, reference electrode, and electrolyte solution. The working electrodes may be prepared by soaking the glass plate coated with TiO₂ in complex compound of Fe(III)-chlorophyll. The obtained working electrode has a brownish white color and can be seen in Fig. 9.

For the preparation of reference electrode, the surface of the glass plate that has been sanded and then coated with graphite pencil of which the tip is made such that the chisel eye so that the coating on the glass plate can be even is heated using a candle so that graphite can attach perfectly. The obtained reference electrode has a black color and can be seen in Fig. 10.

While for the preparation of electrolyte solution, the KI₃ solution was prepared by completely dissolving of KI and I₂ in acetonitrile. Furthermore, both solutions were homogenized, and the solution obtained has red color. For use in the long term, the electrolyte solution is stored in brown glass bottles because it is easily oxidized and decomposed by light.

The bond characterization of complex compounds of Fe(III)-chlorophyll and TiO₂ using FTIR

The chemical bonds formed between complex compound Fe(III)-chlorophyll and TiO₂ were characterized using FTIR. The



Fig. 10. The reference electrode.

tion of TiO₂ suspension, TiO₂ suspension was prepared by dissolving of TiO₂ Degussa P 25 within acetic acid, which serves as solvent. The formed TiO₂ suspension has a white color. Additionally for the coating of TiO₂ on glass plate with doctor blade method,

functional groups on the ligand must have a lone pair of electrons that can bind with TiO_2 [11].

Based on the spectra that can be seen in Fig. 11 at a wavelength of 655.80 cm^{-1} , Ti-O bonds are formed that show that complex compounds of Fe(III)-chlorophyll have bound to Ti. This finding agrees with the literature, which shows the bond between the Ti and O group of the ligand that appears at a wavelength of $600\text{--}400 \text{ cm}^{-1}$ [32]. The prediction of chemical bonds of complex compounds of Fe(III)-chlorophyll with TiO_2 is shown in Fig. 12.

The measurement of DSSC performance

The DSSC tool was assembled by placing working electrode and reference electrode in opposite directions on the glass plate. Drops of electrolyte solution were then placed between the two electrodes. The series was then clamped using clips, and efficiency measurements were taken using a multimeter. The series of DSSC are presented in Fig. 13.

The measurement of current

The measurement of current was done consistently for 14 days. The measurement was performed with variations of working electrode: TiO_2 , TiO_2 -chlorophyll, TiO_2 with complex compound of Fe(III)-chlorophyll and TiO_2 with mixture of chlorophyll and ion Fe(III). Measurement was performed on each DSSC to determine the current produced. In addition, we also compared the current produced in the complex compound with TiO_2 and the mixture between Fe(III) and chlorophyll. This was done to determine the influence of the chemical bond between the complex compound and the ligand on the produced current. The measurement results are presented in Table 6 and Fig. 14.

Based on Fig. 14, it can be seen that the complex compounds of Fe(III)-chlorophyll have a higher current when compared to TiO_2 , chlorophyll and mixture of metal Fe(III) with chlorophyll. This is because the complex compound of Fe(III)-chlorophyll exhibits the effect of metal that is chemically bonded, thus increasing the

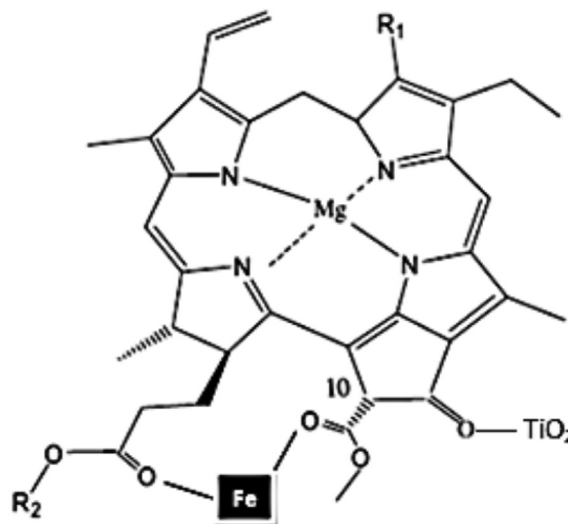


Fig. 12. The prediction of chemical bonds of complex compounds of Fe(III)-chlorophyll with TiO_2 .

ability of the dye sensitizer [33]. In the complex compound, there is also conjugation bonds and the lone pair of electrons, which is easily excited and increases the produced current. The amount of current produced is also due to the intensity of sunlight, which is not fixed (i.e., it tends to fluctuate). If the intensity of sunlight is high, it increases the current produced; in contrast, if the intensity of the sunlight is low, it decreases the amount of current produced.

The measurement of voltage

The measurement of voltage aims to determine the voltage produced by DSSCs, which have been assembled with a variety of different compositions. The measurements were carried out for

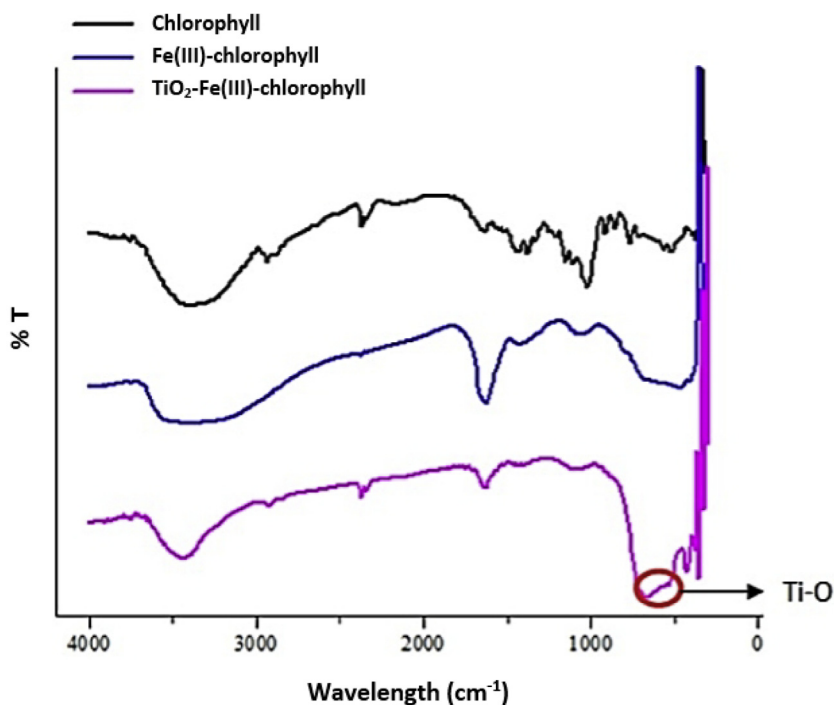


Fig. 11. The spectra of chlorophyll, complex compound of Fe(III)-chlorophyll and TiO_2 with Fe(III)-chlorophyll.



Fig. 13. The series of DSSC.

14 days using various working electrodes: TiO₂, TiO₂-chlorophyll, TiO₂ with complex compound of Fe(III)-chlorophyll and TiO₂ with mixture of chlorophyll and ion Fe(III). The measurement results are presented in Table 7 and Fig. 15.

Fig. 15 shows that the complex compounds of Fe(III)-chlorophyll have voltage values that are relatively higher compared with TiO₂, TiO₂-chlorophyll and the mixture of Fe(III) and chlorophyll. The complex compounds of Fe(III)-chlorophyll have voltage value higher than those of the mixture of Fe(III) with chlorophyll, although the two compounds both contain metal ion Fe(III). The difference is that mixture of Fe(III) with chlorophyll

as ligand is not bound chemically, whereas the complex compound of Fe(III)-chlorophyll has interactions and chemical bonding that cause voltage value to increase. TiO₂-chlorophyll also has higher voltage value when compared with TiO₂, which indicates that the dye sensitizer in the solar cell can increase the voltage conversion capabilities over TiO₂, which only serves as a semiconductor without dye.

The measurement of I-V curve

The determination of DSSC efficiency in converting sunlight into electrical energy is done by measuring the I-V curve. In this study, the measurement of electrical power in voltage produced by DSSCs was conducted by using potentiometer load with resistivity of 100 KΩ. The measurement results of current-voltage (I-V) are shown in Table 8 and Figs. 16–19.

This study carried out measurement of current and voltage of TiO₂, chlorophyll as ligand, mixture of ion Fe(III) with chlorophyll and complex compounds of Fe(III)-chlorophyll and aims to determine the efficiency of each compound. From Figs. 16–19, it can be seen that the value of the short-circuit current (I_{sc}) of TiO₂, chlorophyll as ligand, mixture of ion Fe(III) with chlorophyll and complex compounds of Fe(III)-chlorophyll is 8.00 mA, 14.00 mA, 8.00 mA and 16.00 mA, respectively. We also obtained the value of open-circuit voltage (V_{oc}) of TiO₂, chlorophyll as ligand, mixture of ion Fe(III) with chlorophyll and complex compound of Fe(III)-chlorophyll: 0.10 V, 0.14 V, 0.12 V and 0.18 V, respectively. The maximum power point (mpp) is the point on the I-V curve that produces current-voltage and is obtained by determining the area

Table 6

The current of working electrodes TiO₂, TiO₂-chlorophyll, TiO₂ with Fe(III)-chlorophyll and TiO₂ with mixture of chlorophyll and FeCl₃·6H₂O.

Days	Currents I _{sc} (mA)				Lux
	TiO ₂	TiO ₂ -chlorophyll	TiO ₂ with Fe(III)-chlorophyll	TiO ₂ with mixture of chlorophyll and FeCl ₃ ·6H ₂ O	
1	35.4	38.4	42.0	32.0	59.87
2	38.4	41.0	42.4	31.2	59.74
3	34.2	39.4	41.2	37.0	59.74
4	35.2	40.6	44.0	35.0	59.87
5	37.8	39.6	47.0	37.0	58.21
6	34.4	37.8	43.2	39.4	59.89
7	35.8	39.4	41.0	34.8	59.31
8	35.2	38.8	44.8	36.0	59.75
9	34.6	38.0	46.0	34.8	58.65
10	35.2	34.6	39.6	39.2	57.75
11	34.4	36.0	46.8	28.0	57.06
12	33.6	34.0	43.0	32.0	56.85
13	32.2	35.4	40.4	30.4	57.84
14	31.4	31.0	44.8	32.0	57.31

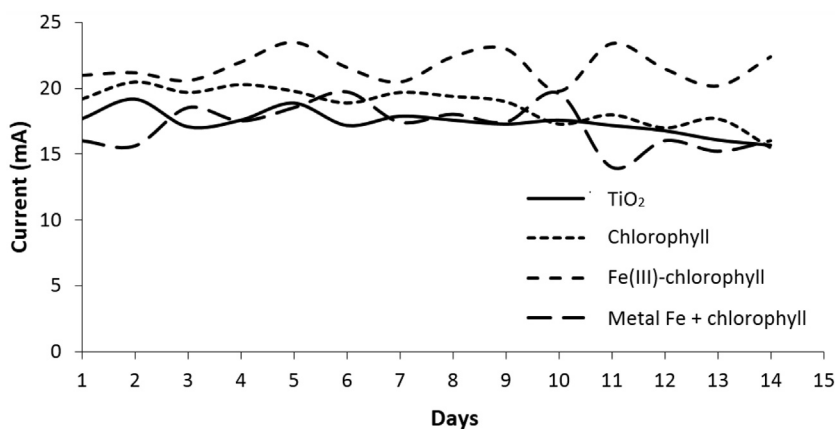


Fig. 14. The measurement result of current for 14 days.

Table 7
The voltage of working electrode TiO₂, TiO₂-chlorophyll, TiO₂ with Fe(III)-chlorophyll and TiO₂ with mixture of chlorophyll and FeCl₃·6H₂O.

Days	Voltage (mV)				Lux
	TiO ₂	TiO ₂ -chlorophyll	TiO ₂ with Fe(III)-chlorophyll	TiO ₂ with mixture of chlorophyll and FeCl ₃ ·6H ₂ O	
1	220	220	380	280	59.87
2	180	240	360	220	59.74
3	200	200	400	280	59.74
4	180	220	320	240	59.87
5	160	240	400	280	58.21
6	220	260	360	240	59.89
7	200	200	380	300	59.31
8	200	180	320	260	59.75
9	140	260	380	300	58.65
10	160	240	380	220	57.75
11	180	220	400	260	57.06
12	180	220	400	280	56.85
13	200	280	420	240	57.84
14	220	220	400	220	57.31

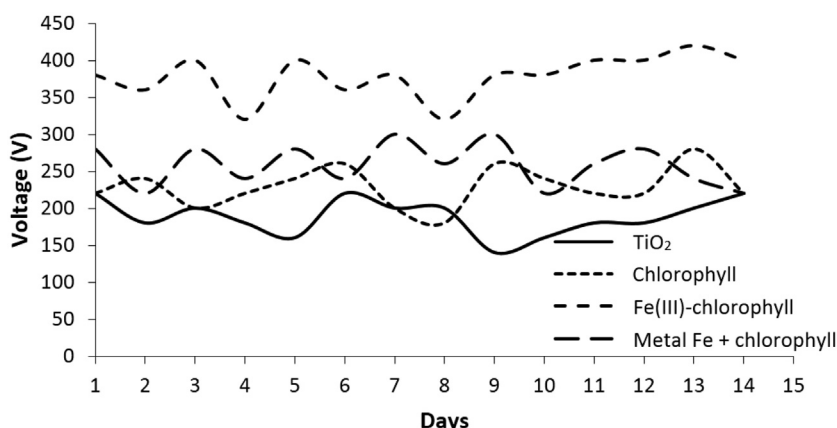


Fig. 15. The measurement result of voltage for 14 days.

Table 8
The measurement results of current-voltage (IV).

Compounds	Voc (V)	Isc (mA)	Jsc	FF	η (%)
TiO ₂	0.10	8	1.5	0.80	0.20
Chlorophyll	0.14	14	3.5	0.85	0.70
FeCl ₃ ·6H ₂ O + chlorophyll	0.12	8	2	0.83	0.33
Fe(III)-chlorophyll	0.18	16	4	1.12	1.35

under the curve. The mpp was obtained by determining the largest area yielded by multiplying the current by the voltage. The higher fill factor (FF) on the solar cell causes the produced efficiency value to also be higher [11].

From this study, it can be seen that the highest efficiency found was in the complex compound of Fe(III)-chlorophyll, equal to 1.35%. The efficiency results of complex compounds are higher when compared to chlorophyll as dye and the mixture of Fe(III)

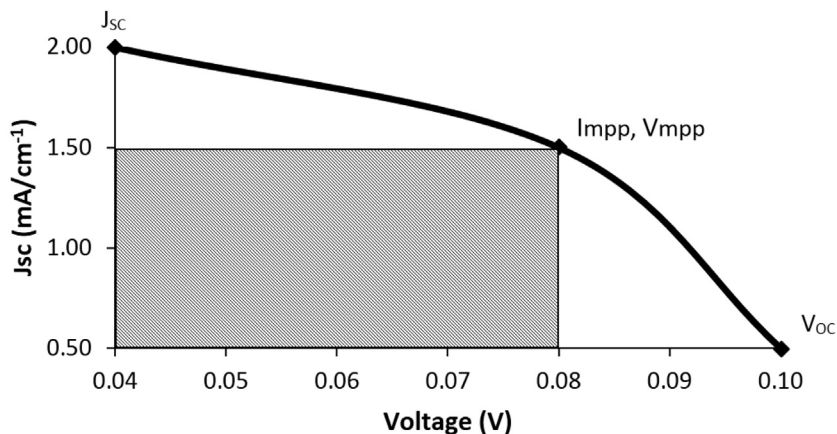


Fig. 16. The I-V curve of TiO₂.

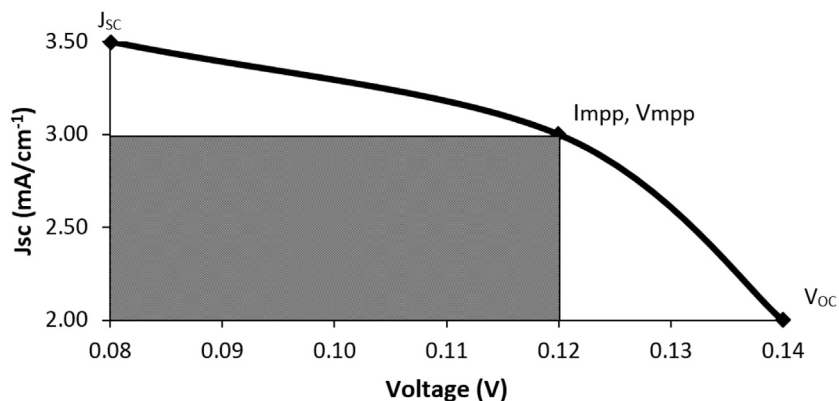


Fig. 17. The I-V curve of chlorophyll.

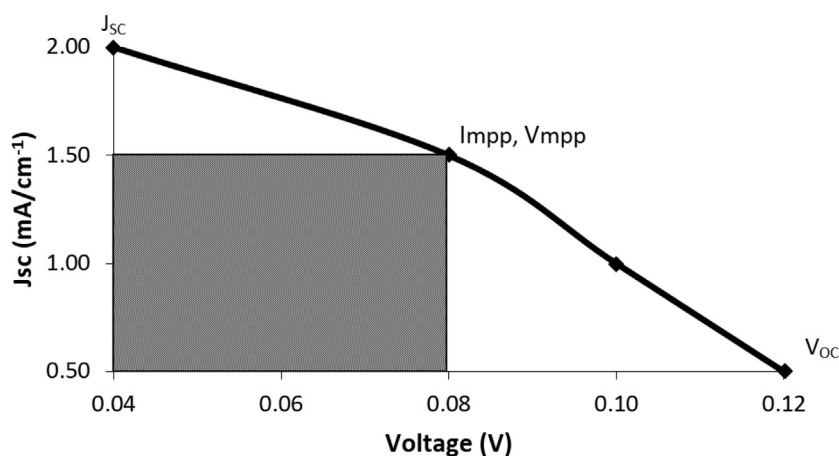


Fig. 18. The I-V curve of mixture of Fe(III) and chlorophyll as ligand.

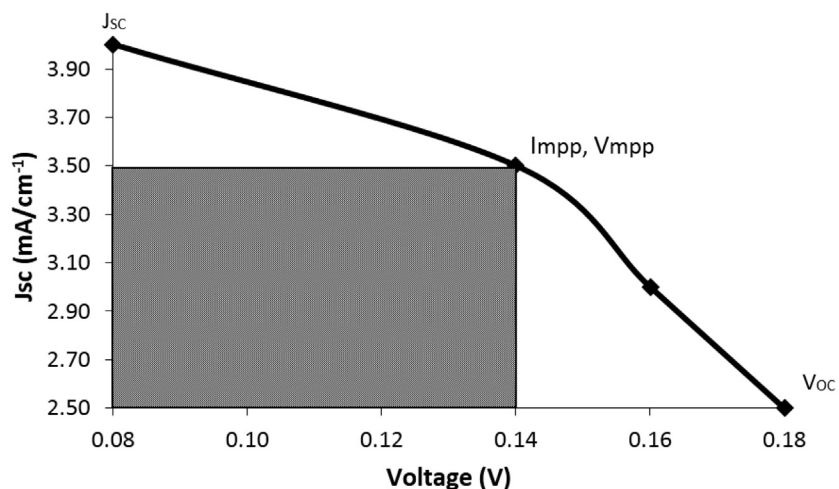


Fig. 19. The I-V curve of complex compounds of Fe(III)-chlorophyll.

with chlorophyll. This is because the MLCT phenomenon occurs in complex compounds of Fe(III)-chlorophyll, which causes more sunlight to be absorbed, which in turn increases the amount of sunlight that can be converted. The comparison of efficiency with previous research is presented in Table 9.

According to Table 9, the dye Fe(III)-chlorophyll solar cell has a higher efficiency value compared with chlorophyll from previous research. The complex compound of Fe(III)-chlorophyll has the advantage of being an anionic compound that can undergo the MLCT phenomenon, has properties such as “collecting sunlight” and can

Table 9

The comparison of efficiency from previous studies.

Compound	Efficiency	References
Chlorophyll extract from spinach leaf	0.54%	Syafinar et al. (2015)
Chl-e ₆	0.73%	Amao et al. (2014)
Iron formazan	4.22%	Listari and Akhlus (2010)
Chlorophyll	0.70%	The results of this current study
Fe(III)-chlorophyll	1.35%	
Mixture of FeCl ₃ ·6H ₂ O with chlorophyll	0.33%	

be used as photosensitizer in the DSSC. The electrons that are captured by the complex compounds cause excited electrons of complex compounds to move toward the conduction band of TiO₂; the electrons then are transferred to the reference electrode and are received by the electrolyte solution. These electrons cycle through and in the presence of sunlight will be excited so that current that is produced can be used as a source of electrical power. With the advantage of the complex compounds that have been made in this study, we can see that adding metal ion Fe(III) improves the performance of chlorophyll in DSSC by improving efficiency as a photosensitizer in DSSCs. Moreover, the addition of metal ion Fe can cause chlorophyll performance to become more stable and not as easily degradable.

Conclusion

The characterization of chlorophyll compounds with the addition of metal ion Fe(III) using UV–Vis spectrophotometer showed the presence of the MLCT phenomenon at a maximum wavelength of 263.00 nm. In the FTIR spectrum, the complex compounds showed the presence of Fe–O vibration of chlorophyll as ligand at a wavenumber of 436.06 cm⁻¹. Analysis of magnetic properties using MSB obtained a magnetic moment value of 9.62 BM. This shows that the complex compound of Fe(III)-chlorophyll is paramagnetic. Based on the electrical conductivity test, it can be seen that the complex compound is an ionic compound. Moreover, the presence of Fe(III) on chlorophyll can increase the efficiency of chlorophyll as a photosensitizer in the DSSC. This can be seen from the increase in the voltage and current conversion value so that the produced efficiency becomes higher at 1.35%.

Competing interests

The authors declare no competing financial interests.

References

- Ardianto, R., Nugroho, W.A. & Sutan, S.M. Performance test of dye sensitized solar cell (DSSC) using capacitive touchscreen layer as substrate and chlorophyll extract from *Nannochloropsis* sp. as dye sensitizer with various thickness of TiO₂ paste. *Jurnal Keteknikaan Pertanian Tropis dan Biosistem* 3(3), 325–337 (2015).
- Swami SK et al. Investigation of electrodeposited cobalt sulphide counter electrodes and their application in next-generation dye sensitized solar cells featuring organic dyes and cobalt-based redox electrolytes. *J Power Sources* 2015;275:80–9.
- Hao S et al. The influence of acid treatment of TiO₂ porous film electrode on photoelectric performance of dye-sensitized solar cell. *Sol Energy* 2004;76 (6):745–50.
- Ananth S, Arumanayagam T, Vivek P, Murugakoothan P. Direct synthesis of natural dye mixed titanium dioxide nano particles by sol-gel method for dye sensitized solar cell applications. *Optik* 2014;125(1):495–8.
- Kushwaha R, Srivastava P, Bahadur L. Natural pigments from plants used as sensitizers for TiO₂ based dye-sensitized solar cells. *J Energy* 2013;2013:1–8.
- Amao Y, Yamada Y, Aoki K. Preparation and properties of dye-sensitized solar cell using chlorophyll derivative immobilized TiO₂ film electrode. *J Photochem Photobiol A* 2004;164:47–51.
- Zhou H, Wu L, Gao Y, Ma T. Dye-sensitized solar cells using 20 natural dyes as sensitizers. *J Photochem Photobiol A* 2011;219:188–94.
- Bosiak MJ et al. Highly efficient benzodifuran based ruthenium sensitizers for thin-film dye-sensitized solar cells. *Dyes Pigment* 2015;121:79–87.
- Fan F-J, Wu L, Yu S-H. Energetic I–III–VI₂ and I₂–II–IV–VI₄ nanocrystals: synthesis, photovoltaic and thermoelectric applications. *Energy Environ Sci* 2014;7(1):190–208.
- Gratzel M. Dye-sensitized solar cells. *J Photochem Photobiol C* 2003;4:145–53.
- Listari, N. & Akhlus, S. Inorganic dye from complex of iron formazan as photosensitizers on Dye Sensitized Solar Cells (DSSC) (in Bahasa Indonesia), Thesis, Institut Teknologi Sepuluh Nopember (2010).
- Koyama Y, Miki T, Wang X-F, Nagae H. Dye-sensitized solar cells based on the principles and materials of photosynthesis: Mechanisms of suppression and enhancement of photocurrent and conversion efficiency. *Int J Mol Sci* 2009;10:4575–622.
- Han J et al. Simultaneous aqueous two-phase extraction and saponification reaction of chlorophyll from silkworm excrement. *Sep Purif Technol* 2013;115:51–6.
- Sumaryanti Utari, Supriyanto, A. & Purnama, B., Optical and electrical characterization of chlorophyll solution from *Spirulina* sp. as dye sensitized solar cell (in Bahasa Indonesia). *J Mater Eng Indonesia* 2011;1(3):141–7.
- Syafinar R, Gomes N, Irwanto M, Fareq M, Irwan YM. Chlorophyll pigments as nature based dye for Dye-Sensitized Solar Cell (DSSC). *Energy Procedia* 2015;79:896–902.
- Refat MS. Synthesis and characterization of ligational behavior of curcumin drug towards some transition metal ions: Chelation effect on their thermal stability and biological activity. *Spectrochim Acta Part A* 2013;105:326–37.
- Mahmudah R, Achir S. The effect of various mordant on the results of the natural dyeing from the branches of mango trees for dyeing of batik on the skirt (in Bahasa Indonesia). *J Tata Busana* 2013;2(1):82–6.
- Zhao X-Z et al. Interaction of curcumin with Zn(II) and Cu(II) ions based on experiment and theoretical calculation. *J Mol Struct* 2010;984:316–25.
- Sokolowska-Gajda J, Freeman HS, Reife A. Synthetic dyes based on environmental considerations. Part 2: Iron complexes formazan dyes. *Dyes Pigment* 1996;30(1):1–20.
- Chen C-C, Ting C-C. Photoelectrode fabrication of dye-sensitized nanosolar cells using multiple spray coating technique. *Int J Photoenergy* 2013;2013:1–8.
- Kumara, M.S.W. & Prajitno, G. Preliminary studies fabrication of Dye Sensitized Solar Cell (DSSC) using extraction of leaf spinach (*Amaranthus hybridus* L.) as dye sensitizers with variations distance light source on DSSC (in Bahasa Indonesia). Thesis. Institut Teknologi Sepuluh Nopember (2012).
- Balraju P, Kumar M, Roy MS, Sharma GD. Dye Sensitized Solar Cells (DSSCs) based on modified iron phthalocyanine nanostructured TiO₂ electrode and PEDOT:PSS counter electrode. *Synth Met* 2009;159(13):1325–31.
- McMills L, Nyasulu F, Barlag R. Magnetic susceptibility of coordination compounds in the general chemistry laboratory. *J Lab Chem Educ* 2014;2 (2):11–4.
- Pancaningtyas L, Akhlus S. The role of electrolytes in performance Dye Sensitized Solar Cells (DSSC) (in Bahasa Indonesia). Institut Teknologi Sepuluh Nopember: Thesis; 2011.
- Tumolo T, Lanfer-Marquez UM. Copper chlorophyllin: A food colorant with bioactive properties? *Food Res Int* 2012;46(2):451–9.
- Miessler GL, Fischer PJ, Tarr DA. *Inorganic chemistry*. 5th ed. Englewood Cliffs: Prentice-Hall; 2014.
- Yuniyanto M. Ophode performance study of metal ions Zn (II) and Cr (III) without plasticizers from aminopropiltrimetoksisilan and oktiltrietoksisilan with chromionofor 4- (2-piridilazo)resorcinol (in Bahasa Indonesia). Thesis. Faculty of Mathematics and Natural Sciences: Universitas Sebelas Maret Surakarta; 2006.
- Xue R, Behera P, Xu J, Viapiano MS, Lannutti JJ. Polydimethylsiloxane core-polycaprolactone shell nanofibers as biocompatible, real-time oxygen sensors. *Sens Actuators B* 2014;192:697–707.
- Vignes, R. Dimethyl Sulfoxide (DMSO) a “new” clean, unique, superior solvent. American Chemical Society. Annual Meeting. Washington DC, August 20–24, 2000.
- Chen P, Finikova OS, Ou Z, Vinogradov SA, Kadish KM. Electrochemistry of platinum(II) porphyrins: Effect of substituents and π -extension on redox potentials and site of electron transfer. *Inorg Chem* 2012;51:6200–10.
- Illiya W, Martak F. Synthesis and characterization of complexes compound of metal cobalt(II) with 2-phenylethylamine (in Bahasa Indonesia). Institut Teknologi Sepuluh Nopember: Thesis; 2011.
- Nakamoto K. Infrared and raman spectra of inorganic and coordination compounds: Part B: Applications in coordination, organometallic, and bioinorganic chemistry. New York: Wiley; 2009.
- Yin J-F, Velayudham M, Bhattacharya D, Lin H-C, Lu K-L. Structure optimization of ruthenium photosensitizers for efficient dye-sensitized solar cells – A goal toward a “bright” future. *Coord Chem Rev* 2012;256:3008–35.